An Economic Analysis of Zoonotic Disease Control in Uganda and the Lao People's Democratic Republic

Walter Otieno Okello

Doctor of Philosophy

University of Edinburgh

2016

ABSTRACT

Background: Despite the acknowledged importance of economic assessments for public health interventions at the human-animal-ecosystem interface, there are currently limited economic methodologies for doing so. In this thesis studies were undertaken to ascertain the economic impact of interventions to control trypanosomiasis and taeniasis/cysticercosis in south-east Uganda and northern Lao PDR respectively. Also, in Uganda studies were done to find out if demand of draft cattle would be an important economic driver for spreading trypanosomiasis due to inter-district trade.

Method: In Uganda, a one year recall cross-sectional baseline survey and an 18 month longitudinal survey of 660 households was conducted; to determine the benefits and changes due to restricted application of deltamethrin insecticide to only the legs, belly and ears of cattle. During the 18 month study, the households participating in the study were divided into six regimes depending on the type of intervention done in their cattle and these were; diminazine injection only, deworming only, no treatment and those had 25%, 50% and 75% of the total village cattle sprayed. Thus, the first three regimes were those households that had their cattle not sprayed with insecticide at all as opposed to the last three. Additionally, cattle trade data was collected for network and value chain analysis in all markets in Tororo and Namutamba districts from 199 cattle traders. In northern Lao PDR, stochastic modelling was done to determine the burden of neurocysticercosis associated epilepsy and soil transmitted helminthes. A cross-sectional study was carried out in 49 households, focusing on the prevalence of cysticercosis and soil transmitted helminths before and after a twelve month intervention to control a hyperendemic focus of *Taenia solium.* The village data was then extrapolated to the wider northern Lao PDR population.

Results: The Uganda study indicated that the restricted application of deltamethrin in cattle induced change of USD 31 per head of adult bovine per year; this was the change in income that directly occurred due to restricted spraying of cattle with deltamethrin. During the intervention period, the annual difference in income between those households that had their cattle sprayed using restricted application protocol and those that did not was USD 123; and this was significant (t= 7.18, p= <0.001). Analysis of variance using households that had their cattle receive no treatment as control showed that restricted application of deltamethrin significantly increased household income compared to diminazine aceturate injection and deworming of cattle only. The incremental benefit cost ratio of spraying 0% to 25% of the cattle was found to be the highest (16:1) compared to spraying 25% to 50% (3:1) and 50% to 75% (1:1) of the cattle. Cattle trade network and value chain analysis revealed that the key cattle markets from which trypanosomiasis is likely to spread into Tororo District are Molo, Namutumba and Soroti. Also, it was found that the risk of spread of human African trypanosomiasis from south-east to north-west Uganda is high due to the increased demand for male cattle for draft work.

In northern Lao PDR, 5,094 (95% CI: 25.6-28,940) DALYs were estimated to be imposed annually due to *Taenia solium* associated epilepsy, with 446.4 (95% CI: 2.2-2,536) DALY imposed per 100,000 person-years. Due to the high benefits to pig production, the net monetary cost per DALY averted for simultaneously controlling *T. solium*, soil transmitted helminthes and classical swine fever was only USD 14, which fell to USD 11 if the separable cost method were applied. If the intervention did not target pigs, then the cost per DALY averted was USD 44; well below the current standard for ’very cost effective ‘of the 1 year’s per capita GDP.

Conclusion: This study provided empirical evidence for evaluating the impact of quantifying the benefits of controlling zoonotic diseases in the livestock sector (Uganda case study) and in both livestock and human health populations (Lao PDR case study); this economic assessment approach can be used for planning future integrated health interventions. The results of this study support the policy of preventing the spread of infection by spraying at least 25% of the cattle using RAP, as well as injecting all cattle in key livestock markets in south east Uganda with diminazine aceturate to prevent HAT. In northern Lao PDR, simultaneous control of *T. solium*, soil transmitted helminths and classical swine fever is the most cost-effective approach. There are still difficulties in incorporating human and animal parameters into a single analytical framework; consequently there is a need to adapt

the approaches undertaken in this study to the analysis of other zoonotic diseases in different settings to improve on their robustness.

LAY ABSTRACT

Background: Despite the acknowledged importance of evaluating the economic benefit of controlling diseases in animals to protect humans, there are currently limited economic methodologies for doing so. In this thesis studies were undertaken to establish the economic impact of interventions to control trypanosomiasis and pork tapeworm in south-east Uganda and northern Lao PDR respectively; diseases which affect both people and animals.

Method: In Uganda, a survey was conducted on 660 households for eighteen months in order to identify and track changes in income and livestock productivity occurring as a result of restricted spraying of insecticide to certain body parts of cattle (such as legs, belly and ears) rather than the whole body. Spraying was conducted in 25%, 50% and 75% of the village cattle population; other groups of cattle received injection only, deworming only or no treatment at all. Also, information on cattle trade was collected in all markets in Tororo and Namutumba districts and a total of 199 cattle traders were interviewed. In northern Lao PDR, studies were done to determine the benefit of combined control of pork tapeworm (in people and pigs), intestinal worms (in people) transmitted from the soil and classical swine fever (in pigs) in 49 households for a period of eighteen months. The intervention involved giving people in the village dewormers; deworming and vaccination of pigs against pork tapeworm and classical swine fever. The information obtained from the village data was then used to understand what the benefits of controlling pork tapeworm, intestinal worms and Classical Swine Fever would be in a larger human and pig population in northern Lao PDR.

Results: The study in Uganda showed that the amount of money gained from restricting spraying of cattle with insecticides to certain body parts was USD 31 for each adult cattle sprayed every year. After one year of the intervention, the difference in money gained from spraying certain body parts of cattle, between those households that sprayed their cattle and those that did not was USD 123. Also, the study revealed that it was too expensive to spray more than 25% of the village cattle to control trypanosomiasis. Apart from studies on spraying cattle, the study showed that the most important cattle markets that would require all the cattle injected with drugs to control spread of trypanosomiasis to other districts in Uganda were Molo, Namutumba and Soroti cattle markets; and that the risk of spread of the disease from south east to north west Uganda was high due to the increased demand for male cattle for draft work. In northern Lao PDR, it was found that pork tapeworm causes a lot of health problems to people. Due to the high benefits to pig production, the cost of combining control of classical swine fever in pigs with pork tapeworm (in people and pigs) and intestinal worms (in people) was only USD 14; considered as extremely good value for money. If the intervention did not target pigs, then the cost for combined control of pork tapeworm and intestinal worms in people was USD 44 which is still considered as extremely good value for money.

Conclusion: This study provided evidence for evaluating the benefits of controlling diseases that affect both people and animals; and this approach can used for planning future programmes that are targeted towards such diseases. The results of this study support the policy of preventing the spread of trypanosomiasis infection by spraying at least 25% of the cattle, as well as treating all cattle in the major cattle markets in south east Uganda. In northern Lao PDR, combined control of pork tapeworm, intestinal worms and classical swine fever was found to highly beneficial; therefore a combined vaccination of pigs against pig tapeworm and classical swine fever was recommended to help the small scale pig farmers. Although the approach used in this study was good there is still more work to be done to make sure that it is a useful method of evaluating diseases that affect people and animals.

DECLARATION

I declare that the research undertaken for the purposes of this thesis is my own work and has never been submitted for the purposes of another degree or professional qualification.

Walter Otieno Okello
May 2016

ACKNOWLEDGEMENTS

I would like to thank the European Commission Seventh Framework Programme and the University of Edinburgh for the opportunity to carry out the Uganda case study as part of the Integrated Control of Neglected Zoonoses (ICONZ) project. I would also like to thank the Australian Centre for International Agricultural Research (ACIAR) and the Australian Animal Health Laboratory (AAHL) for the opportunity to undertake the research in Lao PDR. I am grateful to Professor Sue Welburn, Dr. Ewan MacLeod and especially Dr. Alexandra Shaw for all their support and advice. Similarly, the support received from my family, Makerere University, Mrs. Pauline McManus, the field enumerators and the Tororo (Uganda) and Mai (Lao PDR) district farmers is also highly appreciated.

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

LIST OF ABBREVIATIONS

AAT	Animal African Trypanosomiasis
CBA	Cost Benefit Analysis
CEA	Cost Effective Analysis
CUA	Cost Utility Analysis
CPIA	Country Policy Implementation Assessment
DALY	Disability adjusted life years
DDAF	District Department of Agriculture and Forestry
DFI	Department of Forestry Inspection
DI	Department of Irrigation
DLF	Department of Livestock and Fisheries
DIN	Department of Inspection
DP	Department of Planning
DSIP	Development Strategy and Investment Plan
EAC	East Africa Community
FAO	Food and Agriculture Organization
GBD	Global burden of disease
GDP	Gross Domestic Product
GMA	Gross Margin Analysis
HALY	Health adjusted life years
HAT	Human African Trypanosomiasis
HDI	Human Development Index
HIPC	Heavily Indebted Poor Countries
MAF	Ministry of Agriculture and Forestry
MDA	Mass Drug Administration
NAFES	National Agriculture and Forestry Extension Services
NAFRI	National Agriculture and Forestry Research Institute
NAHICO	National Avian and Human Influenza Coordination Office
NCCDC	National Committee on Communicable Disease Control
NEIDCO	National Emerging Infectious Diseases Coordination Office
NDP	National Development Plan

NPV	Net Present Value
NRM	National Resistance Movement
ICONZ	Integrated Control of Neglected Zoonoses Project
IDA	International Development Association
IETB	Immune Electro-Transfer Blot
IFPRI	International Food Policy Research Institute
IFRS	International Financial Reporting Standard
IMF	International Monetary Fund
ITC	International Trading Center
ITFDE	International Task Force for Disease Eradication
LAK	Lao Kip
LAO PDR	Lao People's Democratic Republic
LC	Local Council
LDC	Least Developed Country
MAAIF	Ministry of Agriculture Animal Industry and Fisheries
MDA	Mass drug administration
MDRI	Multilateral Debt Relief Initiative
MoFPED	Ministry of Finance Planning and Economic Development
NDP	National Development Plan
NCC	Neurocysticercosis
NGPES	National Growth and Poverty Reduction Strategy
PEAP	Poverty Eradication Action Plan
PDAF	Provincial Department of Agriculture and Forestry
PMA	Plan for Modernization of Agriculture
PWE	PersonWith Epilepsy
QALE	Quality adjusted life expectancy
QALY	Quality adjusted life years
RAP	Restricted application protocol
SD	Standard Deviation
SOS	Stamp Out Sleeping Sickness Project
UGX	Uganda Shillings
UNDP	United Nations Development Programme

UBOS	Uganda Bureau of Statistics
USD	United States Dollar
YLD	Years lived with disability
YLL	Years of life lost

Historical Exchange Rates (31/12/2014)

1 USD = UGX 2,788

1 USD = LAK 7,880

CHAPTER ONE

1. INTRODUCTION

1. 1 Introduction to One Health

Over the past decade research in animal and human health has been met with increasingly intricate issues of global change which may surpass local health concern in the scale of their influence. Furthermore it has been postulated that around 868 (61%) of the 1,416 infectious diseases known to affect humans are of animal origin, with zoonotic diseases- a disease or infection which is capable of being naturally transmitted between vertebrate animals and man (Hubalek, 2003) - overall twice as likely to be associated with emerging infectious diseases compared with non-zoonotic disease (Taylor *et al.* 2001). Also, it has been stipulated that up to 75% of the emerging infectious diseases seen in human populations over the last 30 years are of animal origin (Osburn *et al*. 2009; AMVA, 2008). Consequently, the emergence and re-emergence of zoonotic diseases has particularly become a challenge (Gibbs, 2005). The recent sudden increase of occurrence of zoonotic diseases in the 21st century has been attributed to several factors. Most of these issues are related to increase in human population and its corollary rapid urbanisation, intensified livestock production, degradation of ecosystems and globalised movement of people, animals, goods and services. Moreover, the effects of climate change and economic collapse in some countries have become more pronounced (Parry *et al*. 2007; Zinsstag *et al*. 2010). One of the most elementary factors is thought to be the increasing reliance and demand for animal protein for food, which inadvertently puts natural resources under pressure (Delgado *et al* 1999). For example, the swidden agriculture where forests are cleared through slash and burn to expand agricultural land was implicated in the emergence of Malaysia's Nipah virus in 1998 (Kaw, 2003). Increased human contact with wildlife through poaching, bush meat consumption and expanded livestock grazing areas increases the likelihood of zoonotic disease spill over from wildlife reservoirs, such as that seen with Ebola. Climate change has been incriminated in changing disease patterns of vector transmitted diseases such as Rift Valley Fever, Human African

Trypanosomiasis (HAT) and West Nile Virus. Intensification of farming systems, particularly in developing countries, places additional pressure on already strained biosecurity measures, increasing the risk of emerging diseases (Gibbs, 2005). Globalisation and tourism can aid disease spread in less time than the pathogen's incubation period; for example the devastating entry of severe acute respiratory syndrome into Canada in 2004 was traced back to a passenger who was healthy at the time of boarding a flight from China (Gibbs, 2005). Hazardous trading of animals has also been implicated in the introduction of disease on a number of occasions, including Monkey pox brought into America in 2003 through a shipment of rodents from West Africa. It has been estimated that millions of animals are moved from Asia to other parts of the world for use in traditional medicine and food (Gibbs, 2005). War and famine has historically been known to be the main cause of spread of zoonotic diseases. For example the Spanish flu- which has recently been found to be associated with avian and swine influenza strains (Taubenberger *et al*. 2005) - caused a pandemic killing over 50 million people during the first world war (Reid *et al.* 1999). Another example is the occurrence of glanders due to overcrowding of horses, donkeys and mules during the American civil war (Sharrer, 1995). Recently, movement of livestock, through restocking programmes after civil war, has been attributed to spread of human African trypanosomiasis in Uganda (Picozzi *et al*. 2005; Selby *et al*. 2013). Faced with these complex, often fast changing patterns, the inextricable interconnection of humans, livestock and their environment requires integrated approach. This thesis firstly recalls briefly the history of integrative thinking on human and animal health, secondly reviews economic methods used to analyse animal and human health programmes, thirdly presents case studies in Uganda and Lao Peoples Democratic Republic (PDR) and fourthly generally discusses the findings as well as broad observations.

1. 1.1 Brief history of Integrated Health Approaches

The relationships between humans, animals and the ecosystem were noted many centuries ago (Okello *et al.* 2011). Prehistoric healers were mostly priests or soothsayers caring for both humans and animals; gaining medical skills through slaughtering sacrificial animals (Schwabe, 1984). Ancient Egyptian viewed both humans and animals as the "flock of God" and portraying this in their mythology

(Driesch and Peters, 2003). Some African cultures, such as the Fulbe pastoralists in West Africa believe in co-creation of humans and cattle (Zinsstag *et al*. 2010). In India, the Hindu beliefs are heavily influenced by transmigration and reincarnation between humans and animals (Zinsstag *et al*. 2010). In the 4^{th} century B.C, Aristotle, a Greek philosopher showed the similarities and dissimilarities between human and animal taxonomic systems (Zinsstag *et al*. 2015). Between $11^{-}13^{th}$ century, the Zhou dynasty in China was one of the first to have an integrated public health system including medical doctors and veterinarians (Zinsstag *et al*, 2010). A Chinese transcript by Xu Dachun from the 18th century states that: "The foundations of veterinary medicine are as comprehensive and subtle as that of human medicine and it is not possible to place one above the other" (Zinsstag *et al*, 2010). In the 19^{th} century, with the advent in cellular pathology, Rudolf Virchow began to advocate for comparative medicine to link human and veterinary medicine; based on the discovery that disease processes were alike in humans and animals. Furthermore, animal diseases such as rinderpest and trypanosomiasis, not human epidemics, were the major drivers of medical research at the time (Dukes, 2000). In northern America, integrative human and animal thinking was first defined as "one medicine" by William Osler, a student of Rudolf Virchow. However in 1976, Calvin Schwabe having worked with the Dinka pastoralists in Sudan provided a comprehensive rethinking of the "one medicine" to systematically include health, nutrition and livelihoods (Schwabe, 1984; Majok and Schwabe, 1996). Currently, the term 'One Health' is being used to define the concerted multidisciplinary effort to improve the health of humans, animals and the environment at the local, national and global levels (Okello *et al*. 2011; Zinsstag *et al*. 2011). There are other concepts synonymous to one health such as 'one world one health' and 'one world one health one medicine'. A related concept such as ecosystem health (also known as EcoHealth) has extended 'one medicine' to the whole ecosystem including wildlife (Forget and Lebel, 2001; Zinsstag *et al*. 2005). The conservationists use and promote the "Manhattan principles", that the health and sustainable preservation of wildlife in natural reserves is mutually interdependent with the health of communities and livestock surrounding them (Osofsky *et al*. 2005). Also, a concept related to 'One Health' and 'EcoHealth' is conservation medicine that addresses the two-way exchange of pathogens between human society and nature (Aguirre *et al.* 2002).

1.1.2 Review of integrated health approaches

Numerous single disease control partnerships have been developed over the last few decades particularly for neglected tropical diseases such as onchocercosis and filariasis (Molyneux *et al*. 2000; Seketeli *et al*. 2002). A few of the neglected tropical diseases such as schistomiasis, trachoma have been integrated into primary health care (Cline and Hewlett 1996; Mecaskey *et al*. 2003). It has been proposed that control of human African trypanosomiasis (HAT) should be integrated in rural development, disease management and tsetse and trypanosomiasis control (Holmes, 1997). However, currently there has been little integration among these partnerships (Molyneux *et al*. 2005). Integration refers to the establishment of linkages among existing programs to advance the delivery of health interventions given existing obligations and resources (Grepin and Reich, 2008). Other authors have described integration of targeted health interventions as the degree, pattern, and pace of adoption and ultimate incorporation of health interventions into essential health system functions which comprise: (i) stewardship and governance, (ii) financing, (iii) planning, (iv) service delivery, (v) monitoring and evaluation, and (vi) creation of demand (Atun *et al*. 2010). The existence of many widespread elements and general arguments about economies of scale provide strong reasons to consider that integration amongst partnerships can help improve both efficiency and effectiveness. For example it has been argued that integration of health interventions where zoonotic diseases are controlled in animal reservoirs leads to an added value in the form of reduced cost in the human health sector and strengthening of health systems (Zinsstag et al. 2005; Schelling *et al*. 2005).

Given the synergy that can be developed between animal and health sectors, it is imperative to understand the different levels of integration (Grepin and Reich, 2008). Essentially, integration occurs in different domains (what is being integrated), levels (where is integration occurring) and degree (how is integration occurring). According to Grepin and Reich (2008) there are three domains of integration namely; activity, policy and organizational structure. The levels of integration are; global, national (regional) and local; whereas the degree of integration include; coordination, collaboration and consolidation. Examples of integration to control zoonoses are shown in Table 1-1.

Table 1-1: Examples of integrated control zoonoses interventions

Integrated zoonoses control interventions	Integration by:			Source
	Domain	level	degree	
Stamp out sleeping sickness in Uganda	Activity- combined treatment of cattle reservoir and diagnosis and treatment of human patients.	Local- northwest and south-east districts.	Coordination-by Co-ordinating Office for the Control of Trypanosomiasis in Uganda (COCTU). Collaboration- between government, research institutes and private sector	Kabasa, 2007; Molyneux *et al.* 2010
Avian influenza	Activity- control of disease in poultry and surveillance Policy- compensation, biosecurity and effective surveillance. Organizational structure- restructuring of poultry sector and inter-	Regional- south east Asia	Collaboration- between public and private sector and various ministries.	Rushton *et al.* 2005.

	ministerial committee			
Rabies vaccination in Tanzania	Activity- vaccination of dogs against rabies	Local- northwest district	Collaboration- between Ministry of Agriculture and health	Cleaveland *et al.* 2003.
Brucellosis control in Mongolia	Activity- livestock vaccination and treatment of human patients	National	Collaboration- between Ministry of Agriculture, public health facilities and institute for infectious diseases	Roth *et al*. 2003
Taenia solium control in Lao PDR	Activity-joint veterinary and medical interventions	Local- district	Collaboration- between Ministry of agriculture and health Coordination- multi-institutional Consolidation-joint monitoring and training sessions	Okello *et al.* 2016
Taenia solium control in Peru	Activity-joint veterinary and medical interventions	Local- Tumbes region	Coordination-multi-institutional	Garcia *et al.* 2016
Canadian integrated program for antimicrobial resistance	Activity-joint monitoring of antimicrobial resistance in livestock and human health sectors	National	Collaboration- between Ministry of agriculture and health	Deckert *et al.* 2010

Apart from integrated control of zoonotic diseases, there has been past efforts involving joint activities or sharing of infrastructure (such as cold chain and transportation) between animal and human sectors. For example, joint vaccination of cattle and children among pastoralists in Chad, Mali and Mauritania (Schelling *et al*. 2005; Bechir *et al*. 2004) and sharing of cold chain and transport during joint vaccination of cattle and children in South Sudan (Schelling *et al*. 2005). Another example is the Canadian integrated program for antimicrobial resistance surveillance (Deckert *et al*. 2010; Zinsstag *et al*. 2015). Also, there have been suggestions for joint control of schistosomiasis and soil transmitted helminths using common drugs (Utzinger et al. 2004). In Uganda, the Stamp out sleeping sickness (SOS), a public private partnership, was initiated in 2006 to prevent spread of acute human African trypanosomiasis (HAT) from south east to northwest districts by spraying cattle reservoir (Kabasa, 2007; Molyneux *et al*. 2010). However, despite the importance of integration, economic evaluation methods to support this approach are currently limited (Zinsstag *et al*. 2015).

1.2 Economic Methods for Evaluating Human and Animal Health Programmes

1.2.1 Economic Evaluation of the burden of zoonoses in animals

In the agricultural sector, the economic evaluation of livestock health and production lies within economic principles, given the core framework for analysing economic activity relies on a conceptual model whereby resources are transformed into various goods and services for human benefit (McInerney, 1978). Livestock disease can result in negative effects which can be categorised as either direct or indirect losses (Otte and Chilonda, 2000). *Direct losses* from livestock disease occur at the input level, i.e. production losses directly attributable to disease occurrence such as animal mortality and decreased productivity (e.g. lowered feed conversion), and at the output level through reduced quantity or quality of outputs such as milk and eggs and reduced capacity to work (Putt *et al*. 1987; Otte and Chilonda, 2000). *Indirect losses* from livestock disease include reduced suitability of animal products for processing, additional costs of drugs and vaccinations to mitigate the disease, herd modification which may limit farmers' ability to improve the herd and effects on human health and livelihoods, for example zoonotic disease and trade restrictions (Putt *et al*. 1987; Otte and Chilonda, 2000). Aside from reduced production, livestock disease results in secondary upstream or downstream effects on the broader production systems (Putt *et* *al*. 1987). For example, disease control may produce externalities that occur when the actions of one group of individuals affects others without being revealed in the market receipts or costs, as seen with reduced herd immunity as a result of some farmers refusing to vaccinate (Putt *et al*. 1987). Intangible effects are aspects of the disease/disease control programme that may be difficult to quantify, such as the risk of zoonotic disease transmission and expenditure on disease mitigation processes such as surveillance and prevention (Putt *et al*. 1987, Otte and Chilonda, 2000). In this way, the inclusion of expenditures - rather than production losses alone – results in evaluation of the *total cost* of disease; that is the sum of both direct and indirect losses and the control expenditures (McInerny *et al*. 1992; Rushton *et al*. 1999; Otte and Chilonda, 2000).

Livestock economists utilise several economic methods to assess performance and assist decision making at both the farm/herd level, with the most common being partial budgeting, gross margin analysis, enterprise budget, break even analysis, decision tree analysis, simulation and optimisation approaches (Otte; Rushton, 2009; Ngagetize *et al*. 1985; Dijkhuizen *et al*. 1991). Other methods less commonly used at the farm/herd level include marginal analysis (Okello-Onen *et al*. 1998), and linear/dynamic programming (Dijkhuizen *et al*. 1995). Cost-effectiveness analysis is used at both farm/herd and regional/country level, as is decision tree analysis and simulation (Otte and Chilonda, 2000, Rushton, 1999). The most common economic analytical methods used at the regional/national level are cost-benefit analysis and economic surplus (Otte and Chilonda, 2000; Dijkhuizen *et al*. 1995; Rushton, 1999; Gittinger, 1982). The following outlines the methods employed in the two case studies undertaken in this thesis.

a) Gross Margin and Enterprise Budget Analysis

Gross margin analysis (GMA) is used at the farm household or herd level to assess the economic feasibility of an enterprise and its contribution to the farm profit (Rushton, 1999). In GMA, fixed costs are ignored and only variable costs considered; the latter being resources that vary depending on the chosen enterprise and its size and vary proportionately. Fixed costs are resources that do not vary regardless of the size of the enterprise, usually comprising of land, labour and capital (Rushton, 1999). The gross margin is obtained by deducting variable costs from enterprise outputs (Rushton, 1999); the latter encompassing livestock and associated products sold and purchased and changes in herd value. Similar to GMA, enterprise budget analysis is used to measure the farm profit; it is obtained by subtracting both variable and fixed costs from enterprise outputs, or fixed cost from the gross margin. Both GMA and enterprise budget analysis are useful when comparing enterprises and assessing farm productivity, however the static nature of the prices and outputs remains a challenge when utilising these methods (Rushton *et al*, 1999).

b) Decision Analysis Trees and Simulation Models

Decision analysis is used for assessing situations with uncertain outcomes, taking into account the 'riskiness' of the decision (Fetrow *et al*. 1985; Dijkhuizen *et al*. 1995; Morris 1999). This method entails the construction of a decision analysis tree; a graphical representation of the sequence of alternative actions available and the choices determined by chance (Dijkhuizen *et al*. 1995). For example, in animal health some diseases occur sporadically or as epidemics, hence the actual occurrence at the farm/herd level cannot always be predicted (Rushton *et al*, 1999). There are three elements of decision analysis that need to be considered: i) the events that one has control over (alternatives), ii) the probability of the chance event happening and iii) the monetary value of several possible outcomes (Rushton *et al*, 1999). The 'choice indicator' for decision analysis is the optimal choice based on a certain criteria, for example expected monetary value (Galligan *et al*. 1987). Simulation techniques are used if complex feedback loops exist, whereby the impact of one decision about disease control flows through to affect some part of production, which in turn influences another variable, and there is uncertainty about the impact of the flow (Dijkhuizen *et al*. 1995). Simulation methods are commonly used when other optimisation methods are not suitable, particularly where the system under study has many subsystems, contains very dynamic relationships and/or cannot allow for experimentation (Rushton *et al*, 1999). Mathematical models are used to represent a system (depicted as a set of related items which exist within a pre-defined frontier and respond in unison to internal or external stimuli) in real life and the input variables manipulated (Dijkhuizen *et al*. 1995).

Evaluation of the burden of zoonoses in animals is both simple (majority of the direct losses have a monetary value) and complex (if there are several species of animals affected). Furthermore evaluating animals such as wild and companion animals can be complicated given the several roles they play in the society (Shaw *et al*. 2009). Consequently, there are few studies on the impact of zoonoses in wildlife; for example, the occurrence of rabies in African wild dogs and Ethiopian wolf (Cleveland *et al*. 2006; Haydon *et al*. 2006). In contrast, there are a number of studies on impact of zoonoses on domestic livestock; for example Shaw *et al*. (2014) and Okello *et al*. (2015) have reported the economic impact of trypanosomiasis on cattle while Rushton *et al.* 2005 and Basuno *et al*. 2010 reported livestock losses due to avian influenza.

1.2.2 Economic evaluation of burden of zoonoses on humans

The human impact of disease is measured using the burden of disease (Murray *et al*. 1996). Burden of disease is a standardised conceptual framework for amalgamating available data on epidemiology, mortality and individual health status to envisage the level of health in a population and reasons of loss of health (Mathers *et al*, 2007). Thus it can be used to quantify both the fatal and non-fatal effect of a disease or condition on the health of a population; as was done by the ground-breaking Global Burden of Disease and injury study (GBD) which developed comparable global estimates of diseases and injuries affecting United Nation's World Health Organization (WHO) countries (Murray *et al*. 1996).

The three commonly used economic methods for human health are cost benefit analysis (CBA), cost effectiveness analysis (CEA) and cost utility analysis (CUA) (Meltzer, 2001). In health economics, CBA is used when a choice has to be made between two or three interventions, to incorporate indirect costs and benefits and to evaluate economic effect of a single intervention (Meltzer, 2001). CEA is used to derive the net costs and benefits (savings) in terms of predetermined health outcome such cases averted and lives saved; thus unlike CBA, no value is put on life (Meltzer, 2001). CUA is similar to CEA where the health outcome is measured as a utility or quality, for example quality adjusted life year (QALY) (Meltzer, 2001).

Health adjusted life years (HALY) (also synonymously referred to as summary measures of public Health or Composite Health Measures) refer to an approach that simultaneously combines mortality and non-fatal disease outcomes of a particular population into a single deterministic measure (Lopez *et al*. 2006). It can broadly be divided into i) health expectancies, such as disability-adjusted life expectancy (DALE) and quality-adjusted life expectancy (QALE), which measure years of life gained, and ii) health gaps, such as disability-adjusted life years (DALY) and quality-adjusted life years (QALY), which measure loss of life years in contrast with accepted life standard (Mathers, 2002). The most commonly used indicator is the DALY, which unlike QALYs (that show gain which should be maximised) signify the loss which should be minimised (Mathers *et al*. 2007). The DALY has two components: years of life lost (YLL) representing the mortality component of the burden of disease, and years of life lived with disability (YLD), representing the non-fatal component (Murray *et al*. 1996). When determining YLL, 'perfect health' is commonly described as the ability to live healthily up to the estimated life expectancy, which is around 80 years according to the West Level 26 life table (Murray *et al*. 1996; Coale *et al*. 1996). The observed life expectancies are then compared with the standardised life table (Murray *et al*. 1996). The YLD is calculated from the number of years lived with the morbidity or disability and the severity of the morbidity (Mathers *et al*. 2007). Social values such as age weighting and time discount rate (usually 3%) can be added to the computation of DALY (Rushby and Hanson, 2001).

In health economics, the difficulty in placing monetary value on human health led to development of the HALY indicators as earlier described; allowing for comparison of diseases as published by the World Health Organization's (WHO) league table (Shaw *et al*. 2009). However, most of the zoonoses are not represented in the league table majorly because they are under-reported (Coleman, 2002); for example, in Uganda, the ratio of reported cases of malaria to HAT was 133: 1, whilst the DALY ratio was only 3:1 (Fevre *et al*. 2008). Despite under-reporting, the global burden of some of the zoonotic diseases such as rabies and echinococcosis have been published in the league table (Knobel *et al*. 2005; Budke *et al*. 2006). However, these estimates are low globally and high at the local level; because the occurrence of zoonoses depends on the interaction between animals, humans and the environment (Shaw *et al*. 2009).

1.2.3 Total societal burden of zoonoses

Simultaneous estimation of the burden of zoonoses is complex due to: i) analysis of the impact of the disease in both animals and humans, ii) placing monetary value on human life is unethical, and iii) several animal reservoirs may be involved (Shaw *et al*. 2009). Furthermore, it has been postulated that the lack of a non-monetary DALY equivalent for livestock or an agreed monetary value for a DALY pose a major challenge to assessing the cost effectiveness of integrated health approaches for zoonoses control, given the added value when health and agricultural sectors work together to control diseases, compared to each sector working alone (Roth *et al*. 2003; Zinsstag *et al*. 2007; Shaw *et al*. 2009; Zinsstag *et al*. 2015). Consequently, decisions on resource allocation to control zoonoses need to be made on their total socio-economic cost namely: i) monetary and non-monetary direct losses due to ill health or death, and costs of treating and caring for patients affected in the household and hospitals, and cost of prevention, plus ii) monetary and non-monetary direct losses due to ill health or death, and costs of treating and caring for animals affected in the household and veterinary clinics, and cost of prevention (Shaw *et al*. 2009). Schelling *et al* (2007) reported that more studies have included these components. Thus, for brucellosis, using matrix model and separable cost method, Roth *et al* (2003) reported 49,000 DALY averted from cattle vaccination, with potential total benefit of United States dollar (USD) 26.7 million; of which USD 15.4 million went to agricultural sector and USD 11.3 million to health sector. Budke *et al* (2006) reported that the annual global burden of cystic echinococcosis varied from 285,000 and 1,010,000 DALYs if reported and unreported respectively; and resulted in monetary losses of USD 193 million and USD 764 million if reported and unreported respectively in the health sector; and USD 121 million due to liver condemnation in the agricultural sector. Recently, using transmission dynamics, CEA and break-even analysis, Zinsstag *et al* (2009) demonstrated that mass vaccination of dogs against rabies is cheaper than post exposure prophylaxis. Other zoonotic diseases that have been analysed using epidemiological and economic modelling to show non-monetary and monetary burdens include *Taenia solium* cysticercosis (Praet *et al*. 2009) and Longworth *et al*

(2014) to compare the control of avian influenza strategies. Carabin *et al* (2006) showed the monetary burden of cysticercosis while Bhattarai *et al* (2012) and Fèvre *et al* (2008) revealed the non-monetary burden of cysticercosis and human African trypanosomiasis (HAT) respectively. Despite these attempts, the appropriate economic method for evaluation of all costs and benefit of zoonoses on both humans and animals is complicated, as summarized in Figure 1-1.

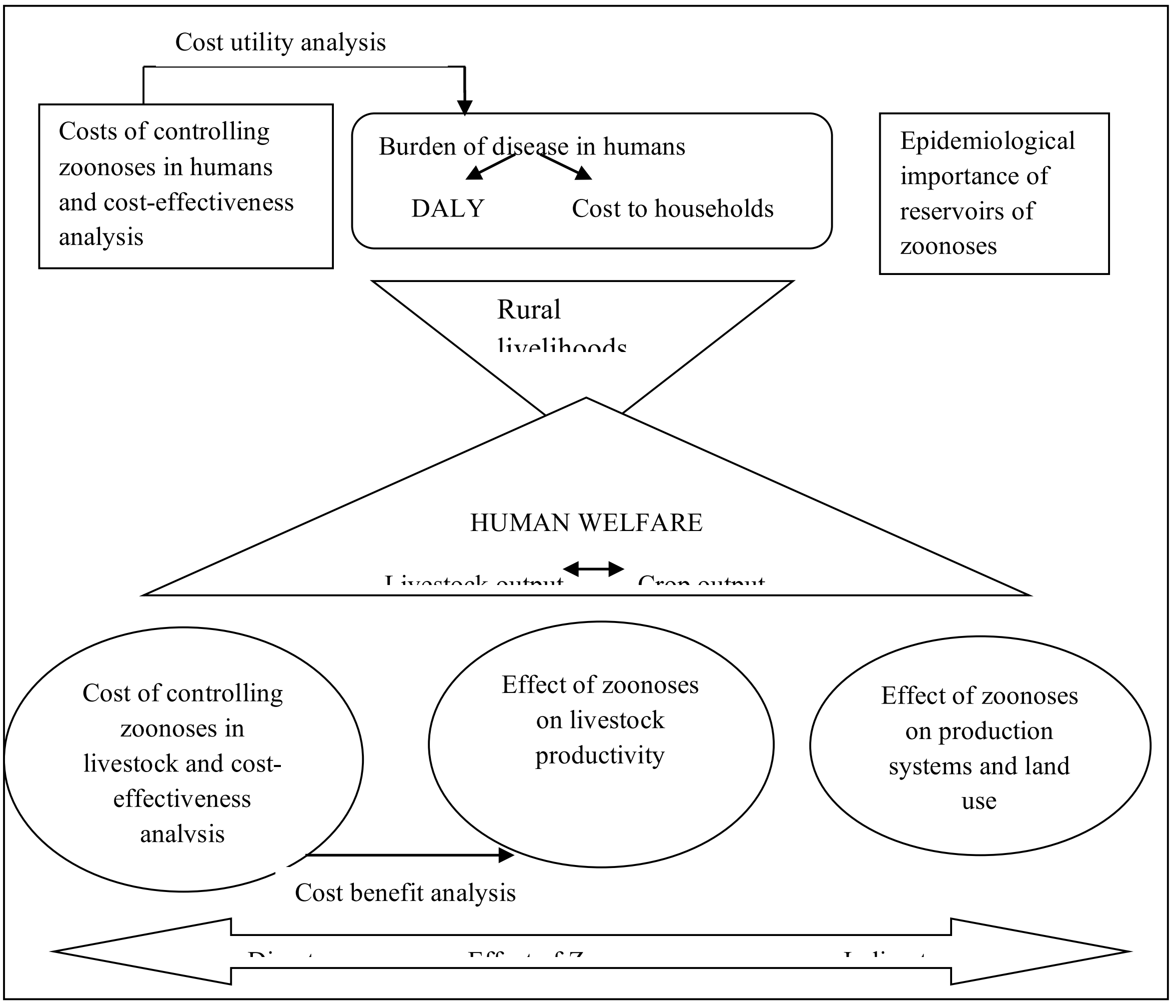


Figure 1-1 Economic analysis methods for Zoonoses

1.3 Use of Network and Value Chain Analyses to Assess the Risk of Zoonotic Disease Spread

Movement of animals and animal products poses a risk of disease spread (Bajardi *et al*. 2011; Hardstaff *et al*, 2015). The pattern by which zoonotic diseases spread through animals and human populations is not only determined by properties of the pathogen such as contagiousness, virulence and incubation period, but also through networks within the population and the livestock value chain (FAO, 2011).

Network analysis has been used in animal and human health to show disease transmission pattern and related risk. For example in public health, network analysis has been used to show spread of human immunodeficiency virus/acquired immunodeficiency syndrome (Klovdahl, 1985). In animal health, network analysis has been used to show transmission of foot and mouth disease in cattle (Robinson *et al*. 2007; Dent *et al*. 2008), Rift Valley fever (Nicolas *et al*. 2013) and poultry diseases (Rasamoelina-Andriamanivo *et al*. 2014).

A value chain can be termed as the "the full range of activities which are required to bring a product or service from conception, through the different phases of production (involving a combination of physical transformation and the input of various producer services), delivery to final consumers, and final disposal after use" (Kaplinksy and Morris, 2000) or simply as a set of people linked by an activity to deliver a explicit product (FAO, 2011). The reasons for analysis of value chains in reference to risk analysis are; identify the main stakeholders within the livestock chain, map out the different means of marketing livestock and livestock products and appraise the marketing chain; thus partly assessing possible risk of livestock disease transmission (Taylor and Rushton, 2011). Risk analysis involves assessing risks and hazards and has four components namely; hazard identification, risk assessment, risk management and risk communication (Taylor and Rushton , 2011). According to the World Animal Health Organisation (OIE), risk analysis process involves; first, evaluating a hazard (an agent that is likely to be detrimental to the ecosystem), second, assessing the likelihood of the unwanted outcome from the hazard occurring and its impact, third, undertaking risk reduction procedures and fourth, informing various stakeholders on the risk reduction procedures and any related legislation for enforcement (Taylor and Rushton, 2011). The probability of disease transmission within the value chain depends on various factors most of which are 'risky behaviours' or 'risky practices' typically as a result of economic drivers. The size of flow through the various parts of value chain is also an important determinant of the likelihood of disease spread (Taylor and Rushton, 2011).

1.4 Uganda Economic Case Study: Background Information

1.4.1 Uganda's geography, governance and economic policy

The Republic of Uganda (as shown in Figure 1-2) is in sub-Saharan Africa and covers a total area of 241,550 square kilometres (km²) of which land area covers 199,807 km² while water and swamp cover 41,473 km². It is mainly a plateau with an altitude of between 1,000 to 2,500 meters above sea level. Generally, there are two rainy seasons in a year; heavy rains from March to May and short rains from September to December.

Figure 1-2: Map of Uganda showing districts, adapted from United Nations

Human development index (HDI) is an indicator of the standard of living as measured by gross national income per capita (which is currently USD 1,335 for Uganda), life expectancy (which is currently 59.2 years for Uganda) and access to knowledge (UNDP, 2015). Uganda is ranked 164 out of 187 countries with a HDI of 0.484

indicating ‘low development’ (UNDP, 2015). The national poverty head count ratio (the percentage of the population living below the national poverty line) is 19.5% for Uganda (World Bank, 2015). In 2014, the total population was estimated at 34,634,650 (UBOS, 2014) as summarized in Table1-2.

Table 1-2: Human population in Uganda

Region	Population
Central	9,529,227
Eastern	9,042,422
Northern	7,188,139
Western	8,874,862
Total	34,634,650

Uganda has had political turmoil since her independence including military coups and civil conflicts. The current president, Yoweri Kaguta Museveni came to power in 1986 through the semi-authoritarian National Resistance Movement (NRM) after numerous years of guerrilla war. Under President Museveni, Uganda was one of the few African countries that instituted economic liberalisation in the 1980s in the form of an economic recovery programme. This was reflected in a prospering economy and a steady growth in gross domestic product (GDP) of 6% and above per annum (Turner, 2005). However, in northern and eastern Uganda, civilians have suffered from the brutal conflict inflicted by Joseph Kony’s Lord’s Resistance Army (LRA) who claims to be fighting the government for the liberalisation of northern Uganda (Turner, 2005).

One key feature of Museveni’s rule is the decentralisation of the government which can be traced back to 1986 when he came to power (Turner, 2005). In 1986 elected Resistance Councils set up the foundation for political decentralisation of local government system and later administrative decentralisation (Turner, 2005). In 1997 the role and tasks of the various tier of government was consolidated and the Resistance Council was renamed Local Council. The decentralised structures began from the district then to county, sub-county, parish and finally the village levels. Individuals were elected at each level and were referred to as Local Council (LC) V, IV, III, II and I respectively (Kapiriri *et al*. 2003). To understand the form of decentralised system in Uganda, a background on various forms of governance is necessary. The United Nations Development Program (UNDP) joint working paper in 1999, describes decentralisation as "... the restructuring or reorganisation of authority so that there is a system of co-responsibility between institutions of governance at the central, regional and local levels according to the principle of subsidiarity, thus increasing the overall quality and effectiveness of the system of governance, while increasing the authority and capacities of sub-national levels and that there are four forms of decentralisation namely devolution, delegation, deconcentration and divestment (privatization)" (UNDP, 1999).

Uganda was one of the first developing countries to institutionalise reforms (Turner, 2005); in 1992/1993 she developed her reforms which were guided by the World Bank's Poverty Eradication Action Plan (PEAP) framework launching this in 1997. The PEAP outlined economic management, governance, human development, security and competiveness as the chief areas for development and poverty eradication; and Uganda's budget framework, budgetary allocations and donor support have been anchored on these key areas from 1997 to 2008/2009 when the PEAP ended (MoFPED, 2010; IMF, 2010). Using the International Monetary Fund's government finance statistics manual guideline of 2001, all the government entities that affect fiscal policy in Uganda are captured and divided into sectors within which distinct institutional units exist (GFSM, 2001). For example, the agriculture sector is broken down into agriculture, animal industry forestry, fishing and hunting sub-units which are again broken down into smaller units such as specific projects/programmes (GFSM, 2001). This was meant to form analytical basis using the midterm expenditure framework and global outlays framework for poverty analysis that tracks expenditures especially those within the poverty reducing sectors (MoFPED, 2009). Categorized as one of the least developed countries, Uganda was the first country to be eligible for the debt relief services from the highly indebted poor countries (HIPC) initiative; which was supported by multilateral, bilateral creditors (IDA and IMF, 2000). To enhance prerequisite of more countries joining the HIPC initiative, the initial HIPC framework was changed to include development of poverty reduction strategy papers

(PRSPs) and floatation completion points (IDA and IMF, 2000); plan for modernisation of agriculture is an example of the PRSPs initiated in 2001 (OPM, 2005). Besides, the Sunset clause that states the deadline for the entry, prolonged the period required for entry by two years in 1998 (IDA and IMF, 2000); it is within this period that Uganda became the first country to qualify in 2000 (IDA and IMF, 2000). The completion points for countries joining HIPC initiative were mainly centred on commitment to fight HIV/AIDS, maternal health and education (IDA and IMF, 2000). In 2009, Uganda was known as a strong performer of policy implementation having scored a country policy implementation assessment (CPIA)[1] point of 3.86 (Okello, 2012). Consequently, it received more funds especially for agricultural and health sectors; receiving 12.93% and 6.29%, of the total funds borrowed respectively (MoFPED, 2011). However in 2011, the government priority changed and the main priority sectors were energy, transport, water and sanitation as the main drivers of the economy (MoFPED, 2011).

Currently Uganda's development plan is guided by the National Development Plan (NDP); and it aims to improve agricultural production and productivity, improve infrastructure in roads and energy, and promote science and technology, service delivery and private sector development (Okello, 2012). One of the key indicators of the success of NDP is increased household per capita income by quantifying changes in agricultural productivity. According to the NDP, agriculture is regarded as a primary growth sector while health is regarded as a social sector (IMF, 2010). However, despite agriculture being regarded as a primary growth sector, its annual budgetary allocation between 2010/11 and 2014/2015 was 5.4% which was less than the 0% required by the New Partnership for Africa Development (NEPAD); an initiative of African countries to eradicate poverty through sustainable development and advocates for agriculture-led development in Africa (Maputo declaration) (NEPAD, 2012).

---

[1] CPIA is a progress indicator and assesses policy implementation and good institutions based on economic management, structural reforms, policies for social inclusion/equity and public sector management and institutions. CPIA is based on a six point criteria (1 being weak while 6 being strongest) and is used for determining allocation of funds by the World Bank especially for poverty reduction and development.

1.4.2 Role of private sector in animal health delivery

Advancing the capacity of the veterinary service delivery to combat and control emerging and re-emerging animal disease including zoonoses is vital for unraveling the benefits of increased demand for livestock products and reducing associated animal and human health related risks (Wymann *et al*. 2007; Hall *et al*. 2004). However, continued fiscal challenges to governments particularly in low and middle income countries have continued to put pressure on the provision of veterinary services; forcing them to seek different institutional arrangements for providing the services (Pica-Ciamarra and Otte, 2008).

In Uganda, the government adopted the structural adjustment programs in late 1980s and early 1990s; resulting to decentralization and privatization of clinical veterinary services and downscaling of the involvement of the public sector in animal health service delivery (Haan and Umali, 1992). Provision of veterinary clinical services, animal breeding and tick control are privatized in Uganda while vaccination of animals against endemic diseases, quarantines and tsetse control are considered public or toll goods and are thus provided by the ministry of agriculture animal industry and fisheries (MAAIF). Separation of veterinary services into public and private goods was done to decrease expenses in public administration. However, the administration costs in the public sector has been on the increase due to significant increase in interest rate (partly because of continued general reliance on donor aid for budgetary support and mismanagement) and increased number of districts over the years (Lister *et al*. 2006). As a result, most of the veterinary services provided by the public sector such as tsetse control are currently being carried out by the private sector with the government playing a more reactive rather than proactive role (Rwakakamba, 2008).

1.4.3 Human and Animal African Trypanosomiasis in Uganda

Transmitted by the *Glossina* species of tsetse fly, trypanosomiasis is endemic to Africa, relentlessly impacting livestock productivity, food security, human health and livelihoods (Swallow, 1999; Eisler *et al*. 2003; Shaw *et al* 2004; Shaw, 2009). The main *Trypanosoma* species affecting animals are *T. vivax, T. congolense, T. simiae* and *T. brucei brucei,* causing a disease condition known collectively as animal African trypanosomiasis (AAT) (Maudlin and Welburn, 1988). The two subspecies of *Trypanosoma brucei,* namely *T. b. gambiense* and *T. b. rhodesiense* affect man, causing a disease known as human African trypanosomiasis (also known as sleeping sickness or HAT) (Steverding, 2008). HAT is a neglected tropical disease of public health concern across Africa, estimated to cause 1.6 million DALY globally per annum (Welburn *et al*. 2006). There are two forms of HAT; the chronic form caused by *T. b. gambiense* found in west and central Africa, and the acute form of east and southern Africa caused by *T. b. rhodesiense* (Barrett *et al*. 2003). The main reservoir of chronic HAT infection is other humans (Welburn *et al*. 2001), whilst in Uganda the main reservoir for acute HAT is domestic cattle, however wild animals may also play a major role in other countries (Welburn *et al*. 2001). Recent cattle movement in Uganda due to socio-economic reasons has led to establishment of new foci that has in turn acted as a source of spread of infection (Fèvre *et al*. 2006; Selby *et al* 2013).

Long-running attempts to control trypanosomiasis in Africa have been directed at vectors, animal reservoirs, the use of trypanotolerant livestock breeds, chiefly in West Africa and the control of the disease in the human population (Maudlin, 2006). Earlier methods that were directed at the vector included clearing vegetation and shooting of wildlife (Potts *et al*. 1952; Maudlin, 2006). Ground-spraying of tsetse resting sites using persistent insecticides was very effective, but faced increasing concern over the use of long-acting insecticides. With the arrival of synthetic pyrethroids, vector control gained new impetus with the use of aerial spraying (Maudlin, 2006). However, aerial spraying is a high technology intervention, best applied on a large scale, which requires a high level of organisation, careful timing and affects non-target species, at least in the short term (Alsopp and Hursey, 2004, Vale and Torr, 2004). Both ground and aerial spraying were necessarily short term seasonal interventions, allowing tsetse to recolonize. The lack of sustainability and environmental concerns led to revisiting the idea of using traps and targets as methods of tsetse control. These had been used in the first half of the twentieth century, but were all relegated to being used for surveys and research (Vale and Torr, 2004). Thus development of range stationary baits: insecticide treated traps and targets/screens with or without odour-baits were being developed from the late 1960s onwards. Live bait technology where cattle were treated with insecticides (as dips or pour-on) was later refined for use in areas with high cattle density.

Bait technology was heavily promoted by donors as way of community-based trypanosomiasis control (Dransfield and Brightwell, 2004). However, despite bait technology being a relatively cheap way of controlling trypanosomiasis, most communities could not sustain its use due not just to socio-economic and technical issues (Schofield and Maudlin, 2001) but also to simple lack of opportunity (Dransfield and Brightwell, 2004). Currently, the restricted application protocol (RAP), where spraying of cattle is confined to the belly, legs and ears, has been used to control tsetse flies and associated trypanosomiasis (Torr *et al*. 2007, Muhanguzi *et al*. 2014a). One other tsetse control method is the sterile insect technique; where large populations of irradiated infertile male tsetse flies are released into a wild tsetse population which has been reduced to low numbers using another tsetse control technique so as to render the few remaining females they mate with infertile (Hendrichs *et al*. 2005). However, it is a technology reserved for situations where it is possible to completely eliminate a tsetse population and permanently protect the resulting tsetse free area from reinvasion by tsetse. For most livestock keepers the major control strategy for trypanosomiasis in livestock is through chemotherapy (Maudlin *et al*. 1988); diminazine aceturate for the treatment of trypanosomiasis and isometamidium hydrochloride for prophylaxis is cheap and easily implemented on-farm or at livestock markets where risk of disease spread occurs (Torr *et al*. 2007, Fèvre *et al*, 2006).

In humans, control of HAT through active and passive screening of populations has been shown to be effective, however, because of the non specific nature of clinical signs and lack of serological tests for acute HAT, detection levels of HAT may be low (WHO, 2012). Because of the involvement of animal reservoirs in rhodesiense HAT, hence difficulty in interruption of transmission, elimination of this disease is considered infeasible (WHO, 2012). Apart from trypanosomiasis, other endemic vector borne parasitic diseases in Uganda include; theileriosis (East Coast fever) caused by *Theileria parva*; anaplasmosis, caused by *Anaplasma marginale*; babesiosis, caused by *Babesia bigemina*; cowdriosis (heart water), caused by *Ehrlichia ruminantium*; fascioliasis, caused by *Fasciola gigantica*; and gastroenteritis, caused by *Haemonchus* spp. (Okello *et al*. 2015).

Uganda is the only country in Africa that has the both chronic and acute form of the human disease. Whilst cases of acute HAT have been known to be restricted to south-east Uganda, the disease has been moving northwards at a rate of approximately one district per year in recent years, with the acute and chronic HAT foci separated by only 150 kilometres by 2005 (Picozzi *et al.* 2005; Welburn and Coleman, 2015). Cattle movement and restocking of infected cattle from south-east Uganda to north-west Uganda has likely played a key role in the outbreak during this period (Fèvre *et al*. 2005; Selby *et al*. 2014).

The pending public health emergency prompted the government and donors to initiate control measures involving vector control and human surveillance (Welburn and Coleman, 2015). In 2006, a large scale HAT public-private partnership control programme (Stamp Out Sleeping Sickness or SOS) involving spraying of cattle using RAP and prophylactic chemotherapy was initiated, treating 85% of the cattle in high risk districts. This intervention reduced the human HAT prevalence by 90%, *T. b. rhodesiense* prevalence in cattle by 70% and overall trypanosomiasis in cattle by 75% with an estimated 0.4-1.6 million DALYs averted and USD 15-60 million saved in healthcare expenditure for health services and beneficiaries (Welburn and Coleman, 2015). It is estimated that use of RAP to control AAT could result in a gain of USD 20 per bovine per year and USD 34 if tick-borne diseases are included; extrapolated as USD 9-10,000 gained per square km^2 of productive land (Welburn and Coleman, 2015).

1.4.4 Ruminant livestock production systems and population

Livestock is vital part of agriculture in Uganda and the livestock systems have evolved due to agro-ecological and socio-economic factors. In Uganda, there are two types of livestock systems, depending on input and output, namely: i) traditional and ii) improved. Traditional livestock system is characterized by minimal inputs and consequently low outputs. In contrast, the improved system is characterized by some level of input such as veterinary care and improved pasture and breed; and consequently higher livestock output depending on cattle breed and grazing method (FAO, 2006). Also, in Uganda, the two main livestock production systems have five grazing methods namely: i) communal (pastoral and agro-pastoral), ii) fenced dairy farms, iii) zero-grazing, iv) tethering, and v) enclosed ranching (FAO, 2006). Communal grazing is common in central (Luweero, Kibooga and Kibaale), south west (Mbarara, Bushenyi, Masaka, Sembabule and Rakai), north and north east (Soroti, Moroto, Kotido and Kumi) districts. There are two subtypes of communal grazing namely; pastoral and agro-pastoral. In pastoral communal grazing milk and meat are the main sources of sustaining livelihoods; population density in this system is low and majority of farmers are nomads and transhumant; and mostly keep tick-borne and trypano-tolerant indigenous herds of cattle (Ankole and local zebu breeds), sheep and goat (small East African, Kigezi and Mubende breeds). Although the livestock have some immunity against tick borne diseases and trypanosomiasis, milk and meat production is low; 300 litres per lactation and carcass weight of 150 kilograms (Mahadevan and Parsons, 1970). Agro-pastoral communal grazing is similar to pastoral grazing, except that the population is sedentary and grow crops; and in most cases practise mixed farming. Mixed farming is common in smallholder farming as found in south east, south west and central districts of Uganda; and most farmers own 1-5 hectares of land. Agro-pastoralists and those practising mixed farming keep livestock for draught, savings, milk and meat and sale of cattle; and keep local and exotic cattle breeds. Fenced grazing system is mostly practised by dairy farmers where most of the land is used for producing fodder or improved pasture; most farmers own 2-10 hectares of land and mostly keep exotic breeds for milk production. Fenced dairy grazing system is found in south west, central and south east Uganda. Zero-grazing is mostly found near urban areas where land is scarce and there is market for milk; also, livestock is continuously housed and fed fodder. Tethering system is found in urban, peri-urban and rural areas of Uganda. Tethering is mostly done to prevent livestock from destroying crops and most farmer keep 1-5 cattle. However, farmers practise communal grazing if the number of cattle increases. Enclosed ranching is an extensive system where mixed type of livestock (cattle, goat and sheep) is kept under pastoralism and ranching; depending on natural resources such as pasture and water (FAO, 2006).

The total cattle population has been estimated to be 11.4 million of which 2.5 million (22.3%) was in the Western Region, 2.5 million (21.8%) in the Eastern Region, 2.5 million (21.7%) was in the Central Region, Karamoja sub-region had 2.3 million (19.8%) cattle and the rest of Northern Uganda had 1.6 million (14.4%) cattle. The district with the highest cattle population is Kotido district with 694,250 (6.1%) cattle. The other districts with at least 200,000 heads of cattle are: Nakapiripirit, Kaabong, Kiboga, Moroto, Kiruhura, Rakai, Soroti, Ntungamo, Apac, Masaka, Yumbe, Nakasongola, Kumi, Mpigi, Masindi, Kamuli, Mubende and Bushenyi (MAAIF, 2008). Table 1-3 provides a summary of cattle population in Uganda by breed and region.

Table 1-3: Cattle population in Uganda

Region	Cattle population	Cattle breed				
		Indigenous			Exotic (including cross breeds	
		Indigenous as % of all cattle	Ankole as % of indigenous cattle breed	Zebu/Nganda as % of indigenous cattle breed	Beef as % of all cattle	Dairy as % of all cattle
Central	2,475,860	90.2	57.9	42.1	0.2	7.9
Eastern	2,488,470	94.3	5.4	94.6	0.7	5.1
Northern	1,641,840	99.4	10.5	89.5	0.2	0.4
Western	2,548,620	87.1	68.3	31.7	0.8	12.2
Karamoja	2,253,960	87.4	8.4	91.6	0.5	12.1
Total	11,408,740	93.6	29.6	70.4	0.8	5.6

1.5 Lao PDR Economic Case Study: Background Information

1.5.1 Geography, economic indicators and ethnography

The Lao Peoples' Democratic Republic (Lao PDR) (see Figure1-3) is a landlocked south-east Asian country that depends heavily on agricultural production, with over

70% of the rural households in the northern part of the country involved in pig production (Okello *et al*. 2014). Lao PDR has major trade routes; Thailand, Mynamar and China (golden triangle) and Thailand and Vietnam to the south. In Lao PDR there are two climatic zones; warm tropical and sub-humid and warm tropical and humid; three topographical zones; north, central and south regions; five agro-ecological zones; Mekong corridor, central-south highlands, Vientiane plain, Northern highlands and Northern lowlands (Wilson, 2007). Administratively, the country is divided into 16 provinces, Vientiane municipality and a special zone called Xaysomboon, headed by governors, a prefect and chief of the special zone respectively as shown in Figure 1-3. The provinces are then divided into 140 districts each having about 11,000 to 12,000 villages.

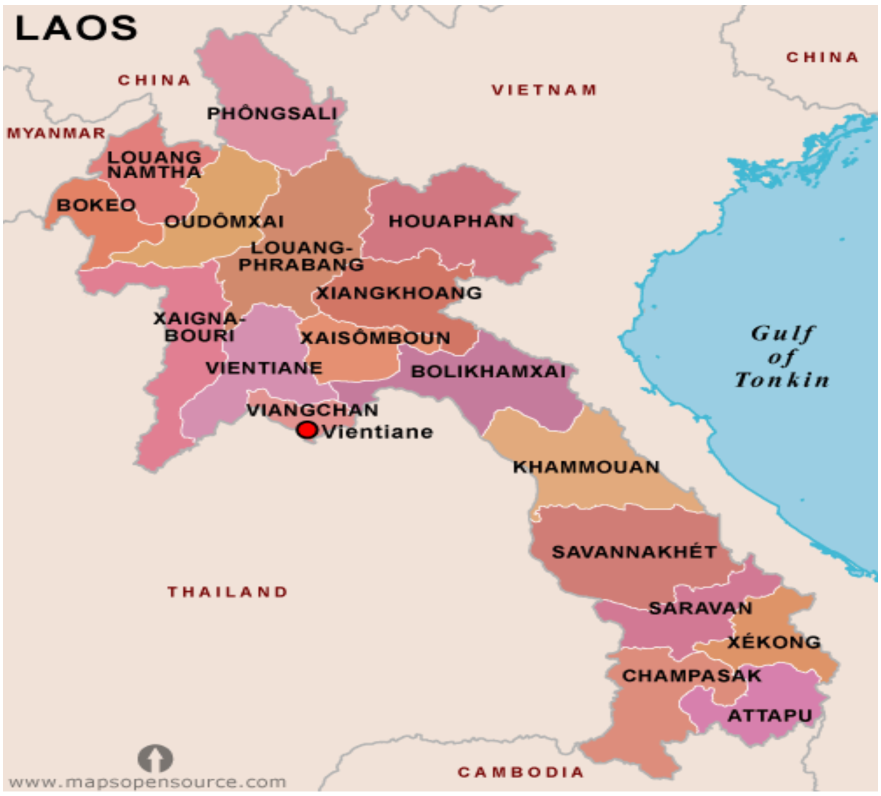


Figure 1-3: Map of Lao PDR showing provinces, ©Maps Open Source

The country covers an area of 236,800 km² with an estimated population of 6,541,432 persons in 2012; according to the Lao PDR census (2005) the national population was 5, 621,982 as summarized in Table 1-4. With an HDI ranking of 139 out of 187, Lao PDR is the least developed country in south-east Asia, with 33.9% of the population living below poverty line (UNDP, 2013).

Table 1-4: Human population in Lao PDR.

Province	Human Population
Northern region	**1,978,211**
Phongsaly	165,947
Luangnamtha	145,310
Oudomxay	265,179
Bokeo	145,263
Luangprabang	407,309
Huaphanh	280,938
Xayaboury	338,669
Xiengkhuang	229,596
Central region	**2,475,806**
Vientiane province	388,895
Vientiane capital	698,318
Borikhamxay	225,301
Khammuane	337,390
Savanekhet	825,902
Southern region	**1,128,749**
Saravane	324,327
Sekong	84,995
Champasack	607,307
Attapen	112,120
Special zone	**39,423**
Xaysomboon	39,423
Total	**5,621,982**

There are four main ethno-linguistic families in Lao PDR; Tai, Austro-Asiatic, Hmong-mien (Miao-Yao) and Sino-Tibetian. The majority of Lao are from Tai family representing 60% of the population. Among this family are the Lao Loum (35% of the population and 58% of the Tai family), Tai Deng, Tai Khao, Phouane, Phutai (all of which represent 20% of the population) and 20 other Tai ethnic minorities (4-6% of the population). The Tai Dam are found in northern Lao, Vietnam, Thailand. They are rice paddy cultivators, keep livestock as well as hunting and gathering. In northern Lao they occupy remote mountainous regions with poor road networks. During the rice planting and harvesting season they move with their livestock to agricultural fields known as *sanaam* depending on the distance (Bardosh *et al*. 2014). Tai Dam do not practice Theravada Buddhism but perform rituals or provide offerings to various spirits known as *phi* (Kashinaga, 2009). They believe that the dead go to the celestial world where they become spirits who protect the living patrilineal descendants (Bardosh *et al*. 2014). They conduct two main rituals; domestic (known as *Xe Huan*) which is held once a year, and, those done when the either of the parents of the household has died (known as *Pat Tong*) (Kashinaga, 2009). When conducting rituals, the spirits are requested to descend to a special cell in the house to share a meal with their descendants, they are then 'fed' and asked for blessings for peace and prosperity (Kashinaga, 2009). Pigs and buffalo – eaten raw - are normally used for the ritual (Kashinaga, 2009; Bardosh *et al*. 2014).

1.5.2 Governance and economic policy

Lao PDR attained independence from France in 1949, gaining full sovereignty in 1954 after the French were defeated by the Vietnamese. In 1975 the king relinquished his throne and the single party communist Lao People's Democratic Republic was formed. From 1975 until 1991 Lao PDR was managed through part resolutions after the first constitution in 1947 was abolished. In 1991 a new constitution was enacted and elections for national assembly done the following year. The administrative structure of governance is composed of three arms; national assembly, executive and central party committee. The President is the head of state and is elected by the national assembly. The Prime Minister is appointed by the President after recommendation by the national assembly. All ministries such as agriculture and health are within the executive arm of government, overseen by the Prime Minister. Lao PDR's local governance system is decentralised; provinces, strategic planning units; districts, planning and budgeting units; and villages, implementing units.

In Lao PDR, central government is responsible for national budgeting and central expenditures; while the provinces make their own budget collect revenue and remit some of the surplus revenue to the central government. Districts receive their budgetary allocations from the provinces. Recently, the office of the Prime Minister is setting up the national board for rural development and poverty alleviation to coordinate policy processes. Lao PDR, similar to most developing countries, has privatised many agricultural services since 1986. Currently, the government considers agriculture, health, education, infrastructure and debt service as priority areas, however domestic expenditure on these sectors has varied from year to year, with the biggest reductions seen in agriculture. Meanwhile there has been tremendous spending in servicing debts, including repayment of loans from the World Bank and Asia Development Bank, with the government committed to lose its status as a least developed country by 2020 via a National Growth and Poverty Reduction Strategy (NGPES).

1.5.3 Overview of the Health and Agriculture sectors in Lao PDR

Agriculture is the most important sector in Lao PDR employing 80% of the population. In 2003 the share of GDP to agriculture was approximately 50%, compared to 15%, 22% and 45% in neighbouring China, Vietnam and Cambodia, respectively. Rice is the most important crop accounting for 60% of the total agricultural output while livestock and fisheries account for 35% and forestry, 5% (Wilson, 2007).

Lao's animal health sector can be divided into three sectors; public, private and other related organizations (OIE, 2011). The veterinary public sector is run by the Ministry of Agriculture and Fisheries (MAF) through the Department of Livestock and Fisheries (DLF) (
4). Apart from DLF, MAF has seven other departments namely; agriculture, forestry, irrigation, inspection, forestry inspection, personnel and planning as shown in
4 (OIE, 2011). It also runs two associated organisations, the National Agriculture and Forestry Research Institute (NAFRI) and National Agriculture and Forestry Extension Services (NAFES). Most of the animal health activities of DLF are run through the

Provincial and District Department of Agriculture and Forestry (PDAF and DDAF respectively); PDAF and DDAF have their own budget allocation and are independent.

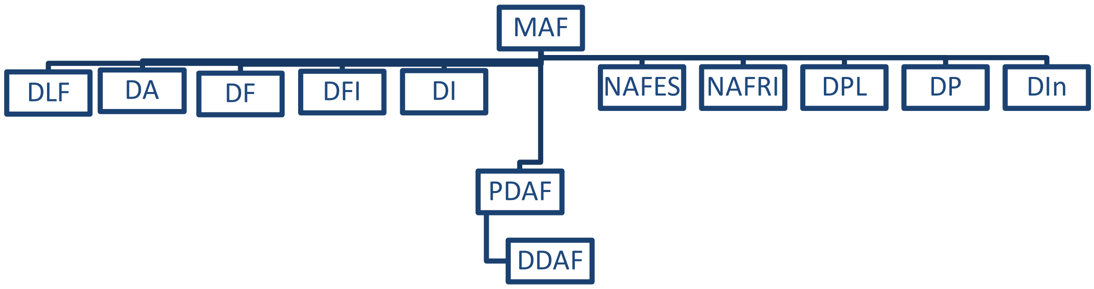


Figure 1-4 Structure of the Lao agricultural sector (Adapted from OIE 2011)
Legend: MAF, Ministry of Agriculture and Forestry; DLF, department of livestock and fisheries; DA, department of agriculture; DFI, department of forestry inspection; DI, department of irrigation; NAFES, national agriculture and forestry extension services; NAFRI, national agriculture and forestry research institute; department of planning; DP, department of personnel; DIn, department of inspection; PDAF, provincial department of agriculture and forestry; and DDAF, district department of agriculture and forestry.

The DLF has four divisions; livestock and veterinary regulator, fisheries, planning and administration; and four centres; National Animal Health (NAHC), Veterinary Vaccine Production (VVPC), Livestock Management (LMC) and National Aquaculture Development (NADC) (OIE, 2011). Most of the public veterinary services; diagnostics, veterinary supply, disease surveillance and administration; are done through NAHC (OIE, 2011). The VVPC produces vaccines such as for classical swine fever (CSF). For example the VVPC sells CSF vaccine at United States dollar (USD) 0.08 for 10 doses (OIE, 2011). Meat and border inspection is done by provincial administration. There are 36 veterinarians, 23 of whom are based at the national level and 13 at provincial level. There are ten provinces without veterinary personnel and these are; Phongsaly, Luang Namtha, Bokeo, Huaphan, Boulixamsai, Khammouane, Saravan, Xexong, Champassack and Attapeu (OIE, 2011). At the village level, village veterinary workers (VVW) provide veterinary services, such as vaccinations, to the farmers. Official statistics indicate that 11,571 VVW have been trained (OIE, 2011).

There are reportedly abattoirs at the national, provincial and district levels, however, the meat inspection capacity is still sub-optimal; furthermore there is currently no legislation on meat inspection (OIE, 2011). The government allocates about 12% of the public resources to agricultural research mainly through NAFRI and NAFES (OIE, 2011). Most technical operations are done through district agriculture and forestry offices (DAFOs) (OIE, 2011). The recent agriculture master plan as stated by Ministry of Agriculture and Forestry Agricultural development strategy 2020 has outlaid eight programmes the government would pursue namely; food production, forestry development, sustainable production, agricultural infrastructure, irrigation, research and extension, commodity production and farmer organization and human resource development (MAF, 2010).

The avian influenza outbreak in 2004 led to coordination of its control between Ministry of Health (MAH) and MAF under the National Avian and Human Influenza Coordination Office (NAHICO) (Phommasack *et al*. 2012). The activities of NAHICO were later expanded and renamed National Emerging Infectious Diseases Coordination Office (NEIDCO) (Phommasack *et al*. 2012). Currently NEIDCO is under the National Committee on Communicable Disease Control (NCCDC) secretariat chaired by the Prime Minister with all the ministries as vice chairs and the Prime Minister's Office (PMO) as the secretariat (Phommasack *et al*. 2012). The NCCDC has been established at the central and provincial level. Disease surveillance, control and response is done by; Department of Hygiene and Prevention, Department of Healthcare, National Center of Epidemiology and Labouratory (NCEL), NAHC and information and communication taskforce (Ministry of information and culture) (Phommasack *et al*. 2012). The main focus of the NCCDC is emerging infectious zoonoses such as avian and human influenza. Other diseases are leptospirosis, trichinellosis, anthrax and rabies (Phommasack *et al*. 2012; OIE, 2011). According to the 2010-11 budget allocations, there was no budgetary allocation for zoonoses control but these were done through donor projects; for example the Australian Center for International Agricultural Research (ACIAR) funded the management of pig zoonoses in 2010 (OIE, 2011). The human health sector in Lao PDR is underfunded and use of health care services low with only 0.7 per 1,000 outpatient consultations yearly and 30 out of 1,000 inpatient admission rate. Also, only 30% of the population has access to acceptable sanitation (WHO and MoH Lao PDR, 2012). The composition of the key health financing indicators in Lao PDR is as follows; Government health expenditure as percentage of overall health expenditure, 5.9%; external funding as a percentage of total health expenditure, 12.6%; out of pocket expenditure, 63%, social health protection (includes state authority for social security, social security office, community based health insurance and health equity funds), 18.5% (WHO and MoH Lao PDR, 2012).

1.5.3.1 Livestock production systems

Smallholder agricultural systems in Lao PDR, comprising 90% of agricultural production, are mixed farming systems including livestock and crop (both staple and cash crops) production. In this context, pig production plays a significant role in smallholder farming systems, as a source of income and capital (Phengsavanh *et al.* 2011). Also, the type of farming in Lao PDR can be divided into two namely: lowland rainfed and or irrigated farming systems of the Mekong plains and upland swidden agriculture (MAF, 2010). Approximately 50% of the population lives in the lowlands, 30%, uplands and 20% mixed lowland and upland (MAF, 2010). In 2011, there were about 978,300 pigs in Lao PDR (DLF, 2011), and approximately 85% of these were kept in smallholder systems, mainly in the mountainous regions (Thorne, 2005); and 55% kept in the northern region as shown in Table 1-5.

Table 1-5: Pig population Lao PDR

Province	Human Population
Northern region	**542,100**
Phongsaly	68,100
Luangnamtha	45,300

Oudomxay	71,200
Bokeo	50,000
Luangprabang	113,100
Huaphanh	98,800
Xayaboury	95,700
Xiengkhuang	69,100
Central region	**327,500**
Vientiane province	70,200
Vientiane capital	32,800
Borikhamxay	40,600
Khammuane	42,000
Savanekhet	72,800
Southern region	**108,700**
Saravane	43,700
Sekong	16,400
Champasack	30,300
Attapen	18,300
Total	**978,300**

The indigenous pigs, namely *moo lath* and *moo Hmong*, are the most predominant pig breeds in Lao PDR; they are mostly black in colour or with some spots of white and weigh 80 to 120 kilograms at maturation (Phengsevanh *et al* ,2010). Apart from indigenous pig breed there are cross breeds based on exotic breeds such as large white, Land race, Duroc Jersey and Berkshire. Pigs are mostly kept in the northern and southern Lao PDR (Phengsevanh *et al*. 2010).

According to Phengsavanh and Stür (2006), there are three pig management systems in Lao PDR namely free ranging, confinement with provision of some shelter and penning. However in northern Lao PDR, the predominant pig management system is free range where pigs are left to roam during most parts of the rice post-harvest period and enclosed during rice harvesting season (Okello *et al*. 2014; Bardosh *et al*. 2014). In some communities pigs are left to roam during the day and penned at night. Semiintensive pig production is mainly done in peri-urban areas where pigs are kept in large pens and fed kitchen waste and other by-products. There are few commercial pig farms with complete confinement. Also, in some villages integrated pig-fish farming is done (Phengsevanh *et al*. 2011).

1.5.4 Taenia solium cysticercosis, Soil Transmitted Helminths and Classical Swine Fever in Lao PDR

In Asia there are three common taeniid tapeworms namely *Taenia solium*, *Taenia saginata* and *Taenia asiatica* that cause taeniasis in humans (Conlan *et al*. 2011). The estimated prevalence of taeniasis in Lao PDR ranges from 0.1-3.3% (Conlan *et al*. 2011). *Taenia solium*, also known as pork tapeworm, causes cysticercosis in pigs and neurocysticercosis (NCC) in humans if the tapeworm larva lodges in the central nervous system (CNS). The definitive host for adult tapeworm infestation is man (Conlan *et al*. 2011). Infested people shed tapeworm eggs in faeces contaminating the environment particularly in open defecation. Pigs, especially free ranging, become infected with *T. solium* when they eat infective human faeces or herbage leading to formation of larval cysts in their tissues, a condition known as porcine cysticercosis (Willingham and Engel, 2006). Humans get infected with adult *T. solium* when they consume a mature metacestode larva in raw or undercooked pork (Willingham and Engel, 2006). The larva matures within 2-3 months after which they shed infective eggs in faeces (Willingham and Engel, 2006). If humans inadvertently ingest *T. solium* eggs, the parasite will develop as a cysticercus, usually in the brain or spinal cord causing a condition known as NCC (Lightowlers, 2013). Clinical manifestation of NCC varies according to the part of CNS affected but the most common neurological sign is seizures (Carpio *et al*. 1998). The NCC incubation varies markedly and affected people can remain asymptomatic for years; *T. solium* cysts in the CNS effectively avoid the host immune system and symptoms occur due to spontaneous degeneration of cysts or following drug treatment (Willingham and Engel, 2006). Neurocysticercosis is known to occur in Lao PDR (Jeon *et al*. 2013); and there has been a wide range of potential risk factors associated with epilepsy namely; open defecation, use of human faeces as fertilizer, eating raw pork (Jeon *et al* ,2013; Bardosh *et al*. 2014; Okello *et al*. 2014).

1.5.4.1 Control, treatment and diagnosis of cysticercosis

WHO considers *Taenia*/cysticercosis as one of 17 neglected tropical diseases (NTDs) and it has declared to upscale control and elimination of *T. solium* by 2020 (Lightowlers, 2013). It is one of the six diseases that have been identified as potentially eradicable by the International Task Force For Disease Eradication (ITFDE) (Okello *et al*. 2014). The ITFDE recommends the following; effective control or elimination of *T. solium* on a national scale, inclusion of multifaceted control strategy in mass or targeted approaches, consideration of economic factors, better knowledge on global burden of cysticercosis and assessment of the impact mass drug treatment on co-endemic parasitic diseases such soil transmitted helminths (Okello *et al*. 2014). There are several control regimes for taeniasis/cysticercosis based on the life cycle; public education, treatment of humans with antihelmintic, vaccination of pigs, improved sanitation and deworming of pigs (Lightowlers, 2013). Mass treatment of people with niclosamide or praziquantel has been applied in various settings with modest results (Sarti *et al*. 2001; Lightowlers, 2013). These drugs are given orally as single-dose and are 90%-95% efficacious against taeniasis; however they have to be given repeatedly due to the persistence nature of cestode eggs in the environment (Lightowlers, 2013). Mass drug treatment of pigs with oxfendazole, at 30mg/kg, has also been done in some countries (Gonzalez *et al*. 1997, Gonzalez *et al*. 1998, Pondja *et al*. 2012); and it is effective in killing the tapeworm cysts, however, scars are left on the tissue (resolve after 12 weeks to 6 months) reducing pork quality (Sikasunge *et al*. 2008). Also, a withdrawal period of 17 days should be observed before slaughter (Lightowlers, 2013). There are several vaccines developed against *T. solium* based on *T. solium* recombinant antigen expressed by the oncosphere stage of the parasite, with TSOL18 shown to induce 99.5%-100% immunity against *T. solium* in pigs in field and experimental trials (Lightowlers, 2006).

A combination of strategies targeting humans and pigs have been applied to control cysticercosis with varying results; for example combined use of public education and human mass drug administration (MDA) with praziquantel and human MDA with mass treatment of pigs with oxfendazole in Mexico (Lightowlers 2013), and more recently in Lao PDR (Okello *et al.* 2016). In the former two studies, prevalence of porcine cysticercosis (using pig tongue palpation and serology) was used as the indicator of success of the intervention (Lightowlers, 2013), whilst human taeniasis carriers were used as sentinels in Okello *et al* (2016) given the challenges of diagnosing porcine cysticercosis in the Asian context (Deckers and Dorny 2003). A combination of vaccination of pigs with TSOL18 and oxfendazole treatment has been shown to be effective, proposing pig vaccination with TSOL18 be done twice yearly four weeks apart, with pigs receiving oxfendazole at the second vaccination (Lightowlers, 2013). An alternative is to identify high-risk foci ('hot spots') and target treatment in these sub-populations though practical tools for identification of such foci need to be developed (O'Neal *et al*. 2012).

Human tapeworm can be treated using praziquantel, albendazole or niclosamide, whilst oxfendazole at 30mg/kg is recommended to treat porcine cysticercosis (Lightowlers, 2013). By using stochastic models it has been established that mass human and pig treatment with taenicidal drugs lead to dramatic decrease of cysticercosis/taeniasis in the short run, but does not eliminate the disease and this is the same for a combined human treatment and pig vaccination (Kysvgaard *et al*. 2007).

There are various methods of detecting human and porcine cysticercosis; immunodiagnosis of parasite antigen or antibodies, cutaneous biopsy and imaging procedures such as magnetic resonance imaging and computerized tomography. For human taeniasis diagnosis is made through coprology complemented by coproantigen tests that detect parasite residues in faeces (Lightowlers, 2013). Porcine cysticercosis detection is primarily done by immunodiagnostic tests, palpation of pigs for lingual cysts and post mortem examination (Lightowlers, 2013).

1.5.4.2 Soil transmitted helminths

Soil transmitted helminths (STH) are the most predominant infections of man, affecting more than two billion people globally (Hotez *et al*. 2006). The most common

STH are hookworm (*Ancylostoma duodenale* and *Necator americanus*), roundworm (*Ascaris lumbricoides* and *Strongyloides stercolaris*) and whipworm (*Trichuris trichiura*) (Hotez *et al*. 2006). During the life cycle, the adult stages of roundworm and hookworm are found in the small intestine while whipworm inhabit the colon where they reproduce sexually, producing several eggs which are passed in the faeces into the environment. Humans get infected when they ingest the eggs in contaminated water or food or when the larvae penetrate the skin as in the case of hookworm infection. Populations infected with these diseases are at risk of developing iron deficiency anaemia (in the case of hook worm), stunted growth and or physical unfitness particularly in the case of round and whipworm in children (de Silva *et al*. 1997). Unlike *T. solium*, the transmission of STH usually do not involve an animal reservoir, with the exception of zoonotic hookworm, however like *T. solium*, sanitation, poverty as well as behavioural and occupational factors play a major role in the transmission of STHs (Hotez *et al*. 2006).

1.5.4.3 Burden of cysticercosis and STH

Globally it is estimated that the DALY per 100,000 person-years from cysticercosis and soil transmitted helminths are 7 and 75 respectively from the 2010 World Health Organization Global Burden of disease study (Hotez *et al*. 2014). However, studies on the burden of these diseases regionally or in sub-district level are limited; with only two studies done in Africa and one in Latin America (Carabin *et al*. 2006; Praet *et al*. 2009; Bhattarai *et al*. 2012). In central Africa it was estimated that NCC caused 9 DALY per 1,000 person-years, 95% credibility interval (CI) of 2.8-20.4 and an overall monetary burden of cysticercosis being 10.3 million Euro with 95.3% due to human cysticercosis and 4.7% porcine cysticercosis (Praet *et al*. 2009). A study on the monetary burden of cysticercosis was done in South Africa revealing that the total burden ranged from 15.0% to 27.5% with 73.1% to 85.4% due to human cysticercosis and 14.6% to 26.9% porcine cysticercosis (Carabin *et al*. 2006). In Mexico it was estimated that the DALY burden due to NCC and headaches was 23,020 (95% credible region (CR): 11,283-43,276) and 2321 (95% CR: 198-8,758); with 0.25 per 1,000 person years of which 90% was due to NCC (Bhattarai *et al*. 2012). Recent studies in Lao PDR revealed hyper-endemic *T. solium* foci in humans in Northern Province with a prevalence of 26.1% (Okello *et al*. 2014) and there is a possibility of other foci being present in northern Lao provinces where *T. solium* is endemic (Conlan *et al*. 2011). There are limited studies on the burden of STHs; it has recently been estimated that worldwide; 819.0 million people (95% CI: 771.7 – 891.6 million) are infested with *A. lumbricoides*, 438.9 million people (95% CI: 406.3 - 480.2 million) with hookworm and 464.6 million (95% CI: 429.6 – 508.0 million) with *T. trichuris*. Also, of the 4.98 million years lived with disability (YLDs) attributable to STH, 65% were due to hookworm, 22% to *A. lumbricoides* and 13% to *T. trichiura* (Pullan *et al*. 2014).

1.5.4.4 Classical Swine fever in Lao PDR

Apart from cysticercosis and STH, classical swine fever (CSF), also known as hog cholera, is endemic in most countries in south-east Asia (Blacksell, 2000; Edwards *et al*. 2000). Outside Asia, CSF occurs in some countries in Eastern Europe, Africa, South and Central America (Edwards *et al*. 2000). Classical swine fever is a highly contagious disease of pigs caused by a virus of genus pestivirus (Blacksell, 2000). Pigs are the only natural host and it spreads through contact (Blacksell, 2000). There is only one serotype of the CSF virus although several strains exist (Blacksell, 2000). Sows can become carriers and the virus can cross the placenta resulting in foetal death or infection of live piglets (Blacksell, 2000). The infected piglets continue shedding the virus for several months before showing clinical signs. Infected pigs exhibit ill thrift, nervous signs, abortion, still births and a mortality rate of up to 90% among other signs (Blacksell, 2000).

1.6 Research design

1.6.1 Case studies in Uganda and Lao PDR

Uganda and Lao PDR are low-middle income countries with very low resources to control endemic zoonotic diseases. Furthermore, control of HAT in Uganda is mostly driven by its effect on livestock productivity; while in Lao PDR control of emerging zoonoses such as avian influenza through donor funding are the priority. Therefore, although this countries are in different continents they share certain characteristics such as low HDI, weak decentralized health and animal health systems, heavy reliance on donor funding, smallholder mixed farming systems and presence of neglected endemic zoonotic diseases. Further, previous studies in Uganda and Lao PDR, in which the economic study is based, have both utilised integrated approaches to control HAT and *T. solium* respectively. In Uganda, using RAP, control of HAT was integrated in two levels namely; i) control of tsetse and trypanosomiasis to control both HAT and animal African trypanosomiasis (AAT), and ii) disease management by both controlling tsetse flies/trypanosomiasis and tick-borne diseases (Muhanguzi *et al*. 2014a; Muhanguzi *et al*. 2014b). In Lao PDR, control of *T. solium* was done in three levels namely; i) combined control with STH using a common drug, ii) combined control with TSOL18 vaccination of pigs, and iii) combined control with existing CSF control programme. Furthermore it was envisaged that a bivalent vaccine with both TSOL18 (for control of *T. solium* in pigs) and CSF would be developed in future. Consequently, one of the main objectives of the study was to compare the two countries in terms of controlling zoonoses using locally adaptable and sustainable integrated control methods.

1.6.1.1 Uganda

a) Human and Animal African Trypanosomiasis

Interest in large scale trypanosomiasis control for the purposes of resource allocation requires knowledge of the economics of controlling the disease (Shaw *et al*. 2014). In Africa there has not been any comparable field based cost estimate of RAP based on field data, despite the fact it could be the cheapest control method (Shaw, 2009). In this regard information was required on:

i) The cost of RAP to enable comparison with other methods to control trypanosomiasis

ii) The cost of RAP to different stakeholders

iii) The socio-economic impact of RAP to animal health and rural livelihoods

iv) The acceptability of RAP to livestock keepers; given the success of the control programme relies on their willingness to participate and pay for the costs.

Based on the above, the null hypotheses of the RAP study were;

i. That there was no significant RAP induced change in annual income per bovine.
ii. That there was no significant difference in annual mean household income between those households that participated in the RAP intervention and those that did not.
iii. That there was no significant change in annual household income across all the households before and after the intervention.
iv. That there was no significant annual mean household difference between households in regimes 1,2,3,4 and 5 compared to 6 (control) after the RAP intervention.
v. That spraying of 25% of the total village cattle population using RAP was the least beneficial compared to spraying 50% and 75%.
vi. That there was no significant difference in characteristics between villages/households in high and low HAT prevalent areas.
vii. That there was no significant annual change in working capacity (number of days worked per year) of draught oxen after RAP intervention.
viii. That there was no significant difference between costs of RAP to farmers in Uganda compared to Zimbabwe.
ix. That there was no significant change in acreage used for cultivation (thus food security) after the RAP intervention.
x. There was no significant change of the contribution of cattle enterprise to the overall household gross income due to RAP intervention.

Based on the null hypotheses, the main objectives of the Uganda case study were:

- To understand the key characteristics of households in a cohort of villages with a high prevalence of *T.brucei sensu lato* (s.l) sampled in a concurrent epidemiological study for future prediction of occurrence of HAT.
- To ascertain the mean RAP-induced change in annual household income and most importantly income gained per bovine.
- To ascertain the cost of RAP per cow from the farmers' perspective and use information obtained from the epidemiological study to ascertain the total cost

of RAP within the eighteen month intervention period using economic analysis methods.

- To ascertain the most economic percentage of cattle coverage.
- To ascertain the socio-economic impact of RAP on cattle production, food security and rural livelihoods by assessing its direct and indirect benefits within the eighteen month intervention period.

b) Cattle value chain

It has been reported that movement of cattle pose a risk to spread of HAT due to trade and restocking programmes (Fevre *et al.* 2001; Selby *et al*. 2013). However, currently there are no studies on cattle value chain in Uganda linking herd dynamics (what is happening at the farm level) to cattle markets and eventually consumption of livestock products. Thus, information was required on: i) Herd composition including importation of young draught cattle, ii) stakeholders involved in cattle trade, iii) patterns on cattle trade, iv) value addition on cattle products including intermediate ones (mainly animal traction) and v) mapping of the cattle trade. Based on these, the null hypotheses of the value chain study were:

i. Demand of draught cattle was not significant in inter-district spread of HAT.
ii. There were no key cattle markets involved in enhancing spread of HAT within the cattle trade network.
iii. Uganda cattle trade network was weak, had no smaller communities (sub-group of markets within the network capable of enhancing even a quicker spread of HAT) within it and spread of HAT would occur from one cattle market.
iv. Drugs for controlling trypanosomiasis were not commonly sold in livestock markets.

Thus, based on the null hypotheses, the objective of the value chain study were:

- To ascertain whether demand for draft cattle is one of the major driving factors for movement of cattle and in turn risk of transmission of HAT.
- To examine the main cattle markets within the network important in control of trypanosomiasis.

c) Brief summary of how objectives were achieved

Although each chapter have more details on the materials and methods, the research objectives in Uganda were achieved by; i) collection of household, livestock and market data, ii) analysis of livestock data using GMA, and iii) analysis of market data using network and value chain analysis. The concurrent epidemiological study involved baseline collection of cattle blood samples from 57 out of 63 villages in Tororo district to choose those with high *T.brucei sensu lato* (s.l) prevalence. Afterwards, the cattle from villages with the high HAT prevalence were sprayed with deltamethrin using RAP (spraying 25%, 50% and 75% of the village cattle population) once a month for 18 months; and there was control group of villages that did not have their cattle sprayed but were either injected once with diminazine aceturate or dewormed every six months or had no intervention at all.

The socio-economic household was collected during the baseline study (collection of cattle blood samples in 57 out of 63 villages) and after the RAP participating villages (those with high prevalence of *T.brucei s.l.*) have been identified for 18 months. The household and livestock variables between villages dropped (because the prevalence of *T.brucei s.l* was low) and those chosen (because the prevalence of *T.brucei s.l.* was high) was compared using exploratory data analysis, chi-square test and logistic regression to find out the key characteristics of households with cattle highly infected by *T.brucei s.l.* for future prediction of the same. The determination of the change in income due to RAP was done by first dividing the households into two namely RAP and non-RAP. The former applied to households in villages which had 25%, 50% and 75% of their cattle sprayed using RAP, while the later had their cattle receive diminazine aceturate (a curative trypanocidal drug) injection only, dewormers only or no treatment. The cost of RAP to farmers (who were considered a major stakeholder) was achieved by collection and analysis of all costs incurred during the 18 month intervention. The evaluation of the regime (0-25%, 25-50% and 50-75%) that provides the highest benefit-cost ratio was done by comparing the marginal benefit (derived from the mean annual income per bovine) and the marginal cost (as obtained in the concurrent epidemiological study and cost of RAP to farmers). Also, other benefits of RAP such as decreased cattle mortality, increased work oxen output and cultivation acreage (hence improved food security) were evaluated. Finally, the demand for draft cattle was analysed using bio-economic herd modelling and the potential risk of HAT spread among districts in Uganda evaluated by interviewing cattle traders to understand the pattern of movement of cattle and value addition along the cattle marketing chain.

1.6.2 Lao PDR: T. solium, STH and Classical Swine Fever

There is currently no study that has been done to ascertain the regional burden of cysticercosis and STH in Asia. Also, currently there are limited economic analytical methods that combines non-monetary and monetary burden of disease in humans and animals as a single outcome; and combined impact of controlling two or more neglected tropical diseases simultaneously. Lack of analytical tools hinders a true analysis of the cost effectiveness of control and elimination strategies. Therefore,
null hypotheses of the study in Lao PDR were:

i. That there was no significant difference between *T. solium* burden in northern Lao PDR and West Cameroon; this was comparable since both were in rural areas.
ii. That there was no significant difference between integrated and non-integrated control of *T. solium.*

Based on the null hypotheses, the objectives of the Lao study were to:

i) Evaluate the non-monetary and monetary burden of cysticercosis and STH in northern Lao PDR region.

ii) Assess the cost effectiveness of simultaneously controlling cysticercosis, STH and CSF.

The inclusion of STH and CSF, which are not zoonotic diseases, was done to integrate government disease control priorities in the area. It was envisaged that future control of zoonotic diseases will be pegged on control of other neglected tropical diseases and livestock diseases; and should be delivered as a 'rapid impact package' (Molyneux and Hotez, 2005). Therefore integration of control zoonotic diseases with other diseases would create government 'buy in' and demand of 'safe' animal products. For example, integrating control of cysticercosis and CSF through vaccination would increase pig productivity (due to reduced mortalities from CSF) as well as cystic free pork.

Although the materials and methods on how the above objectives were achieved is detailed in Chapters 4 and 5, they were generally achieved by: i) collection of household, livestock, human health and secondary data, and ii) analysis of data using cost GMA, cost utility and cost effectiveness analysis. Secondary data obtained from the literature were subjected to stochastic modelling and Bayesian techniques. The cost to the health sector per DALY averted if cost were shared with the animal health sector in simultaneously controlling cysticercosis was done by extrapolating the field data to the larger northern Lao PDR population; because it is not possible to calculate the burden of disease in a small sample size. Accordingly, the cost per DALY averted for controlling cysticercosis was compared to the less than one third of the Lao PDR's gross domestic product (GDP) has currently recommended by the World Health Organization (WHO) as measure of cost-effectiveness threshold (WHO, 2003).

1.7 Description of projects used for data collection

In Uganda data was collected through the Integrated Control of Neglected Zoonoses in Africa (ICONZ-Africa). The ICONZ-Africa is a seventh framework European project that aims to improve human and animal health in developing countries. The eight neglected zoonoses under study were Anthrax, Bovine Tuberculosis, Brucellosis, Cysticercosis, Echinococcosis, Leishmaniasis, Rabies and Human African Trypanosomiasis. The project was carried out in 8 African countries (Mali, Morocco, Mozambique, Nigeria, Tanzania, Uganda, Zambia and South Africa) and had twelve work packages namely; i) management and coordination, ii) mapping global research on neglected zoonoses, iii) knowledge and information on neglected zoonoses, iv) improvement and development of disease controls tools, v to viii) integrated intervention packages for clusters of neglected zoonoses (bacterial zoonoses, dog/small ruminants, pigs, vector borne), ix) socio-economic and institutional aspects, x) cultural and gender aspects and xi) capacity building and xii) communication and dissemination. The economic study on zoonoses was majorly done on Human African Trypanosomiasis through work packages 8 (vector borne cluster) and 3 in Uganda.

In Lao PDR data was collected through the One Health Smallholder Pig Systems Project funded by Australian Center for International Research (grant AH2009/001 and AH2009/019). The project aimed to utilize One Health approach to optimize pig production as well as improve human health. Before the onset of the project a baseline survey was carried out between the Australian Center for International Research and International Livestock Research Institute to find out the existing zoonotic diseases in northern Lao PDR. The baseline survey revealed that trichinellosis, Japanese encephalitis, *Taenia solium* and Hepatitis E virus. *Taenia solium* was the most prevalent followed by trichinellosis and Japanese encephalitis was the least prevalent. Subsequently, the One Health project chose to study *Taenia solium* given its high prevalence in northern Lao PDR.

CHAPTER TWO

2. AN ECONOMIC EVALUATION OF RESTRICTED APPLICATION PROTOCOL (RAP) FOR THE CONTROL OF TRYPANOSOMIASIS IN UGANDA

2.1 Economic Analysis of Trypanosomiasis Control

Trypanosomiasis can be controlled through the use of chemotherapeutic or chemoprophylactic drugs or by controlling the insect vector, the tsetse fly. Most often both approaches are combined in order to improve the effectiveness of control measures. Economic evaluation of trypanosomiasis control methods is important for resource allocation and to advocate for donor funding (Shaw, 2003). The economic analysis of an intervention or project necessitates determination of the likelihood that it will contribute significantly to society, and that this contribution will be large enough to justify the required resources (Gittinger, 1982). Although economic and financial analysis are complementary, there are differences; i) financial analyses focus on the viewpoint of specific individual stakeholders or stakeholder groups economic analyses take the societal view, ii) economic analyses should be based on opportunity costs and where these diverge from market prices shadow prices are sometimes used , iii) in economic analysis, some financial costs and benefits (e.g. subsidies, taxes, interest on borrowed capital) are considered as transfer payments within society, and therefore omitted (Gittinger, 1982).

Livestock farmers produce meat, milk, wool, animal traction and eggs and aim to ensure that their livestock are as productive as possible. Livestock productivity is formally defined as the efficiency of converting inputs into outputs and thus an indicator of the return of main limiting resources in the livestock production system (Rushton *et al*. 1999). A simple livestock production system model - as developed by Rushton *et al* - involves use of inputs such as water, feed, veterinary services, capital and management within the livestock production system to produce outputs; which can be end products such as milk, meat and eggs or intermediate goods such as animals, draft power and manure (Rushton *et al*. 1999). The impact of disease in any given livestock production system is the reduction in productivity by either a) decreasing the value of outputs for a given level of inputs or b) necessitate an increased level of input to attain a given level of output, or both (Rushton *et al*. 2009). The cost of inputs and outputs can be listed as items and the various factors of production (labour, land and capital) that they apply to or categorized as either variable or fixed (McInerny *et al*. 1992). Variable costs are those that fluctuate in the short term and are directly related to the quantity of output produced, declining to zero if the output is zero, so for livestock producers these include feed, casual labour, and veterinary inputs, while fixed costs only fluctuate in the longer term and are still incurred even if output is zero, for example full time salaries, machinery and vehicle maintenance costs, and depreciation (Putt *et al*. 1987).

2.1.1 Measuring the impact of trypanosomiasis

Trypanosomiasis impacts on the management of livestock production systems such as herd composition, herd size, grazing patterns and breed/species kept by the farmer. The presence of tsetse and trypanosomiasis also influences human migration and settlement (Swallow B, 1999, Reid *et al* 1999). Studies involved in determining the impact of trypanosomiasis have generally used three approaches.

First, there are a number of studies that have used longitudinal surveys monitoring the health and productivity of animals, whereby animals are grouped according to number of times they have been detected as parasitaemic, and productivity indicators compared among the groups several times. For example; Rowlands *et al* (1995) found that the calving rate to be 81%, 78% and 72% for cattle groups with 0%, 14%-50% and 60%-100% levels of parasitaemia respectively (Rowlands *et al*. 1995); Trail *et al* (1991) found calving rates of 88% and 66% and weaning weights of 138kg and 135kg, respectively, for low and high level parasitaemia cattle groups (Trail *et al*. 1991). This approach is accurate but can be very costly as monitoring large numbers of animals over several years is required.

The second approach involves monitoring and comparing the health and productivity of animals in neighboring low and high trypanosomiasis risk areas. For example, Brandl *et al* (1988) found annual herd growth (1.1%, 3.7%, and 4.1%), milk (9%, 27% and 38%) and animal off-takes (5%, 14% and 31%) for high, medium and low trypanosomiasis areas respectively. This method has the advantage of measuring the productivity of entire herds rather than individual animals, but it can be biased due to confounding environment and management factors (Brandl, 1988).

The third approach involves comparing health and productivity indicators of animals before and after the intervention. For example, Camus reported that the calf mortality rate was 35% and 17% before and after the intervention respectively (Camus, 1995); Fox *et al* found pre-intervention weaning weights, calving rates and calf mortality rates of 124kg, 58% and 14%, compared to post-intervention rates of 145kg, 77% and 5% (Fox *et al*. 1993); Gemechu *et al* (1997) found that the crude mortality, calf mortality and abortion rates were 16%, 5% and 58% before an intervention, dropping to 8%, 20% and 2% after the intervention; and Kristjanson *et al* (1999) reported that annual herd growth, milk production and animal off-takes increased from 0%, 5.9% and 10% respectively without trypanosomiasis control to 37%, 22% and 25% with trypanosomiasis control.

The most commonly often cited productivity indicators on the impact of trypanosomiasis are a reduction in the calving rate of 1-12% in trypanotolerant cattle breeds and 11-20% in trypanosusceptible cattle breeds and increases calf mortality of 0-10% in tolerant and 10-20% in susceptible cattle breeds (Swallow, 1999). Also, two studies indicated that milk off-take was reduced by 10% and 26% in trypanotolerant cattle breeds (Swallow, 1999).

In African mixed crop-livestock systems, a particularly important effect of trypanosomiasis is its effect on draft power; it reduces availability of draft animals hence crop production; additional work oxen increase crop yields, the area cultivated and release labour for other tasks (Swallow, 1999). Studies on the control of trypanosomiasis using pour-on in Ghibe valley of Ethiopia revealed that farmers were able to plow an extra 0.5 hectares of land per work oxen; and trypanosomiasis reduced work capacity of draft cattle by 38% (Swallow, 1999). Shaw *et al* (2014) used a modified version of the model developed in Shaw *et al* (1989) to predict benefits of trypanosomiasis control in terms of milk, meat and draft power and herd growth.

Trypanosomiasis has also been shown to impact negatively on herd size. For example at the farm level, the number of tropical livestock units (TLUs)[2] per household was highest in trypanosomiasis low risk areas and lowest in high risk areas in Gambia (Swallow, 1999). However, given there was no significant relationship between herd size and trypanosomiasis risk, the most important determinant of herd size was reported to be livestock management (Swallow, 1999). At the country level, the cattle densities are much lower in tsetse infested areas (Bourn *et al*. 1978). At the continental level, it was estimated that the livestock density per square kilometer was 6.2 TLU in tsetse infested sub-humid regions compared to 9.9 TLU in tsetse free sub-humid regions; and the TLU per square kilometer in the tsetse infested humid regions and tsetse free humid regions was 2.8 and 9.8 respectively (Jahnke *et al*. 1987). Using a herd simulation model, Kristjanson *et al* found that the average cattle density (cattle head/km^2) in tsetse-free and tsetse-infected regions respectively were i) 12.3 and 10.6 (semi-arid zones), ii) 8.4 and 6.1 (sub-humid zones) iii) 5.6 and 1.3 (humid zones) and iv) 21.4 and 17.3 (highland zones) (Kristjanson *et al*. 1999). Kristjanson *et al* also modeled meat and milk off-take and estimated that tsetse free areas produced 97% more meat and 83% more milk than tsetse infested areas. Using geographical information system, Gilbert *et al* (1999) estimated that the 44.7 million heads of cattle in tsetse-infested areas could increase to 90 million heads of cattle without the presence of tsetse flies. When possible, livestock keepers graze their cattle away from tsetse belts, keeping to areas where they are less likely to become infected. However during the wet season, they often have no choice but to graze their cattle in tsetse-infested areas in order to avoid animals causing crop damage, and during drought they must search for pasture which may be in the tsetse belt; thus there can be a large seasonal

[2] One TLU is commonly taken as an animal weighing 250 kilograms - converted as 10 sheep/goats or 0.7 cattle, 1.25 donkeys or 1 horse (Mugalla *et al*. 1999; Jahnke, 1982; FAO accessed 12/6/2013)

variation in the exposure of cattle to tsetse flies (Wacher *et al*. 1994). Removal of tsetse flies in an area changes the grazing patterns and other economic activities: farmers graze their cattle and expand their farming activities in areas that were previously infested by tsetse flies (Ardnt 1995; 1996). For example, in Nigeria, the Fulani pastoralists traditionally moved their cattle northwards to avoid tsetse flies during the rainy season causing conflicts between them and sedentary farmers (Swallow, 1999). Conversely, control of trypanosomiasis might lead to in-migration of people leading to better control efforts and development (Govereh, 1999). In Ethiopia in-migration after tsetse control resulted in migrant households having 78% more draft cattle, 56% more cattle and cultivating 37% of land compared to indigenous populations (Swallow, 1999). In Zimbabwe, differences in cattle ownership between immigrating and indigenous populations were found to be 61% and 38% respectively; similarly 75% compared to 27% owned work oxen. Households with draft cattle generated higher returns compared to non-oxen owning households; and migrants with draft cattle generated 43% more income per unit of land and 143% more income per unit of labour compared to non-oxen migrant households (Govereh, 1999).

2.1.2 Measuring the cost of tsetse and trypanosomiasis control

Early studies of the economics of trypanosomiasis, starting in the 1950s focused on the cost side, particularly on tsetse control (Shaw, 2009). Numerous cost estimates have been published over the years, based on field work undertaken in all parts of tsetse-infested Africa; covering tsetse operations aiming at control, local elimination, both to prevent animal and human trypanosomiasis; as well as the cost of treatment and prophylaxis of livestock and case finding and treatment of humans for both the acute (*rhodesiense*) and chronic (*gambiense*) forms of HAT. There has been a steady output of publications including the costs of such interventions. Much of the historical data has been summarized in Allsopp and Hursey (2004), Shaw (2004), Shaw *et al*. (2013) and the benchmark study comparing different interventions was Barrett (1997). In Uganda, Shaw *et al*. (2007) has estimated the cost of various techniques using a cost model and updated these in Shaw *et al*., (2013).

This thesis focuses on ways control the disease in animals and humans at a village level. Thus the techniques of interest are currently used bait technologies: traps and targets (stationary baits) and insecticide treated cattle (ITC - mobile baits); techniques such as aerial spraying (designed for large scale use) and the sterile insect technique (exclusively applicable where long term permanent elimination of tsetse is a feasible and cost-effective objective) are not considered. Similarly, ground spraying (using residual insecticides) vegetation clearing and wildlife destruction, which are no longer used for environmental reasons are not considered; although they were all used in Uganda in the past and were costed in a pioneering economic study which primarily looked at the benefits for cattle ranching from tsetse control (Janke, 1974). The cost of traps and targets has been estimated to be USD 266 and USD 466 per km², respectively in Zimbabwe and Uganda (Barrett 1997; Shaw 2013); and USD 305 per km² in Botswana (McCord *et al*. 2012); compared to USD 85 per km² for insecticide treated targets ('tiny targets')(Shaw *et al*. 2015) . The cost of traps for reclamation has been estimated between USD 1-2 per hectare per year (Brandl, 1988). Shaw estimated the cost of insecticide treated cattle using pour-on to be USD 86 per km² when 5 cattle are treated and USD 123 per km² when 10 cattle are treated); compared to USD 30 per km² when RAP is used (Shaw *et al*.2013). Torr *et al* (2007) initially estimated that the cost of spraying using alpha-cypermethrin was USD 0.002 per animal per day (Vale and Torr, 2005), or USD 0.22 per animal per year; compared to USD 2 per animal per year when full body spraying was done using the same insecticide. However, these preliminary estimates did not take into account the fact that the cost of delivery – getting the insecticide onto the cattle, whether by the farmers or in conjunction with local veterinary services or a specific project – is unlikely to decline at the same rate as the reduction in the amount of insecticide, when changing from whole body spraying to RAP. Shaw *et al* (2013) showed that by adding the cost of delivery, the cost of RAP was USD 6 per animal treated per year.

Trypanocidal drugs are used both prophylactically and therapeutically to control trypanosomiasis in animals. It was estimated that 35 million doses of trypanocidals are administered annually in Africa; with farmers spending about USD 30 to 40 million annually (Holmes and Geerts, 2004). The annual cost of trypanocidal drugs in Uganda in 2014 was ranged around USD 1.5 per treatment for diminazine aceturate (curative) and USD 2.0 per treatment isometamidium (prophylactic), varying according to the quantity bought and location (Muhanguzi *et al*. 2015). Trypanocides should be administered by a veterinarian or animal health professional, and costs for this vary widely, while some livestock keepers inject their own animals. Farmers use trypanocidal drugs depending on their ability to pay, breed of the cattle, and their knowledge about trypanosomiasis and whether they are sedentary or transhumant (Swallow, 1999). Most farmers in Africa prefer to use curative rather than prophylactic drugs, with an average of 1.5 treatments per year; with preferential treatment to draft cattle and cows found in southern Africa (van den Bossche, 1999).

2.2 Objectives of the study on RAP

The objectives of the study on RAP were:

- To identify the key characteristics of villages with high prevalence of *T.brucei s.l.*
- To ascertain the RAP-induced change in income gained per bovine.
- To ascertain the cost of RAP per cow as incurred by farmers
- To ascertain the optimal percentage of village cattle to be sprayed using RAP.
- To ascertain other socio-economic impact of RAP such as cattle productivity, and food security.

2.3 Methodology

2.3.1 Intervention protocol

The economics of the RAP study was undertaken as part of a broader epidemiological intervention study examining the impact of different regimes on the prevalence of trypanosomiasis in cattle; using a protocol which was fixed by that study (Muhanguzi *et al*. 2014a). All trypanosome species present were recorded, however the focus was on *Trypanosoma brucei* s.l, which includes *T. brucei rhodesiense* the pathogen which causes the acute form of HAT, as the underlying objective of the study was to find ways of preventing HAT epidemics by controlling the disease in cattle. The presence of the two major trypanosomes pathogenic to cattle, *T. vivax* and *T. congolense* was also recorded. The villages included in the trial were selected on the following criteria;

- being a minimum of 2 kilometers (diameter of more than 1 kilometer) from other intervention villages
- A baseline cattle population of more than 50
- A baseline *T. brucei s.l.* prevalence in cattle of more than 15%

According to information obtained from the epidemiological study, the selection of villages was done in two steps using >citation (package = "EpiR") (Stevenson *et al.* 2012) in R console version 2.15 , with the first step involving selection of villages with a *T. brucei s.l.* prevalence of more than 15% and a baseline animal population of more than 50 animals. The second step was to select the villages according to the distance to the neighboring village. One hundred and seven distinct allocation sequences were generated so as to select 22 villages which fulfilled the criteria (Muhanguzi *et al.* 2014a). The 22 villages were randomly allocated to six different treatment regimens which are described in Table 2-1.

Table 2-1 Treatments applied to village cattle in each regime over 18 months

Regime	Number of villages	Double dose of diminazine aceturate at the beginning of the trial	% of village cattle administered RAP monthly	Dewormer administered 6-monthly
1	4	Yes	None	No
2	4	Yes	25	No
3	4	Yes	50	No
4	4	Yes	75	No
5	4	Yes	None	Yes
6	2	No	None	No

All cattle were ear tagged at the beginning of the trial with a tag sequence indicating village and animal number, e.g. KAJ65 will mean the 65^{th} cattle from Kajalau village. This tag was registered by the registrar of animal brands in Uganda before use in the experiment. Blood samples were taken on FTA (fast technology for analysis of nucleic acid) cards; a Whatman technology that simplifies the handling and processing of nucleic acids. Blood sampling was done after 3 months and polymerase chain reaction analysis done at the department of biomedical sciences laboratories at the University of Edinburgh to determine prevalence of *T. brucei s.l.*

2.3.2 Sampling

2.3.2.1 Epidemiological sampling

According to Muhanguzi *et al* (2014a), 57 villages were initially sampled (as shown in Figure 2-1) to find out the percentage of village cattle that need to be sprayed by RAP to prevent clinical re-infection with HAT. Accordingly, 6,023 cattle were bled to find out the baseline *T. brucei s.l* prevalence in the initial villages. Consequently, the baseline villages were subjected to the intervention and 22 villages that met the criterion were chosen for the RAP intervention; and randomly allocated to 6 regimes as stated earlier.

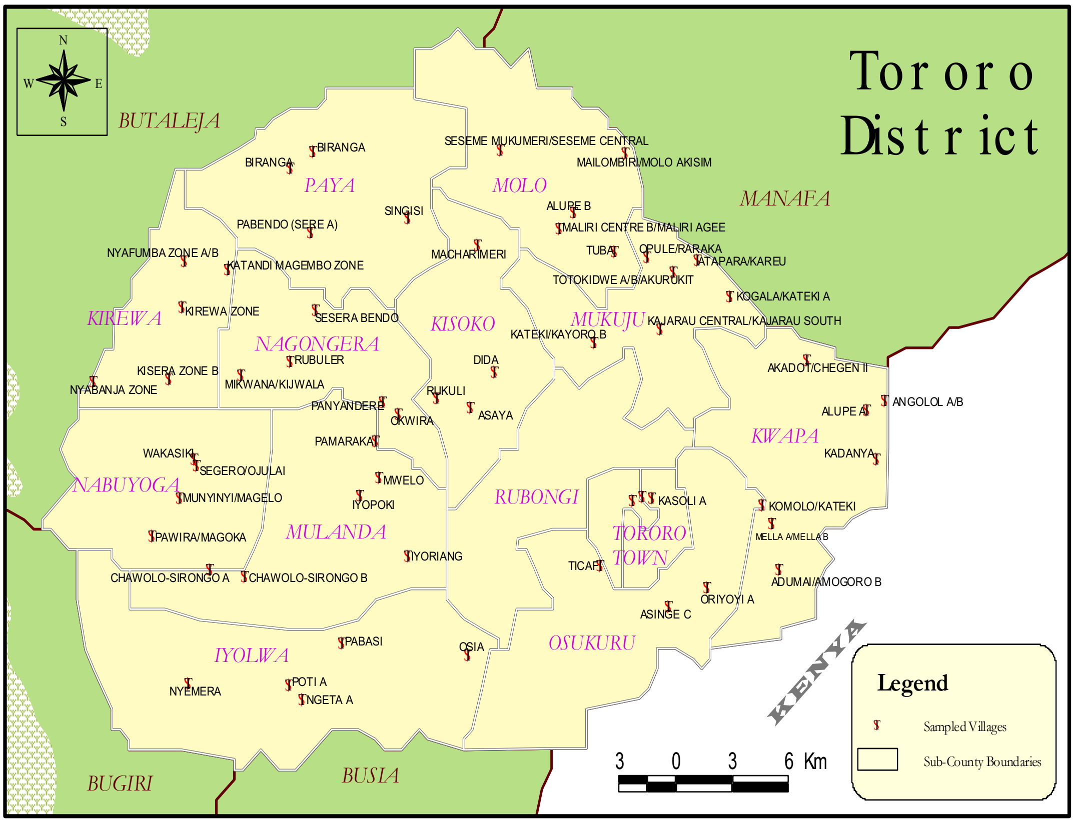


Figure 2-1 Map of sampled villages

The total number of cattle and households participating in the RAP intervention (6 regimes) was 2,968 and 968 respectively. However, 2 villages (regime 6) were dropped due to lack of resources to carry out molecular analysis at the end of the 18 month intervention period. Thus, the total number of cattle and RAP participating villages was 2,658 and 20 (allocated to 5 regimes) respectively as shown in Figure 2-2.

2.3.2.2 Economic sampling

Sample size determination for the economic study was based on concurrent epidemiological study on prevalence of *T. brucei* done by Muhanguzi *et al* (2014a). It was estimated that the total population of people in Tororo district was over 500,000 according to the 2008 population census and that the mean number of cattle per village was 93; and the total number of villages (clusters) in Tororo district was 61. CSurvey 2.0 was used to determine the sample size of the baseline of households to be sampled before the RAP intervention (UCLA, 2008). The prevalence of *T. brucei s.l.* was estimated to be 15%; maximum acceptable 95% confidence interval to be 5 percentage points and homogeneity parameter was set as design effect. The average number of eligible persons per household was set as 1. Subsequently, it was determined that a sample size of 660 households (30 households per 22 villages) was sufficient for the economic baseline survey; representing 68% (660/989*100) of the total RAP participating households.

The initial 22 villages sampled for the baseline survey comprised villages that met and those that did not meet the intervention criteria; households from these villages were accordingly termed as *'baseline group of households'* as shown in Table 2-2. The 22 intervention villages comprised of 10 original baseline survey villages that met the criteria (as shown in Table 2-2 and Figure 2-2) and 12 new villages that were added after dropping 12 initial baseline survey villages that did not meet the intervention criteria (as shown in Table 2-2 and Figure 2-2). Intervention households were randomly chosen from a list of participants that was compiled by the epidemiological study team; and these were designated as '*intervention group of households*' as shown in Table 2-2 and their number stayed constant throughout the study. The 22 RAP intervention villages, containing the '*intervention group of households*' were allocated into 6 regimes, as shown in Table 2-3, as per the epidemiological study. Baseline data was collected from '*intervention group of household*s' before the intervention using twelve month recall; after using spin dial to determine the starting household (UCLA, 2008). Subsequently six month recall for up to eighteen months was used to update data on cattle 'exits' and 'entries' as well as number of times farmers took their cattle for spraying for the '*intervention group of households*'.

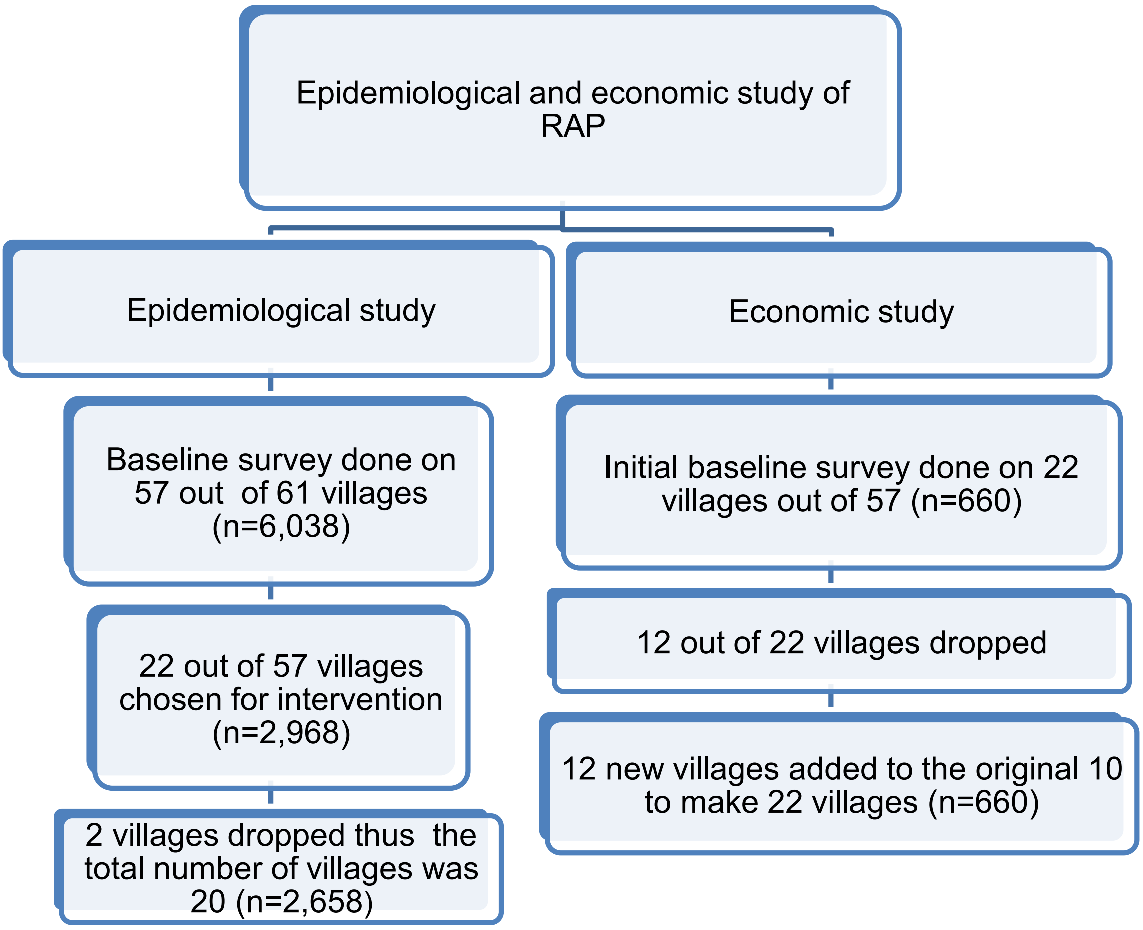


Figure 2-2 Flow chart of the study design

Table 2-2 Village categories during the baseline survey and the intervention

Initial villages out of the all (57) villages (baseline group of households)	Villages dropped	New villages added	Villages that participated in the intervention study (intervention group of households
Amogoro B	Amogoro B	Alupe B	Alupe B
Akworot	Akworot	Atapara	Atapara
Alupe A	Alupe A	Kajarau central/Kajarau south	Chawolo-Sironga B
Biranga	Biranga	Kasoli A	Dida
Chawolo-Sironga B	Iyoriang	Mailombili (Molo Aksim)	Kadanya
Dida	Iyopoki	Mikwana (Kijwala	Kajarau central/Kajarau south
Iyopoki	Mwelo	Munyinyi Magelo	Kasoli A
Iyoriang	Miusi	Ngeta A	Kirewa
Kadanya	Poti A	Pabendo (Sere A)	Macharimeri
Kirewa	Seseme-Mukumeri	Pamaraka	Mailombili (Molo Aksim)
Macharimeri	South east central	Segero/Ojulai	Mikwana (Kijwala
Mwelo	Tuba	Singisi	Munyinyi Magelo
Miusi			Ngeta A
Nyabanja			Nyabanja
Nyafumba A/B			Nyafumba
Oriyoi A			Oriyoi A
Pasaya			Pabendo (Sere A)
Poti A			Pasaya
Rubuler			Pamaraka
Seseme-Mukumeri			Rubuler
South east central			Segero/Ojulai
Tuba			Singisi

Table 2-3 Regime allocation of the households

Regime 1	Regime 2	Regime 3	Regime 4	Regime 5	Regime 6
Alupe B	Kajarau central/Kajarau south	Chawolo-Sironga B	Kadanya	Atapara/Kareu	Macharimeri
Nyafumba A/B	Mailombiri/Molo Akisim	Dida	Kasoli	Mikwana/Kijwala	Segero/Ojulai
Rubuler	Nyabanja	Kirewa	Munyinyi/Magelo	Pabendo/Sere A	
Singisi	Oriyoi A	Ngeta A	Pamaraka	Pasaya	

2.3.3 Use of semi-structured questionnaires and participatory methodologies

The semi-structured questionnaires (see Appendix 1 and 2) were developed using the agricultural household definition with a reference person system (Canberra group, 2001). The reference person for the survey was the head of household but any one household member was eligible to answer the questions. The main structured questionnaire was designed to incorporate household characteristics and livestock productivity including use of draft power. The cost of RAP questionnaire was added to the main questionnaire to collect data on cost incurred by the farmer during RAP activities such as time taken to take the cattle for spraying, ropes, cost of crush repairs, labour used to take the animals for spraying etc. Other costs collected from the farmer were related to cost of crop production such as overhead costs, labour, cost of improved seeds and cost of manure/fertilizers etc.

The semi-structured questionnaires were informally pre-tested among colleagues and formally in Macharimeri and South East central villages that were not randomly selected. A stakeholder analysis was carried out and the objectives and purpose of the intended study was discussed with the stakeholders. The community and other stakeholders were encouraged to participate at all levels to ensure 'community buy-in' to the study and to gain their trust. A total of 22 focus group discussions (one in each village) and 23 key informant interviews were done to complement the quantitative data. The focus group discussions were conducted by choosing and having discussions with a mixed group of farmers, animal health providers, herdsmen, local village elders and veterinary and crop shop attendants. The average number of participants in the focus group discussions was 6.5 with a standard deviation (SD) of 1.1. The key informant interviews were done with local veterinary staff, local council chiefs and local women group leaders.

2.3.4 Statistical analysis of intervention data

Although, cattle exits and entries were updated every six months, the overall data collected was treated as a repeated measurement comparing results before and after the intervention. This was because updating cattle exit and entries was only done to improve precision using six month recall as opposed to being the only parameter of evaluating change before and after the intervention. A paired t test was done to determine if there was an overall annual change in income across all households before and after the intervention. Also, a comparison between mean incomes between RAP and non-RAP groups was done using one-way analysis of variance. This is because RAP group comprises of 360 households while non-RAP households has 300 households hence a paired t test cannot be used. Sensitivity analysis was done using a cattle herd model in Microsoft excel sheets. Univariate and multivariate analysis was done using R and Tinn-R software (Faria, 2012). The null hypothesis for the study is that:

- There is no significant change in mean annual income across all households before and after the intervention.
- There is no significant difference in mean annual income between RAP and non-RAP households after the intervention.

2.4 Exploratory data analysis

A comparison was made between villages/households that were chosen and those that were dropped; establishing the characteristics of the *'baseline group of households'*. This was achieved by first analyzing the data using multiple correspondence analysis (MCA), >citation (package= "FactoMiner") (Le S *et al*. 2008) in R version 3.2.1, to determine which variables were inter-related, secondly, testing the significance of the associations observed in MCA using Pearson chi-square test, in SPSS version 16 (SPSS, 2007) and thirdly using the variables that are significantly related as predictors of trypanosomiasis prevalence (as this was the interest of the study as opposed to other intervention criteria that included ownership of 50 cattle and distance between the villages) via logistic regression (logit model), in SPSS version16 (SPSS, 2007). Multiple correspondence analysis was used to analyze data containing more than two categorical variables, thus a group of individuals with similar answers to a question and the association between the variables. Chi-square test was used to examine whether the distribution of categorical variables differed from one another. Logistical regression examines the relationship between the dependent categorical variable (whether a village was dropped or chosen according to the *T. brucei s.l* prevalence) and one or more independent categorical variables by estimating probabilities using a logistic function, which is the cumulative logistic distribution. The categorical variables analysed included type of trypanocide used (samorin™ and diminazine), acaricide used (tacktick™, triatix™, amitix™, tsetse-tick™, decatix™ and dip-spray™) ownership of draught cattle (draught and no draught cattle) and category of cattle owned (small, medium and high). Although, antibiotics are not used for treatment of trypanosomiasis, some farmers used them (particularly oxytetracycline). The category of cattle owned was based designating owning 1 to 3 cattle as small, 3 to 10 as medium and over 10 cattle as high. Also, the villages that were chosen (those that met the intervention criteria) were deemed to have 'high' trypanosomiasis prevalence (over 15%) and those villages that were dropped (those that failed to meet the intervention criteria) as having 'low' trypanosomiasis prevalence (below 15%).

2.5 Economic analysis

2.4.1 Impact of RAP at the household/farm level

At the farm level gross margin analysis (Okello, Muhanguzi *et al*. 2015) and enterprise budget (Rushton *et al*. 2009) were used to determine the profitability of cattle enterprise before and after the intervention; and total household income was evaluated before and after the intervention using pooled data (Okello *et al*. 2015). The gross margin was assessed using the following formula:

$$Gross\ margin = enterprise\ output - variable\ costs \quad (1)$$

Enterprise output was the sum of livestock output and the increase in herd value over the 18 months period; the livestock output was obtained by subtracting the sum of cattle bought and received into the herd from the sum of cattle sold, income earned from use of draft cattle, averted labour costs from using own draft cattle and cattle gifted 'out'. Since this was an economics study stolen cattle were viewed as "involuntary gift" hence were computed as livestock and products 'out' when determining the overall livestock output. Variable costs include the costs of veterinary services, vector control, feed, ropes, the value of labour used while ploughing and fines for crop damage. On average, the current local price of labour was USD 1.61 per day paid during peak agricultural activity; consequently the value of family labour associated with draft cattle ploughing was conservatively estimated to be USD 0.48 or 30% of this (Okello *et al*. 2015). It should be noted that, conventionally, in farm budgets casual labour is considered a variable cost whereas family labour is considered at the fixed cost level. However, use of work oxen is significantly bound with changing labour requirements; it involves both labour cost specifically for managing draft animals and an overall labour saving due to use. Accordingly, these varying labour components were, respectively, included in the variable costs and in livestock output, where the value of own-farm use of work oxen was based on the equivalent labour saved. Enterprise budgeting is closely related to gross margin analysis; however, the latter does not include fixed cost. Although rural farmers in developing countries rarely own farm machinery, farmers with draft cattle usually own a plow. Thus depreciation of the plow is the main fixed cost incurred by low resourced farmers. The depreciation of the plow was computed using the straight line method (Reynolds, 1961). Enterprise budget was computed using the following formula (Rushton *et al*. 2009):

$$Enterprise\ budget = Gross\ margin - fixed\ cost \quad (2)$$

2.5.2 Marginal analysis

Marginal analysis was used to determine the additional net benefit of spraying an extra 25% of the cattle using RAP i.e. 50% from 25% and 75% from 50%. The following framework adapted from Rushton *et al* 2009) and insecticide and project delivery cost data obtained from Muhanguzi *et al* (2015) during the concurrent epidemiological study were used to compute which of the regimes i.e. 2 (25% RAP), 3 (50% RAP) had the highest change in net benefit. The data from Muhanguzi *et al* (2015) covered the epidemiological study cost for the RAP intervention to the livestock keepers and included delivery cost, overheads and depreciation and is provided in Table 2-4. The current study's interviews with farmers enabled their costs to be collected over the 18-month period, so as to complete the calculation of the full costs of the intervention.

The formula for change in net benefit as adapted from Rushton *et al* (2009) is as follows:

$$Change\ in\ net\ benefit = marginal\ benefit - marginal\ cost \quad (3)$$

Where marginal benefit referred to the annual household income per household per regime (i.e. regimes 2 to 4) after the intervention and the marginal cost referred to the annual overhead cost per regime (i.e. regimes 2 to 4). To estimate the total cost of RAP, the overhead cost obtained from Muhanguzi *et al* (Muhanguzi *et al*. 2015) was added to the cost of RAP to the farmer computed in this study.

Table 2-4 Overhead cost data

Regime	Annual insecticide and project delivery cost per bovine (USD)	Reference
2 (25%)	1.72	Muhanguzi *et al*. 2015
3 (50%)	3.45	Muhanguzi *et al*. 2015
4 (75%)	5.17	Muhanguzi *et al*. 2015

2.5.3 Cost of RAP from the farmers' perspective

The cost of RAP to farmers was analyzed by collecting information on costs incurred by the farmers such as time taken to take the animals for spraying, time taken to collect animals for spraying, money spent on ropes, money spent on maintenance of crush, on hired labour, etc.

2.6 Results

2.6.1 Exploratory data analysis

According to the multiple correspondence analysis of the '*baseline group of households*' there was strong inter-relation between high prevalence of trypanosomiasis with use of Samorin™ (isometamidium chloride), use of Amitix (amitraz), use of Triatix™ (amitraz), not knowing acaricide used, moderate cattle population and ownership of work oxen as shown in Figure 2-1. Further analysis of the association between vector control methods, draft cattle ownership, trypanocide used and prevalence of trypanosomiasis using Pearson Chi-square test revealed use of Samorin™ (p value=<0.001) , use of Amitix™ (p value=0.039), use of Triatix™ (p value=0.040) and not knowing the acaricide used (p value=<0.001) were significantly related with the prevalence of trypanosomiasis. Table 2-5 provides a summary of all the Pearson chi-square test and respective p values.

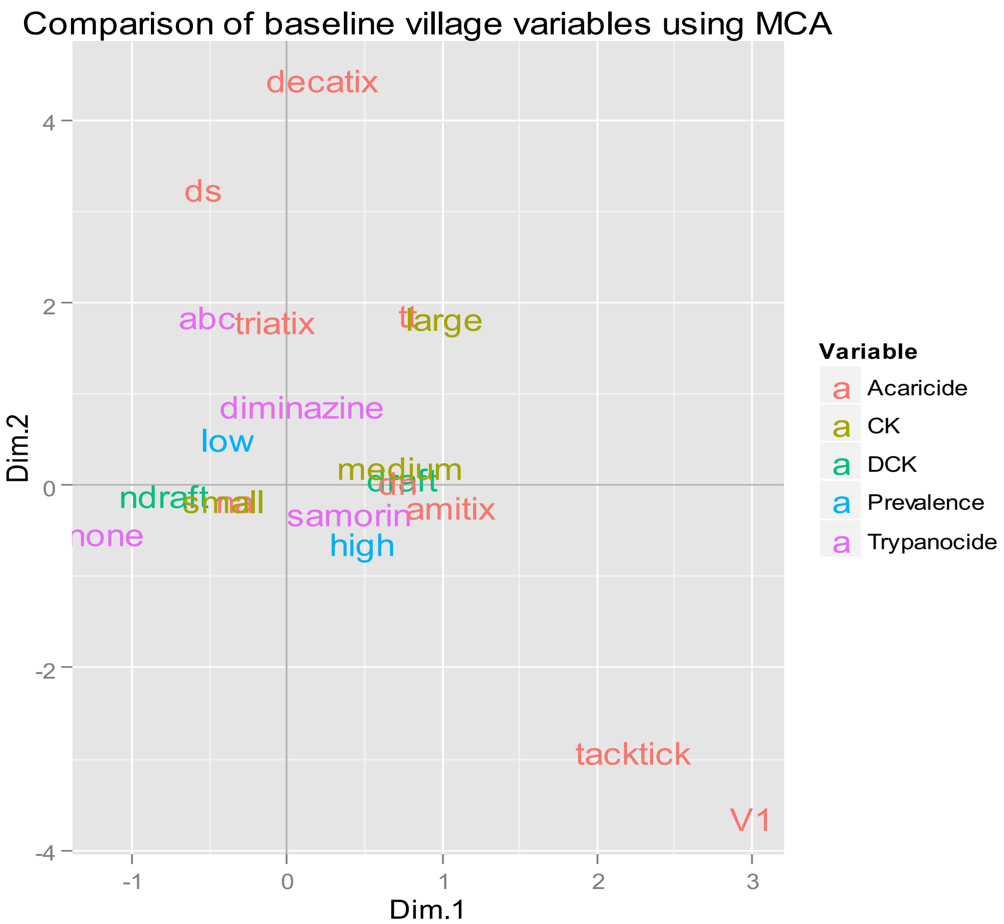


Figure 2-1 Association between variables of the baseline villages

Legend; Acaricide = Type of acaricide mentioned (tacktick, triatix, amitix, tsetse-tick (abbreviated as tt), decatix, dip-spray (abbreviated as ds) and do not know (dn). CK = number of cattle per household (small, medium or large). abc = antibiotic. DCK = type of draft cattle ownership (draft for those with work oxen or no draft (abbreviated as ndraft). Prevalence = level of occurrence of T. brucei sl (low or high). Trypanocide = type of trypanocidal treatment mentioned which were samorin™, diminazine aceturate (plotted as diminazine), and none (for farmers who did not use any trypanocide or try to treat their animals with antibiotics).

Table 2-5 Pearson Chi-square test results

Parameter	Pearson Chi-square	p-value
Samorin™	11	<0.001
Diminazine aceturate	3	0.070
Don't know trypanocide used	27	<0.001
Ownership of draft cattle	32	<0.001
Medium cattle density	1	0.649
Amitix™	4	0.039
Triatix™	4	0.040
Tsetsetick™	0.059	0.808
Handpicking	2	0.116

A logistic regression (logit model) was conducted to predict prevalence of trypanosomiasis for 660 households using ownership of draft cattle and use of Samorin™ and Triatix™ as predictors. A test of the full model against a constant only model was statistically significant, indicating that the predictors as set reliably distinguished between high and low prevalence of trypanosomiasis (chi-square=42.4, p=<0.001, df=3). Nagelkerke R-squared of 0.83 indicated a strong prediction and grouping. Prediction success overall was 61.7 (63 for high, 60.6 for low trypanosomiasis prevalence). The Wald criterion demonstrated that all groupings made a significant contribution to prediction with ownership of draft cattle making the highest contribution (Wald criterion of 33.6 compared to 4.7 and 4.5 for Samorin™ and Triatix respectively) as shown in Table 2-6. Amitix™ was not a significant contributor to the prediction hence it was excluded. Exp (B) value (as shown in Table 2-6) indicated that when ownership of draft cattle is increased by one unit (one extra work oxen) the odds ratio is 2.5 times as large and therefore the prevalence of trypanosomiasis is likely to increase by 2.5. Goodness of fit was measured using Hosmer and Lemeshow Test and the p-value was 0.99; indicating that the model was a good fit since it was not significant.

Table 2-6 Logistic regression model

Independent predictor variable	Standard error	Wald criterion	Significance (p-value)	Exp(B)
Use of amitraz (Triatix™) for vector control	0.49	4.5	0.033	0.351
Ownership of work oxen	0.16	33.6	0.000	2.577
Use of isometamidium chloride	0.18	4.7	0.030	0.675
Constant	0.50	4.2	0.039	2.815

2.6.2 Household characteristics and livestock production parameters

There were a total of 3,806 household members in the 'baseline group of households'; with a mean of 5.7 people (SD 2.1). The number of households that; lived in mud-walled and grass-thatched houses were 418 (63.3%), those living in mud-walled and tin-roofed housed were 155 (23.4%) and those living in brick-walled and tin-roofed houses were 87 (13.1%). The average level of education was primary schooling. The total number, mean and SD of livestock kept by the baseline group of households are as shown in Table 2-7. In addition to cattle, sheep, goats, pigs and chicken there were 144 other livestock kept (these included 71 ducks, 53 turkeys, 16 dogs and 4 cats). A breakdown of the number of cattle kept in each 'baseline group of household' village is shown in Table 2-8. Also, the most common method of vector control was hand picking (50% of the respondents) and other methods included spraying, pour-on and application of paraffin or grease as shown in Table 2-9. The type of cattle treated for ticks and tsetse flies has been summarized in Table 10.

Table 2-7 Livestock kept across all the baseline group of households

Type of livestock	Number	Number of households with the livestock species	Number of households without the livestock species	Mean (includes households without livestock species)	SD
Cattle	2001	660	0	3	1.8
Sheep	382	168	492	0.5	1.3
Goat	1528	460	200	2.3	2.7
Pig	751	315	345	1.1	1.8
Chicken	6565	589	71	9.9	10.9
Other	144	644	16	0	0

Table 2-8 Number of cattle across all the baseline group of households

Village	Number of cattle
Amogoro B	76
Akworot	69
Alupe A	77
Biranga	77
Chawolo-Sironga B	139
Dida	72
Iyopoki	99
Iyoriang	105
Kadanya	97
Kirewa	96
Macharimeri	115
Mwelo	102
Miusi	92
Nyabanja	67
Nyafumba	69
Oriyoi A	71
Pasaya	111
Poti A	76
Rubuler	89
Seseme-Mukumeri	102
South east central	115
Tuba	85

Table 2-9 Vector control methods as obtained from the questionnaire

Vector control method	Number of respondents	Mean frequency vector control method is used per year	SD
Spraying	194	3.5	2.8
Hand picking	298	11.3	5.6
Application of paraffin	21	9.6	3.7
Application of grease	5	7.2	3
Pour-on	7	1.1	3.6

Table 2-10 Type of cattle treated for ticks and tsetse flies

Type of cattle treated	Number of respondents
Calf only	0
Calf and cow	19
Calf and heifer	1
Calf and young male	0
Calf and adult male	0
Calf and work oxen	0
Young male only	15
Adult male only	8
Work oxen only	134
Work oxen and heifer	33
Work oxen and cow	55
Heifer only	85
Heifer and cow	28
Cow only	89

The total number of household members in the intervention households was 4,048; with a mean of 6.1 and SD of 2. The ratio of male to female was 88.8 males for 100 females; Figure 2-4 summarizes the population structure of the intervention households. The total number of adults (18 years and over) was 1,783 (44%) out of which 1,387 (77.7%) were involved in farming. Only 10 (0.5%) farmers supplemented their income with business; and none of the farmers received any remittance outside the district. Out of the 1,387 farmers, 515 (37.1%) had no formal education, 719 (51.8%) had attained primary school education, 143 (10.3%), secondary school and 10 (0.7%) college education. The number of households that; lived in mud-walled and grass-thatched houses were 398 (59.5%), those living in mud-walled and tin-roofed houses were 187 (28.3%) and those living in brick-walled and tin-roofed houses were 80 (12.1%).

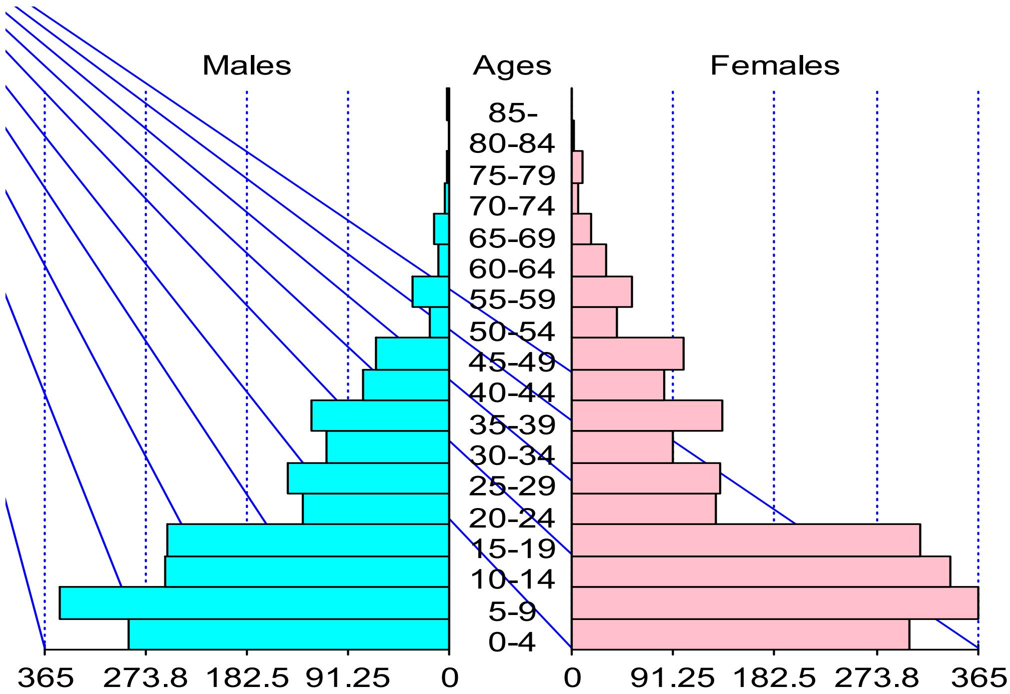


Figure 2-4 Population pyramid of the RAP participating households

The total number, mean and SD of livestock kept by the intervention villages are as shown in Table 2-11. In addition to cattle, sheep, goats, pigs and chicken there were 332 other livestock kept (184 ducks, 112 turkeys, 27 dogs and 9 cats). A breakdown of the number of cattle kept in each intervention village is shown in Table 2-12.

Table 2-11 Livestock kept across all the intervention group of households

Type of livestock	Number	Number of households with the livestock species	Number of households without the livestock species	Mean (includes households without livestock species)	SD
Cattle	2,341	660	0	3.5	3
Sheep	149	60	660	0.2	0.9
Goat	1,122	426	234	1.7	2.1
Pig	808	311	349	1.2	2.2
Chicken	5,399	504	156	8.1	8.9
Other	332	103	557	1.6	2.5

The pre-intervention herd composition has been summarized in Table 2-13. Before the intervention, there were 249 (10.6% of the total cattle population) young males used as work oxen and 620 (26.5% of the total cattle population) adult males used for draft. Subsequently work oxen (including young male under 'training' for draft work) comprised 37.1% of the total cattle population. The pre-intervention results revealed that there were 449 calves between June 2011 and June 2012 and 116 (59 female calves and 57 male calves) died by the end of June 2012. Consequently the calf mortality was found to be 25.8%. The results also revealed that; 24 young males, 23 young females, 26 cows and 43 adult males died between June 2011 and June 2012. Consequently, the total number of cattle that died over the one year period was 244 resulting in an overall mortality of 10.1%.

Table 2-12 Breakdown of number of cattle in each intervention village

Village	Number of cattle
Rubuler	91
Nyafumba	94
Alupe B	52
Singisi	57
Nyabanja	139
Oriyoi A	124
Kajarau central/Kajarau south	64
Mailombiri/Molo Akisim	82
Dida	99
Kirewa	132
Chawolo-Sirongo B	178
Ngeta	127
Kadanya	101
Pamaraka	80
Kasoli	180
Munyinyi/Magelo	123
Pasaya	89

Atapara Kareu	118
Pabendo/Sere A	74
Mikwana/Kijwala	124
Macharimeri	135
Segero/Ojulai	78

The total number, mean and SD of cattle owned post-intervention was 2,440, 3.6 and 3.1 respectively; and the herd composition is as shown Table 2-13. There were 276 (11.3% of the total cattle population) young males used as work oxen and 647 (26.5% of the total cattle population) adult males used for draft. Subsequently work oxen (including young male under 'training' for draft work) the total number of draft cattle was 923 or 37.8% of the total cattle population. The post-intervention results revealed that there were 407 calves between June 2012 and December 2013 and 60 (31 female calves and 29 male calves) calves died by the end of December 2013. Consequently the calf mortality (including still births and abortions) was found to be 14.7% across all the households. The results also revealed that 17 young males, 13 young females, 22 cows and 34 adult males died between June 2012 and December 2013. Consequently, the total number of cattle that died over the 18 month period was 146 resulting in an overall mortality of 6.1% across all households. Also, the study found that the mean age at first calving was 4 years with a SD of 0.4.

Table 2-13 Herd composition pre and post intervention

Age (in years)	**Herd Composition pre-intervention**		**Herd Composition post-intervention**	
	Females %	**Males %**	**Females %**	**Males %**
0 to 1	7.0	7.2	7.0	7.2
1 to 4	16.5	4.4	16.5	4.1
4+	27.2	0.6	26.8	0.6
Working oxen 1 to 4	-	10.6	-	11.3
Working oxen 4+	-	26.5	-	26.5
Total	50.7	49.3	50.3	49.7

The total number of households (n=660) that had draft cattle before the intervention was 350 (53%) and the number of households with 1, 2, 3 and 4 plus draft cattle have been summarized in Table 2-14. The total number of households (n=660) that had draft cattle after the intervention was 368 (55.7%) and the number of households with 1, 2, 3 and 4 plus draft cattle has been summarized in Table 2-15. Since nearly 60% of all households have the same herd size (2 oxen) it was felt that analyzing the pooled data from the whole sample would be representative.

Table 2-14 Summary of annual pooled data on days worked by draft oxen per household

Number of work oxen owned per household	% of households interviewed	Average total number of days worked by draft oxen	Number of days ploughing on own farm and SD	Number of days hired out for ploughing on other people's farms and SD
1	6.3	52.7	19.1 (10.5)	33.6 (10)
2	55.8	52.2	19.8 (8)	32.4 (8.7)
3	8.3	50.5	17.8 (7.4)	32.7 (6.8)
4+	29.4	53.0	18.2 (9)	34.8 (6.9)
Average number of days per household per year	-	52.1	18.7	33.4

Table 2-15 Summary of household draft oxen ownership and work patterns

Number of work oxen owned per household	% of households	Average draft oxen days worked per household		
		Total days worked	Ploughing on own farm (SD)	Hired out for ploughing on other people's farms (SD)
1	4.6	96.5	33.7 (12.3)	62.8 (7.6)
2	59.2	87	25.5 (10.0)	61.5 (9.0)
3	7.3	82.4	23.9 (9.1)	58.5 (7.3)
4+	28.8	86.4	24.5 (9.8)	61.9 (9.2)

Average recorded over the 18 month study	88	26.9	61.1
Adjusted figure for 12 months	61.5	18.8	42.7

2.7 Gross margin and marginal analysis

2.7.1 Cattle gross margin analysis

2.7.1.1 Gross margin analysis of the baseline households

Analysis of the questionnaires found that the total annual income (both cash and in kind) from all households from hiring out work oxen for ploughing was USD 77,832. Supplementary benefit, in the form of annual avoided cost was the cost of human labour that would be used to plow by hand if a farmer did not own his own work oxen, valued at USD 29,844 across all households. One year recall revealed that there were 2,112 (991 male and 1,121 female cattle) valued at USD 471,347 at beginning of the year (opening valuation); at the end of the year (closing valuation), there were 2,001 cattle (993 male and 1,008 female cattle), valued at USD 436,318 thus the overall change in herd value (closing valuation minus opening valuation) was –USD 35,029. The variable cost comprised of expenses incurred in treatment of mastitis (USD 133), value of labour used on own farm (USD 4,884),value of labour used on other people's farms (USD 8,834), cost of using trypanocides for treatment including value of labour used (USD 2,491), expenses incurred spraying for ticks and tsetse flies including value of labour used (USD 3,084), value of other vector control methods such as hand picking including labour used (USD 167), expenses incurred by borrowing draft cattle (USD 7,761) and other expenses (USD 1,409); totaling USD 28,763. By deducting variable cost from the livestock output, the total annual gross margin across all the households was USD 47,326 as shown in Table 2-16; equivalent of USD 72 (SD 211) per household per year. To compute the net income, depreciation of plow was subtracted from the gross margin. The annual total value of plow depreciation was USD 496 across all the households or USD 0.7 per household. Consequently the annual total net income across all the households was USD 46,831 or USD 71 per household. By including only cash items in gross margin analysis the annual total net cash income from cattle enterprise was USD 60,592 or USD 92 per household per year before the intervention.

Table 2-16 Cattle gross margin calculation for the 'baseline group of households'

Item	Value (USD)
a) Total value of livestock products, animals sold or transferred out of the herd	
● Annual income from hiring out draft cattle for ploughing	77,832
● Annual income from hiring out draft cattle for other work	366
● Animals sold	11,066
● Animals given out as loan repayments	5,964
● Value of animals slaughtered	4,160
● Value of human labour saved	29,844
● Value of milk sold	5,502
Subtotal (a)	134,734
b) Total value of animals bought and brought in to the herd	
● Animals bought	19,323
● Animals brought in as gifts or loan repayments	4,293
Subtotal (b)	23,616
c) Change in herd value during the year	−35,029
d) Total livestock output (a-b + c)	76,089
e) Total variable cost	28,763
f) Total gross margin (d-e)	47,326

2.7.1.2 Gross margin analysis pre and post intervention and marginal analysis

Before the intervention, the total annual amount of cash and income in kind received from hiring out draft cattle for work was USD 83,452 and USD 288 respectively; USD 83,150 (99.6%) of the USD 83,452 cash received from hiring out draft oxen was from hiring out draft oxen for ploughing while the remainder (USD 302) was from hiring out draft oxen for other draft work (mainly pulling logs). The value of the total annual labour saved (labour averted) by not ploughing own-farm through hand held hoes was USD 30,002. The total cash received from sale of cattle, milk and the value of cattle slaughtered and those given out as loan payments or gifts, value of cattle bought and brought into the herd in form of acceptance of gifts or loan repayment has been summarized in Table 2-17. At the beginning of the 12 month period (opening valuation), there were 2,478 cattle (1,162 male and 1,316 female) valued at USD 529, 183.9; and at the end of the year (closing valuation), there were 2,341 cattle (1,147 male and 1,194 female), valued at USD 517,628.9; thus the overall change in herd value was –USD 11,555 as shown in Table 2-17.

The variable cost comprised of expenses incurred in treatment of mastitis (USD 73), value of labour used on own farm (USD 5,123), value of labour used on other people's farms (USD 9,282), cost of using trypanocides for treatment including value of labour used (USD 2,014), expenses incurred spraying for ticks and tsetse flies including value of labour used (USD 3,084), value of other vector control methods such as hand picking including labour used (USD 167),expenses incurred by borrowing draft cattle labour (USD 8,296) and other expenses (USD 1,521); totaling USD 29,561. By subtracting variable cost from the livestock output, the total annual gross margin across all the households was USD 72,661; equivalent of USD 110 (SD 206) per household per year as shown in Table 2-17.

After the intervention, the total amount of cash and income in kind obtained from hiring out work oxen was USD 164,124 and USD 432 respectively over the 18 month period; USD 163,786 (99.7%) of the USD 164,124 cash and income in kind received from hiring out draft oxen was from hiring out draft oxen for ploughing while the remainder (USD 338) was from hiring out draft oxen for other draft work (mainly pulling logs). The total value of labour saved (labour averted) by not ploughing own-farm using hand held hoes was USD 46,995 over the 18 month period. The total cash received from sale of cattle, milk and the value of cattle slaughtered and those given out as loan payments or gifts, value of cattle bought and brought into the herd in form of acceptance of gifts or loan repayment has been summarized in Table 2-17. At the beginning of the 18 month period (opening valuation), there were 2,341 cattle (1,147 male and 1,194 female) valued at USD 517,629; and at the end of the 18 month period (closing valuation), there were 2,440 cattle (1,213 male and 1,227 female), valued at USD 518,343; thus the overall change in herd value was USD 714. The variable cost comprised of expenses incurred in treatment of mastitis (USD 137), value of labour used on own farm (USD 7,614), value of labour used on other peoples' farm (USD 15,013), cost of using trypanocides for treatment including value of labour used (USD 1,254), expenses incurred spraying for ticks and tsetse flies including value of labour used (USD 1,387), expenses incurred by borrowing draft cattle labour (USD 3,998) and other expenses (USD 5); totaling USD 29,408 across all the households. By subtracting variable cost from the livestock output, the total gross margin across all the households was USD 172,476; equivalent to USD 120,733 across the entire households per year or USD 261 (SD 325) per household over the 18 month period as shown in Table 2-17 or USD 183 (SD 227) per household per year.

Table 2-17 Cattle gross margin calculation for the 'intervention group of households'

Item	Value (USD) pre-intervention	Value (USD) post-intervention
a) Total value of livestock products, animals sold or transferred out of the herd		
● Annual income from hiring out draft cattle for ploughing	83,452	164,124
● Annual income from hiring out draft cattle for other work	288	432
● Animals sold	8,292	15,137
● Animals given out as loan repayments	2,550	4,819
● Value of animals slaughtered	3,161	2,346
● Value of human labour saved	30,002	46,995
● Value of milk sold	6,382	9,762
Subtotal (a)	134,127	243,615
b) Total value of animals bought and brought in to the herd		
● Animals bought	16,843	36,922
● Animals brought in as gifts or loan repayments	3,507	5,525
Subtotal (b)	20,350	42,447
c) Change in herd value during the year	−11,555	714

d) Total livestock output (a-b + c)	102,222	201,882
e) Total variable cost	29,561	29,406
f) Total gross margin (d-e)	72,661	172,476
g) Income per household (n=660)	110	261

To compute the net income before the intervention, depreciation of plow was subtracted from the gross margin. Also, it was noted that of the 23 farmers with one draft cattle, only 12 paid cash for borrowing extra work oxen at a total value of USD 493 while the rest borrowed cattle from relatives and friends without paying; and the remainder of the total cash paid by those with more than one work oxen, who had to borrow extra work oxen to finish ploughing if the ones they had was sick, was USD 7,803 (94% of the total annual expenses incurred by borrowing work oxen). The annual total value of plow depreciation was USD 531 across all the households or 0.8 per household. Consequently the annual total net income across all the was USD 72,130 or USD 109 per household; resulting in a annual net income of 31 per head of adult bovine. By including only cash items in gross margin analysis annual total net cash income from cattle enterprise before the intervention was USD 65,555 or USD 99 per household per year before the intervention; contributing of the total cash household income per year. The annual total cash income from cattle and crop enterprises has been summarized in

.

To obtain the net income, the depreciation of the plow was subtracted from the gross margin after the intervention. The total value of plow depreciation was USD 556 across all the households over the 18 month period. Consequently the total net income across all the households was USD 171,546 or USD 260 per household over the 18 month period; or annual total of USD 120,082 across all households; equivalent to USD 182 per household per year after intervention or USD 52 per head of adult bovine per year. By including only cash items in the gross margin analysis the total net cash income from cattle enterprise was USD 149,259 or USD 226 per household over the 18 month period before the intervention; and annual total of USD 104,482 across all the households per year; equivalent to USD 158 per household per year after the intervention.

The annual total cash income from crop enterprise was USD 271,406 across all the households or USD 411 per household after one year of intervention. Subsequently total cash income was USD 569, as shown in

, with the cattle enterprise contributing 27.7% of the total cash income per household per year after the intervention.

Table 2-18 Total cash income for the 'intervention group of households'

Item	Pre-intervention	Post-intervention
Average annual cash income from cattle enterprise per household (USD)	99	158
Average annual cash income from crop enterprise per household (USD)	364	411
Total cash income	463	569

Also, by grouping RAP participating households into two namely, RAP and non-RAP an, the annual RAP induced change in household income was found to be USD 110 as shown in Table 2-19. However, to obtain the RAP induced change in each bovine, the average annual RAP induced change in each household (USD 110) was divided by the mean number of cattle in each household (3.5); resulting in USD 31per head of adult bovine per year.

Table 2-199 RAP induced change in income across all households

Intervention period	**Type of household**		**Difference**
	RAP	Non-RAP	
Income after 18 months USD (SD)	341 (329)	164 (293)	177
Averaged income after 1 year USD (SD)	239 (230)	115 (205)	124
Income before intervention USD (SD)	116(215)	102(194)	14
Difference in income after 18 months of intervention	225	62	163
Difference in income after 1 year of intervention	123	13	110

2.7.2 Marginal analysis

Given the average number of cattle per household was 3.5, 4 and 4.1 for regime 2, 3 and 4 respectively, the annual benefit of using RAP per head of cattle was found to be USD 53, USD 64 and USD 67 for regime 2, 3 and 4 respectively as shown in Table 2-200. Also, it was found that the incremental benefit cost ratio of spraying 25% of cattle was 16:1; 50% was 3:1 and 75% was 1:1 as shown in Table 2-200.

Table 2-200 Change in benefit between RAP regimes

% of cattle village sprayed	Annual benefit per bovine (USD)	Marginal benefit (USD)	Annual cost per bovine sprayed (USD)	Additional cost (USD)	Change in net benefit (USD)	Average benefit-cost ratio (USD)	Incremental benefit-cost ratio (USD)
0	-	-	0	-	0	-	-
25	53	53	1.92	1.92	51.08	31:1	16:1
50	64	11	3.65	1.73	9.27	6:1	3:1
75	67	3	5.37	1.72	1.28	2:1	1:1

2.8 Cost of RAP to farmers

The total number of cattle that were sprayed using RAP across 360 households (RAP participating households) was 1,406, with each household having an average of 3.9 (SD 3.7) cattle within the 18 month time period. The average number of times farmers took their cattle for spraying was 16.2 (out of a possible 18 times) over the 18 month intervention period, representing a compliance of 90%. The total cost incurred by all the farmers to participate in RAP during the 18 months has been summarized in Table 2-211; majority of the expenditure was on labour used to take cattle for spraying (69.5%) and buying ropes (20.3%). Given the total number of cattle was 1,406 across all RAP participating households; the cost of RAP per head of cattle was estimated to be USD 0.4 after the 18 month intervention; equivalent to USD 0.26 per year. By adding the annual cost of RAP (USD 0.2) to the project cost obtained from Muhanguzi *et al*. (2015), the total annual cost of RAP was estimated to be USD 1.92 for spraying

25% of cattle; USD 3.65 for spraying 50% of cattle; and USD 5.37 for spraying 75% of cattle.

Table 2-211 Cost of RAP over 18 months period

Item	Cost of RAP to farmer across all households in USD (n=360)
Value of labour cost during entire RAP exercise	442
Value of labour used hand picking ticks	5
Payment to casual labourer/herdsman	11
Cash spent on ropes	129
Crush repair	16
Fines paid for crop damage	19
Payment for restraint of cattle	3
Payment for water to mix pyrethroids	11
Total	636

A Pearson's product-moment correlation analysis was used to assess the strength of the relationship between total number of cattle and total cost of RAP in 360 households. First, a marginal plot was used to determine the linearity of the relationship and the dispersion of data using box plots. Secondly, the data was checked for normality in R version 3.2.1. Thirdly, from the marginal plot, it was noted that there were several outliers and Grubbs test was used to find out if they were significant. It was found that the outliers were minimal with only two outliers i.e a household owning 32 cattle and another incurring a total cost of USD 12 due to RAP. The results revealed that there was a weak positive correlation between number of cattle owned and total cost of RAP per household, $r(355) = 0.155$, $p<0.003$.

In terms of labour usage for RAP, all the RAP households (n=360) reported that it is the head of the household that took cattle for spraying. Apart from the head of household, 41 households mentioned son, 6 mentioned wife, 3 mentioned grandson, 1 mentioned children, 1 mentioned neighbors, 6 mentioned herds man/casual labourer and 5 did not answer. To gauge the knowledge of farmers understanding of RAP and vector control (n=360), 260 respondents (73%) indicated that the whole cattle should be sprayed while 100 (27%) indicated restricted spraying to control ticks and tsetse.

The responses for those whose mentioned restricted spraying in relation to belly is summarized in Table 2-222. The degree of freedom (df) for all the calculations was 1.

Table 2-222 Cross tabulation of responses to restricting spraying

Body part	Responses mentioning both variables in %	Responses not mentioning both variables in %
Belly and back	82.0	18.0
Belly and ears	85.1	14.9
Belly and legs	93.1	6.9

2.9 Change in acres of land hired

Before the intervention 44 out of 660 households (6.7%) hired an extra 48.4 acres of land; whilst after the intervention 118 out of 660 households (17.8%) hired an extra 188.8 acres for cultivation as shown in Table 2-23; equivalent to 83 out of 660 households (12.5%) and 132 acres hired in one year; representing a 175% annual increase in acreage hired for cultivation.

Table 2-23 Extra land hired for cultivation across all households

Intervention period	% of households hiring land for cultivation	Total land hired (in acres)
Pre-intervention	6.7	48
Post-intervention (18 months)	17.8	189
Adjusted figure for 1 year post intervention	12.5	132

2.10 Statistical analysis

A paired t-test was conducted to compare the average household income across all households before and after 1 year and 18 months of the intervention. There was a significant difference in the mean household income across all households before (mean=USD 110; SD=206) and after (mean=182; SD=227) 1 year of the intervention; t (659) = 11.7, p=<0.001. Also, there was a significant difference in the mean household income across all households before (mean=USD 110; SD=206) and after (mean= 261; SD=325) 18 months of the intervention; t (659) = 17.4, p=<0.001.

The comparison between household income and after 1 year of the intervention was done among RAP and non-RAP households. There was a significant difference in the mean household income across RAP households before (mean=USD 116; SD=215) and after (mean=239; SD=230) 1 year of the intervention; t (659) = 11.7, p=<0.001. Also, there was a significant difference in the mean household income across non-RAP households before (mean=USD 102; SD=194) and after (mean=115; SD=205) 1 year of the intervention; t (659) = 11.7, p=<0.001.

The study revealed that there was no statistically significant difference in the mean household income between RAP and non-RAP households before the intervention using one way analysis of variance (F(1,658)= 0.7, p= 0.383). However, after 1 year of the intervention, there was statistically significant difference in the mean household income between RAP (USD 239) and non-RAP (USD 115) households after the intervention using one way analysis of variance (F(1,658)= 51.6, p= <0.001) as shown in Figure 2-2.

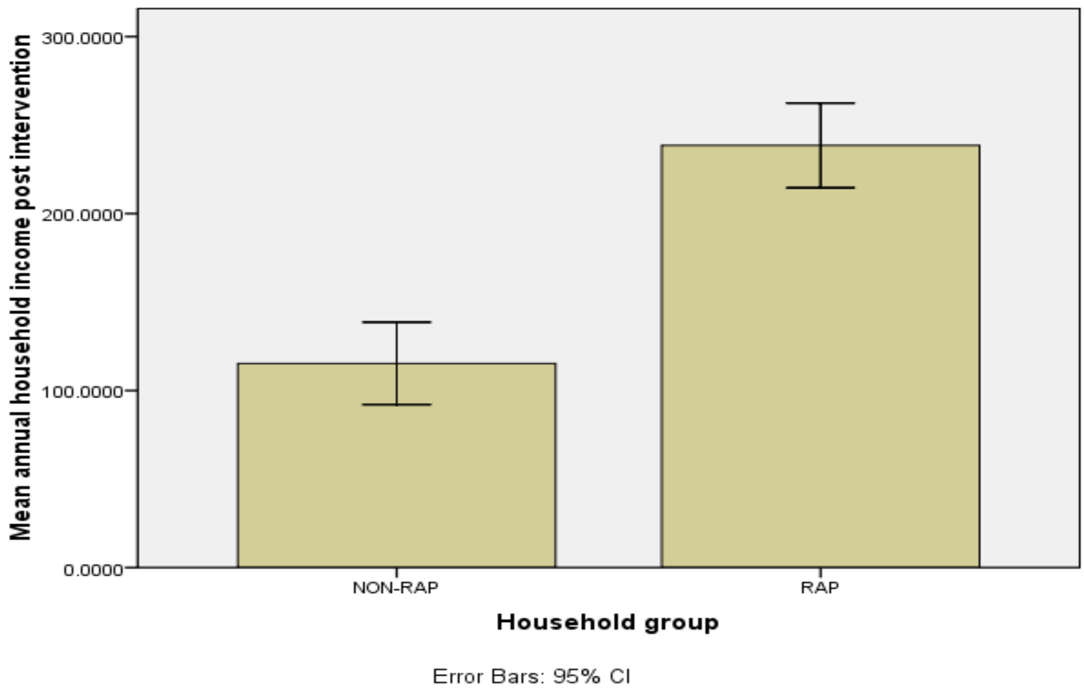


Figure 2-2 Average income between RAP and non-RAP households after 1 year of intervention

The average income per household from cattle was compared among the regimes using one way analysis of variance (ANOVA) and choosing regime 6 as the control; the results have been summarized in Table 2-23. The ANOVA revealed that there was no significant difference between regime 6 (control), 1 (diminazine aceturate injection once only) and 5 (deworming).

Table 2-23 Analysis of variance of the household income

Regime	N	Mean	SD	95% CI	Grouping
1	120	107	201.2	68,146	A*
4	120	276	242.6	237,315	
3	120	255.3	204.7	216.3,294.3	
2	120	184.2	234	145.2,223.2	
5	120	127.9	201.5	88.9,166.9	A*
6 (control)	60	153	213	74,214	A*

*The difference in income for groups sharing the same letter is not statistically significant.

2.11 Discussion

The characteristics of villages that met the intervention criteria were significantly different from those that did not. First, the intervention villages had a relatively higher number of household members and lived in better dwellings (using type of dwelling as a wealth indicator). Secondly, villages that met intervention criteria had a comparatively higher number of households owning work oxen compared to the villages that did not. It was also revealed that number of work oxen is the most significant contributor to prediction of prevalence of trypanosomiasis. The high draft cattle population could be significant in the transmission of trypanosomiasis as use of draft cattle for ploughing is a risk factor for animal African trypanosomiasis in cattle and human African trypanosomiasis in humans; as discussed in more detail in Chapter 3. This could be partly due to extensive grazing of draught cattle to gain weight, exposing them to tsetse infested areas (tethering is mostly done in the homestead to prevent cattle from destroying crops after which they grazed communally). Thirdly, apart from high draft cattle population, the intervention households mostly used isometamidium chloride as drug of choice for treatment of trypanosomiasis. Isometamidium chloride is more expensive than diminazine aceturate therefore the local health providers might be administrating it to sick draft cattle households since they are much more willing and able to pay for expensive drugs. It has been reported that cost of delivering diminazine aceturate is USD 1.42 compared to USD 1.78 for Samorin™ (Muhanguzi *et al*. 2015). Isometamidium chloride is mostly used for prophylaxis and is effective against *Trypanosome* species (Magona *et al*. 2004). However, it has been reported the efficacy of isometamidium chloride is affected by presence of impurities (Sahin *et al*. 2014) which could be the case in the study area. Fourthly, the most common acaricides used by intervention households were Amitix™ and Triatix™. These two acaricides are made up of amidines and they are the cheapest acaricide in south-east Uganda; and are not effective against tsetse flies (Bardosh *et al*. 2012). Tick control requires repeated spraying (ideally twice a month) thus can be costly in the long run; consequently most farmers practiced handpicking and sprayed for ticks infrequently. Minimal use of pyrethroid insecticides and the overall lack of preventive measures of controlling tsetse flies probably contributed significantly to exposure of animals thus of people to trypanosomiasis.

The herd composition before and after the intervention revealed that although the number of female cattle was higher that of male cattle, the livestock production system in Tororo district is geared towards animal traction with 37.8% of the herd being work oxen after the intervention, up slightly from 37.1% beforehand. Given the high number of draught cattle, female cattle composition of 50.3% would not be enough to replace old work oxen; forcing farmers to bring in young male cattle from outside the district. Consequently replacing old work oxen with young draught from outside the district increases the risk of spread of HAT as discussed in Chapter 4. Also, the herd composition remained relatively similar before and after the intervention with exception of number of cows decreasing whiles those of young males increasing marginally. The decrease in the number of cows was attributed in part to farmers selling off their cows during the intervention to purchase young males for purposes of draft work as indicated by the herd composition. Also, the increased number of households owning draft cattle by 5% could have contributed to the increased number of young males. Chapter 3 further explores the herd dynamics of the cattle production system, and highlights other reasons why the number of females might be declining.

The overall household income before and after 1 year and 18 months of the intervention increased significantly. The higher income observed after the intervention is attributed to; decreased mortality hence increased herd growth and increased draft cattle productivity as they were able to work longer periods without the farmer having to borrow extra work oxen to finish the work. The mortality decreased by 4.2% increasing change in herd value from a negative figure, –USD 36,958 in the year, before the intervention to a positive figure of USD 714 after the intervention; hence there were more cattle in the herd providing more milk, more calves and more draft power to the households. The average working days increased from 52.1 to 61.5 per year (an 18% increase) due to fewer work oxen falling sick due to the intervention; and subsequently farmers were able to plow more land improving household income. Furthermore availability of work oxen partly led to a 290% increase in the acres of additional land rented by farmers for cultivation, thus potentially improving food production in the study area. Also, the revelation that the RAP induced change in income per bovine was USD 31 per year was a significant finding. An earlier study for the sub-region estimated the RAP induced change in income per bovine to be USD 22 per bovine per year in mixed crop livestock systems (Shaw *et al*. 2014).

This study showed that the income of households who sprayed their cattle using RAP was higher than those who did not due to improved cattle productivity (increased number of ploughing days per bovine), demonstrating the impact of RAP on household income. Also, the study revealed that investing in spraying 25% of cattle provides the highest returns; it offers a return of 16:1 on the total investment (insecticide, project delivery and farmer's costs). Upgrading to 50% increases the average benefit-cost ratio for the intervention, but only offers an incremental benefit-cost ratio or marginal return of 3:1 although this is still a very advantageous return. However, increasing to 75%, again slightly increases the average benefit-cost ratio, but only increases the increases the incremental benefit-cost ratio to 1:1. From the livestock keeper's viewpoint, these ratios are much higher – but this would change if livestock keeper's had to bear more of the delivery costs, perhaps sourcing and applying the insecticide themselves. Furthermore, farmers would tend to select the animals they value most (cows and draught animals) as shown in this study. It has been shown that tsetse feed preferentially off larger animals, so the effect of spraying this selected 25% subset of their herds would have an added effect on tsetse populations (Torr *et al*. 2001; Torr *et al*. 2007); and benefit even non-participants since trypanosomiasis control is a public good. Additionally the ANOVA of the six regimes found that the household income gained from spraying 25%, 50% and 75% of cattle was not statistically significant compared to the control (no treatment); and the study also found that diminazine aceturate injection and deworming do not improve household income. Other authors have shown that spraying 25% offers sufficient protection to cattle from clinical re-infection with *T. brucei s.l.* (Muhanguzi *et al*. 2014); others have predicted that spraying 27% of the cattle population is sufficient to control *T. brucei s.l.* (Kajunguri *et al*. 2014).

Cost analysis revealed that monthly participation in RAP exercise cost USD 0.4 per bovine during the 18 months of study. Thus, the annual cost of RAP to the farmer was estimated to be USD 0.26 per bovine, allowing for comparison with other findings. Other studies have estimated cost of RAP to be USD 0.2 per bovine per year when RAP is carried out fortnightly (Torr *et al*. 2007); extrapolated as USD 0.4 per cattle per year when spraying cattle monthly using RAP. Therefore the findings in this study compares well with the study done in Zimbabwe. Nonetheless, administrative costs and subsidies need to be included to the cost of RAP to the farmer to determine its full economic cost, which can then compared with other control strategies.

This study found that the cost of labour (non-cash item) and buying ropes (cash item) were the two most significant expenditures incurred by the farmers during the RAP intervention, accounting for 89.8% of the expenses. Farmers forego certain activities such as herding, planting, harvesting, socializing etc to participate in spraying. Moreover, they have to gather the cattle, take them for spraying, participate in the spraying and bring them back to the homestead. There are few communal crushes in Tororo district, thus farmers frequently used ropes for tethering and restraint during spraying. For this reason, farmers spent substantial amount of cash buying ropes. Therefore the location chosen for spraying and efficiency in restraint are critical factors to consider in communal spraying as they duly influence the total cost incurred by the farmer; such information could be used to lobby for communal crushes.

It would be appropriate to assume that there is a strong association between number of cattle and the total cost of RAP, that is, that increase or decrease in cattle number would concurrently lead to a change in cost of RAP. Conversely, it was revealed in this study that the association between cattle ownership and total cost of RAP was weak. This meant that number of cattle owned per household was not significantly affecting the overall cost incurred per household during the 18 month spraying with RAP. This was partly because most households (54.6%) owned small herds which are typical of mixed rain-fed livestock production systems such as in Tororo district. Therefore in crop-livestock systems, direct costs of RAP seem not to significantly vary with the cattle numbers owned per household.

Understanding farmers' beliefs, knowledge, skills and attitude about vector control is important in ensuring successful adoption and sustainability of new technologies such as RAP. Most farmers in the study site believed in spraying the whole cow as indicated by 73.3% of those interviewed. This is because current vector control methods based on individual cows have been targeting ticks not tsetse flies. Even though some farmers (26.7%) mentioned restricted spraying, especially on the belly and legs, results show that spraying predilection sites for ticks such as ears is also important to farmers. Therefore the question of whether to include predilection sites for ticks in the spraying protocol without affecting enzootic stability would be one to consider in future.

2.12 Conclusion

The study chapter was set out to; first, explore the characteristics of villages/households with a relatively high prevalence of *T. brucei s.l.*; secondly, to find out the net change in income due to RAP; thirdly, to ascertain the regime/treatment above which it would be uneconomical to spray cattle using RAP from the donors perspective; fourthly, to find out the cost of RAP from the farmers perspective; and lastly, to find out the knowledge, practices and attitudes of farmers towards vector control and RAP in particular. This is one of the few studies that revealed that villages/households with a high numbers of work oxen have a higher prevalence of *T. brucei s.l.* despite the preferential treatment of work oxen. It was shown that the high *T. brucei s.l.* prevalence was due to inappropriate vector control methods, use of ineffective insecticides such as amitraz and inadequate application of insecticides and trypanocides. The finding that spraying 25% of cattle offers the highest incremental benefit-cost ratio is important from the donor's point of view if the aim of controlling trypanosomiasis is to improve livestock productivity as well as prevent spread of acute human African trypanosomiasis. However, control of trypanosomiasis using privatized systems might require a larger proportion of cattle to be sprayed for the local animal health providers to break even depending on the cattle population, willingness and ability of farmers to pay. The study revealed that the cost of RAP to farmers was low and mostly entailed the opportunity cost of taking the cattle for spraying. However, cost of RAP would be high if delivery cost is included. It was also found that most farmers do not have sufficient knowledge about RAP and that the number of cattle per household does not determine the cost of RAP to farmers within the mixed crop livestock farming system. Therefore there is still a need to create awareness about RAP with emphasis on its rationale and to determine other body parts of the cattle that need spraying according to the tick predilection sites in Tororo district.

2.12 Summary of key findings

(a) Net annual change due to the RAP intervention per head of adult bovine

The study revealed that the annual net change in income per household was USD 110. Given that the average number of cattle per household was 3.5, it was estimated that the annual RAP-induced change in income per bovine was USD 31; a finding which compared well with earlier estimates of USD 22 (Shaw *et al*. 2014).

(b) Cost of RAP from the farmers' perspective

The study found that the annual cost to the farmer for implementing RAP was USD 0.2 per bovine, consistent with earlier studies (Torr *et al*. 2007). However, given this study did not take into consideration costs incurred by the project for overheads/consumables (eg local animal health providers salaries, drugs), the 'true' cost of RAP to the farmer is likely to be significantly higher when not subsidized by development projects. Instead, opportunity costs such as labour or time used in taking cattle for spraying and buying of ropes were the main expenses incurred by the farmers who participated in the RAP exercise.

(c) Overall change in mean cattle income post RAP-intervention

The null hypothesis of the broader research objective was the assumption that there would be no increase to the mean household income after 12 and 18 months of the RAP intervention, respectively. However, the paired t-test found a significant difference in the overall mean income after both 12 months ($t(659) = 11.7$, $p=<0.001$) and 18 months ($t(659) = 17.4$, $p=<0.001$) of the intervention, thus rejecting the null hypothesis. It was also assumed that there would be no difference in the mean income from cattle enterprise between the RAP and non-RAP households after the intervention. However, analysis of variance (ANOVA) revealed that the difference in mean income between RAP and non-RAP households was statistically significant ($F(1,658)= 51.6$, $p= <0.001$) after 1 year of the RAP intervention, again rejecting this null hypothesis.

(d) Collateral benefits of using RAP to control trypanosomiasis

Several collateral benefits to using RAP to control AAT were identified, particularly regarding food security. The study found that the average number of days draft cattle worked increased by 18.0%, from 52.1 to 61.5 days per year. This increased availability of draft cattle reduced the time taken for farmers and other community members to plow their fields and increased the amount of land being hired out for cultivation by 175% within one year of the intervention, thus contributing to increased food security in the area.

(e) RAP regimes that conferred the highest income

Analysis of the gross margin from the cattle enterprise was carried out via ANOVA to compare the six RAP regimes. The ANOVA results established that the annual mean income from cattle enterprise in regimes 6 (control), 1 (diminazine aceturate injection once only) and 5 (deworming of cattle only every six months) was not significantly different. However, there was significant difference in the mean annual income between regime 6 (control) and regimes 2, 3 and 4, indicating that injecting diminazine aceturate once only and deworming cattle every six months as a stand-alone interventions do not improve the income gained from the cattle enterprise; spraying cattle with RAP is required.

(f) RAP regimes that conferred the highest net marginal returns

The results indicated that the incremental benefit cost ratio of spraying 0%-25% was 16:1 compared with spraying 25%-50% and 50%-75% which were 3:1 and 1:1 respectively. Therefore the study found that spraying 25% of cattle (regime 2) conferred the highest returns. Other authors have showed that spraying 25% of cattle was the most effective in preventing clinical re-infection with *T. b. brucei* that causes acute HAT compared to spraying 50% and 75% of the cattle population(Muhanguzi *et al*. 2014); other authors predicted that spraying 27% of cattle is sufficient to treat *T. b. brucei* (Kajunguri *et al*. 2014).

(g) Household/village differences between those chosen for RAP and those that were not

Possible associations between the characteristics of households within the baseline group of households were explored through examining the differences between households chosen for the RAP exercise and those that were not. Households chosen for RAP tended to have higher numbers of draft cattle; used mainly isometamidium chloride to control trypanosomiasis and used amitraz to control vectors. The suspicion of high density/ownership of draft cattle being a potential significant risk factor for transmission of acute HAT is discussed further in Chapter 3. Other explanations for these observations are the possibility that the isometamidium chloride used in Tororo district contains high impurities - or is being misused – thus leading to high *T. brucei s.l.* occurrence. Similarly, whilst amitraz is a cheap and effective acaricide, it does not kill tsetse flies, thus also potentially contributing to the high prevalence of *T. brucei s.l.* The study also found that these three factors (ownership of draft cattle, use of isometamidium chloride and amitraz) are strong predictors of acute HAT prevalence.

CHAPTER THREE

3. ECONOMIC DRIVERS AND RISK OF HUMAN AFRICAN TRYPANOSOMIASIS: CATTLE TRADE NETWORKS AND HERD MODEL

3.1 Introduction

Smallholder mixed farming where farmers keep small numbers of indigenous breeds of cattle, sheep, goats, pigs and poultry is the most dominant livestock production in eastern and northern Uganda. Also, the main reason of keeping livestock in mixed production system of Uganda is draught for crop cultivation; with work oxen representing 36.5% to 43.7% of the herd population (Ocaido *et al*, 2005; Okello *et al*, 2015). Consequently, farmers are forced to bring in young draught cattle from other areas to replenish the old work oxen, creating movement of cattle from district to district (Shaw *et al*. 2014). Movement of animals is an integral part of livestock trade; however it presents an opportunity for rapid spread of diseases, including zoonoses (Fèvre, 2006; Bajardi *et al*. 2011). In Uganda, between 39.5% (Selby *et al*. 2013) and 54.0% (Fèvre *et al*. 2001) of cattle involved in inter-district trade, moved from *T. b. rhodesiense* endemic areas into pathogen free north and central districts, mostly due to restocking programmes (Selby *et al*. 2013). Moreover, living in proximity to livestock markets was a human risk factor in contracting sleeping sickness (Fèvre *et al*. 2001). In Madagascar, movement of cattle has been linked to potential spread of Rift Valley fever (Nicolas *et al*. 2013); whereas introduction of infected Indian cattle to Belgium en route to Brazil famously led to the introduction of rinderpest in Europe in 1920, leading to formation of the Office International des Epizooties (Zepeda *et al*. 2000).

Thus, livestock dynamics offer a unique prospect of understanding the risk and pattern of potential disease transmission, however, due to the intricate nature of such patterns; their depiction requires a detailed knowledge and representation of complex networks (Danon *et al*. 2010). The major constituents of a network are actors and links. Actors are the fundamental units of the network and the links (also known as ties or arcs) are the lines that connect two actors (Newman, 2003). The links can be directed (for example flow of movement of cattle in one direction only) or undirected (for example flow of movement of cattle to and fro) (Hanneman *et al*. 2005). A network can therefore be described as a group of actors (or *nodes, points or vertices*) that are connected with one another (Lopez *et al*. 2009). It may have one or more actors, or one or more types of connections between a pair of actors, which can either be central or peripheral (Newman, 2003). A network may also be embedded in larger networks (Hanneman *et al*. 2005). Complex network analysis has been used in social sciences, psychology, medicine, anthropology and biology (Lopez *et al*. 2009). In public health, contact network analysis using modelling of disease spread has widely been used to simulate or predict epidemics; for example to study the occurrence of epidemics such as severe acute respiratory syndrome (Meyers *et al*. 2005) and *Mycoplasma pneumonia* (Meyers *et al*. 2003).

3.2 Key Types and Properties of Networks

There are generally four classes of networks, namely social, information, technical and biological (Newman, 2003). Social networks are usually derived from social sciences and generally refer to groups of people with some pattern of relations between them (Scott, 2013). The earliest published studies that utilize social network analysis concepts were in 1930s and 1940s when the concept of sociograms was developed (Moreno, 1934; Heider, 1946). Sexual contact relationships in the transmission of human immunodeficiency virus/acquired immunodeficiency syndrome (Klovdahl, 1985; May *et al*. 1987) are examples of networks that have been studied using social network analysis. Apart from social networks in people, animal social networks have demonstrated the possibility of disease transmission like rabies and canine distemper (Hirch *et al*. 2013; James *et al*. 2009). There are limited animal health studies that have used social network analysis in animal health. These studies have mostly been done in Europe, mainly on the spread of foot and mouth disease (FMD) in cattle (Christley *et al*. 2003; Christley *et al* 2005; Woolhouse *et al*. 2005; Webb, 2006; Robinson *et al*. 2007; Dent *et al*. 2008), and a few studies on FMD in sheep (Webb 2005; Kiss *et al*.

2006) and in swine (Bigras-Poulin *et al*. 2007). Other studies have used social network analysis (SNA) in determining spread of tuberculosis in bushtail possums (Corner *et al*. 2003), equine influenza in horses (Christley and French, 2003), *Escherichia coli* O157 in cattle (Turner *et al*. 2008) and avian influenza in poultry (Dent *et al*. 2008). Even more limited are studies that have used social network for studying livestock trade networks (Bajardi *et al*. 2011; Hardstaff *et al*. 2015;) particularly in Africa (Rasamoelina-Andriamanivo *et al*. 2014) or linking livestock trade to risk of spreading zoonotic diseases (Nicolas *et al*. 2013).

An example of an information network is the study of information exchange (Haythornthwaite, 1996). Technical networks comprise of man-made designs intended for distribution of goods or services, such as road networks and air routes (Newman, 2003). Biological systems such as food web (Strogatz, 2001), metabolic (Jeong *et al*. 2000; Stelling *et al*. 2002) and gene regulatory pathways (Newman, 2003) can be represented as biological networks. Although there are different types of networks, they all share some common properties such as small world effect, clustering, degree, distributions and network resilience (Strogatz, 2001; Newman, 2003; Hanneman *et al*. 2005; Lopez *et al*. 2009). The small world effect shows how elements such as diseases and information within a network are capable of spreading quickly in the real world situation, depending on the number of pathways (Newman, 2003). Another common property of networks is clustering; also known as transitivity (Newman, 2003). In most networks it has been found that if actor A is connected to actor B and actor B to C then there is a high probability that actor A and C are connected; forming a triangle (Newman, 2003). A clustering coefficient is used to measure the probability of a set of triangles occurring; that is the mean probability that two actors that are network neighbors of the same other actor will be themselves neighbors (Newman, 2003). Clustering is used to analyze the density of triangle actors in a network and directed graphs that have the two connections pointing to in opposite directions. If the two connections in question are pointing in the same direction then reciprocity is measured (Watts *et al*. 1998). The degree distribution of a network is the frequency distribution of the degrees in the network; the degree of an actor is the number of links connected to it (Newman, 2003). Networks display a range of degree distribution from one extreme end where the distribution of connections is almost as if they were formed uniformly at random, for example Erdos-Renyi random graphs (Newman *et al*. 2002) to the other where they are scale free (Hubermann *et al*. 1999). Random graphs are graphs whose properties such as number of actors and links can be determined randomly (Newman *et al*. 2002) and have a binomial or Poisson distribution (Newman, 2003). Unlike random graphs, scale free graphs have a Poisson distribution which is skewed to the right (Newman, 2003; Li *et al*. 2005). Most networks rely on the connectivity function (presence of paths leading between pairs of actors) for their existence (Newman, 2003). However, removal of these connections from the network would typically increase the number of paths and eventually the pair of actors will become disconnected and communication between them will cease (Hanneman *et al*. 2005) depending on the level of network resilience to removal of actors. Network resilience is importance in the field of epidemiology, where removal of actors can be equated to disease control such as vaccination (Newman, 2003); vaccination would prevent spread of disease between individuals and also obliterate the paths of disease spread (Newman, 2003).

3.2.1 Network Analysis

Network analysis involves studying the relationships between actors, in this case markets, rather than the attributes of the actors themselves (as is the case in statistics or socio-economics), therefore many common statistical techniques may not be applicable in network analysis (Hanneman *et al*. 2005). For example, the elements in the networks are usually not normally distributed, as they follow exponential or "power law" (Hanneman *et al*. 2005), whereby a relative change in one element leads to a relative proportional change in the other element, independent on the initial size of those elements (Barabasi *et al*. 2003; Li *et al*. 2005). A key advantage of complex network analysis methodology compared to other approaches is its inherent capacity to handle bi-directional relations such as animal movement, trade and contact between people (Martínez-López *et al*. 2009). Network analysis is used in conjunction with graph theory, which provides the theoretical framework for analyzing network properties and capacity to compare different networks (Martínez-López *et al*. 2009). A graph, or sociogram, is composed of actors and links and it may represent either simple or complex relationships among actors. Each link may be directed, in which case it originates from a source actor and reaches a target actor, or undirected. Directed links are represented with arrows in the graph and can be reciprocated (represented with double headed arrows). Undirected ties are represented with line segments (Martínez-López *et al*. 2009).

Network analyses broadly involve analysis of the intra and inter network metrics based on the actor connectivity, determined by metrics including number of paths, path length and network strength (Martínez-López *et al*. 2009). A portion of the network where any two actors, A and B, are reachable from each other by pursuing a path is known as a *strong component* of the network. Identification of strong component of network is crucial for example in epidemiology because introduction of a disease in an actor of a strong component is likely to lead to transmission of disease to other actors within the strong component (Martínez-López *et al*. 2009).

Centrality is a terminology used to identify the relative importance of the various actors in the network. An actor with a high value degree centrality is better-linked to other actors than one with a low degree of centrality (Martínez-López *et al*. 2009). Cohesiveness of a network is another intra-network metric, evaluated by discovering groups of actors that are part of a common structure; and these groups can be in the form of cliques (a group of actors linked to each other at a path distance equal to or less than a given criteria) (Hanneman *et al*. 2005), k-plex (a group of actors that are linked to every other actor but not to certain actors, k) (Martínez-López *et al*. 2009) or k-core (a group of actors that are connected to at least k actors in the group) (Martínez-López *et al*. 2009). The concept of grouping actors allows for selection of group of actors using their lower or upper limits for the value of k, for example identifying a k-core of actors with a certain number of connections in the network (Martínez-López *et al*. 2009). Cohesiveness of the network can also be used to evaluate network resilience. Removal of certain actors and connections may lead to weakness of the structure of the network. Actors and links that if removed from the network lead to disconnection of the network into two separated groups are referred to as cut-points and bridges respectively; and this concept can be used in disease control (Martínez-López *et al*.

2009). Related to this is network fragmentation, given by the proportion of pairs of actors that are not linked to each other (Borgatti *et al*. 2003). A network with a high value of fragmentation will have actors that are more separated in terms of links than a network with a low value of fragmentation, in which actors will be more linked to each other (Borgatti *et al*. 2003). Density measures the level of the links between pairs of actors within the network (Friedkin, 1984). It is calculated as the proportion of contacts that could probably arise in the network in comparison with those that are actually observed in the network (Friedkin, 1984). The higher the network density, the greater the proportion of links observed between pairs of actors in the network. There is also a relationship between network fragmentation and density (Martínez-López *et al*. 2009). A network with highly linked markets, such as trade of animals between regions with intensive production systems, will probably be less fragmented and denser than a network composed of extensive production systems, where animal mobility and trade between regions is less frequent and the network is expected to be more fragmented and less dense (Martínez-López *et al*. 2009). Finally, the clustering coefficient provides information on the mean probability of individual actors being directly linked (Watts and Strogatz, 1998) as defined earlier. The possible limit value of the clustering coefficient is 1 which indicates that every actor is directly connected to all other actors in the network; and the value of 0 indicates the total absence of links between networks, i.e. there is no network (Martínez-López *et al*. 2009).

Detecting and characterizing subtle patterns or regularities in data sets is a common problem in data analysis (Evans, 2009). When analyzing the structure, dynamics and functions of network it is empirical to identify sets of related actors, known as communities (Radicchi *et al*. 2004). Community structure in a network is the manifestation of tightly connected groups of actors, with only sparser connections between groups connected (Newman, 2006). The concept of community is universal and it is linked to the categorization of objects for ease of understanding the network dynamics (Newmann *et al*. 2004). By clustering links, as opposed to actors, it is possible for actors to belong to several communities divulging the overlapping and nested network structures as well as the key actors that form links across several communities (Palla *et al*. 2005; Evans, 2009). The standard method of identifying communities in networks is by use of hierarchical clustering and measuring for structural equivalence using network block modelling (Clauset *et al*. 2008; Kalinka *et al*. 2011). Hierarchical clustering involves assigning each actor its cluster and then merging the closest pair of clusters into a single entity (Palla *et al*. 2005; Kalinka *et al*. 2011). Actors may play different roles or be connected by a certain role in the network; mathematical structure that is equivalent to the role played by the actors or a role binding several actors is known as the 'block' (Sailer, 1978). Consequently a block model is the set of blocks and their relations; and structural equivalence is the substitution of roles with regards to relational links in the network (Sailer, 1978). Actors may also belong to several communities (Fortunato *et al*. 2010); link community analysis is used to identify a set of actors that belong to a community wholly embedded in a larger community (Ahn *et al*. 2010). Other indices revealed by link community analysis include community relationship, community centrality and community modularity and connectedness (Kalinka *et al*. 2011). Relationship between communities is based on the number of shared actors (Jaccard coefficient) (Kalinka *et al*. 2011). Exploration of this relationship results in identification of meta-communities (Kalinka *et al*. 2011). Community modularity is the number of links falling within groups less the expected number in a comparable network with similar links placed randomly (Newman, 2006). It can be positive or negative with the former representing a high likelihood of existence of a community structure (Newman, 2006).

There are various sampling methods used for collecting data for social network analysis. These are; full network method, where information about each node's links with all other nodes is collected (Hanneman *et al*. 2005); snowball method, where information about all or some of the links is collected from a focal node or set of nodes then the named nodes are followed and so on (Heckathorn, 1997; Hanneman *et al*. 2005); targeted method, where the target population is first mapped and properties of the population is then used to develop a sampling frame (Heckathorn, 1997); key informant approach, where only the key informants are interviewed (Heckathorn, 1997); and respondent driven approach, where the actors recruit their peers in the study and are given an incentive (Heckathorn, 1997).

3.3 Value chain and Animal Disease Risk Assessment

Networks in the value chains that connect production systems, markets and consumers represent a network for spread of diseases as infected animals and contaminated animal by products move along the chain; therefore value chain networks should be considered in disease risk management strategies (Taylor and Rushton, 2011). A value chain can be termed as the "the full range of activities which are required to bring a product or service from conception, through the different phases of production (involving a combination of physical transformation and the input of various producer services), delivery to final consumers, and final disposal after use" (Kaplinksy *et al*. 2000) or simply as a set of people linked by an activity to deliver an explicit product. The characteristics of value chains are that they are: consumer driven, based on national, or local or custom laws and are managed by individuals who set regulations on how people interrelate, generate and transport commodities and the linkages are either uni- or bi-directional (Kaplinsky *et al*. 2000; Taylor and Rushton, 2011). The reasons for analysis of value chains in reference to risk analysis are to identify the main stakeholders within the livestock chain, map out the different means of marketing livestock and livestock products and appraise the marketing chain; thus partly assessing possible risk of livestock disease transmission. Risk analysis involves assessing risks and hazards and has four components namely; hazard identification, risk assessment, risk management and risk communication (Taylor and Rushton, 2011). The risk analysis process involves; first, evaluating a hazard (an agent that is likely to be detrimental to the ecosystem), second, assessing the likelihood of the unwanted outcome from the hazard occurring and its impact, third, undertaking risk reduction procedures and fourth, informing various stakeholders on the risk reduction procedures and any related legislation for enforcement (Zepeda *et al*. 2001). The probability of disease transmission within the value chain depends on various factors most of which are 'risky behaviors' or 'risky practices' typically as a result of economic drivers (Taylor and Rushton, 2011). The size of flow through the various parts of value chain is also an important determinant of the likelihood of disease spread (Taylor and Rushton, 2011).

3.4. Structure and Dynamics of Livestock Markets

Livestock markets are part of the value chain (Rushton, 2011). Understanding risk of disease spread through the value chain and market networks requires sound knowledge of the structure and dynamics of livestock markets in particular (Rushton, 2011; Rasamoelina-Andriamanivo *et al*. 2014). A livestock market, just like any other type of market, is the system through which resources are located; prices are established to enhance exchange; income is allocated; and capital is accrued (Ajala *et al*. 2007). There are a number of market analysis approaches such as commodity chain approach (Shaffer, 1980); structure, conduct and performance (Bain, 1968); and transaction cost economics (Hobbs, 1997). Commodity chain analysis refers to the general group of economic agents or activities that directly add to the determination of the ultimate product. Hopkins *et al*. (1986) described commodity chain as "a network of labour and production processes whose end result is a finished product". Thus the chain comprises the whole series of operations which, starting from the raw material, or an intermediate product, finishes downstream, after numerous stages of change or increases in value, at one or several end products at the level of the consumer (Hopkins *et al*. 1986). At each stage along the chain, the approach permits three types of analysis: costs and margins (price transmission analysis), spatial flows (places, volumes, and directions), and the social relations of trade (Leplaideur, 1992). Structure, product and performance paradigm was developed by Joe Bain and he stated that structures such as marketed volumes and ease of entry and exit of buyers and sellers affect participant's behavior in carrying out their exchange function, price determination and product differentiation (Bain, 1968). Performance of markets can be evaluated based on the level of competition and efficiency in those markets (Williams *et al*. 2006). The transaction cost economics framework, unlike neoclassical economic theory, recognizes that economic activity does not take place in a frictionless economic setting (Williamson, 1985). Transaction costs would comprise inter alia, the costs of looking for trade partners; transfer of the product; and negotiating with prospective trading partners (Kyeyamwa *et al*. 2008). The transaction costs theory envisages that transaction costs rise with distance (Gabre-Madhin, 2001) and uncertainty surrounding the transaction (Kyeyamwa *et al*. 2008).

There are four major functions of livestock markets namely; physical, exchange, social and facilitating. The major physical function of the market is transport. Physical function involves bringing the commodity, buyers and sellers together. Usually this involves farmers and roaming small traders walking animals to the livestock markets through village paths. The large cattle and long distance traders typically move and deliver cattle to secondary and tertiary markets using hired trucks (Kyeyamwa *et al*. 2008). Exchange function involves the various market chain actors, negotiation between trading partners, prices paid for commodities, and functions conducted by the different members in the marketing system (Gausi *et al*. 2004). The facilitating function comprise of actors that could potentially maintain the general efficiency of the market (Kyeyamwa *et al*. 2008).

The main economic actors in the formal and informal cattle market as animals move from the farm to the consumer are farmers, transporters and several groups of traders (Turner *et al*. 2002; Kyeyamwa *et al*. 2008). In developing countries, there are three tiers of exchange of cattle (Kyeyamwa *et al*. 2008). The first tier involves farm gate sales where farmers sell livestock to roaming livestock traders. The first tier is characterised by low volumes of sale, usually 1-2 cattle per transaction (Kyeyamwa *et al*. 2008). The second tier involves farmers or roaming traders selling cattle to relatively large cattle traders at the primary or local livestock market. The third tier involves livestock traders from primary markets selling relatively large volumes of cattle to secondary markets. Long distance livestock traders typically buy large volumes of cattle from secondary markets and sell them to cities or districts within or outside the country (Kyeyamwa *et al*. 2008). At each tier the prices of cattle is guided by the biophysical characters of the animal, transport costs, knowledge of the demand and supply situation and negotiation skills (Kopytoff, 1996; Turner *et al*. 2002). Because of such varied factors in price determination farmers in developing countries are mostly involved in the first tier (Kyeyamwa *et al*. 2008). The main actors at the primary and secondary tiers are livestock traders (Kyeyamwa *et al*. 2008).

3.5. Bio-economic Herd Modelling

Livestock markets act as economic and cultural points for management of livestock (Kyeyamwa *et al*. 2008). Farmers sell and buy cattle depending on their needs; thus, market livestock dynamics is closely linked to herd dynamics particularly in developing countries (Turner *et al*. 2002). Cattle herds in the farm comprises different types of livestock each of different ages and sexes; consequently livestock demographics lead to complex production systems with varying level of productivity such as growth rate, milk yield, draft power and survival rate (Itty, 1997). Also cattle enterprises require large investments whose return can be over several years (Itty, 1997). Herd size and structure enable productivity to be compared across different production systems; thus herd models can be used for planning and to project future herd sizes, structures and off-take under different production systems or policies (Kristjanson, 1999). However, precise forecasts necessitate data on the age structure of the herd and age-specific reproduction, mortality and growth rates (Upton, 1989). Herd models can either be stochastic or deterministic; stochastic models demonstrates herd productivity when herd growth has reached its steady state; while deterministic models follow herd output over a number of years; depending on level of disease control (Baptist, 1992). Therefore stochastic models do not show the dynamic aspect of livestock production while deterministic ones allow for inclusion of reproductive performance (Itty, 1992). An example of a stochastic bio-economic herd model is the livestock production and efficiency calculator (James and Carles, 1996). Deterministic herd models include; the international livestock center for Africa (ILCA) bio-economic model developed by von Kaufmann *et al*. (1990) and used by Itty (1992); bio-economic simulation model with economic surplus as used by Kristjanson (1999); and dynamic herd models as used by Habtemariam (1983), Brandl (1985), Shaw (1989) and Dolan (2000). The herd simulation model used by Shaw *et al*. (2014) is different from other models in that it incorporates productivity of draught cattle and computes the number of work oxen to be 'imported' into the herd depending on the herd structure and local requirements for draught animals.

3.6. Objectives for chapter three

The objectives of studying livestock dynamics at the herd and market level were:

- To establish whether demand for draft cattle is a major socio-economic driver of risk of transmission of HAT.
- To ascertain the key livestock markets to be targeted for control of HAT
- To establish the common livestock drugs sold in cattle markets

3.7 Methodology

3.7.1. Sampling frame for cattle trade networks

A list of all live livestock markets in Tororo and Namutumba districts was obtained from the district veterinary office. Using a full network data collection method (Hanneman *et al*. 2005), all (9 in total) the livestock markets in the two districts were visited and all the identified cattle traders (n=197) were interviewed using semi-structured interviews (see Table 3-1).

Table 3-1 Cattle markets visited

Market	Number of cattle traders interviewed
Siwa	12
Peta parima	13
Mairo seven	13
Molo (Mairo eight)	40
Pasinde	18
Munyole	14
Mukuju	12
Wawulera	11
Namutumba	64
Total	197

The semi-structured questionnaires were developed to capture: interviewee information; the livestock markets where cattle traders mostly sourced their cattle from in the whole livestock trade cycle (annual); the livestock markets where these were mostly sold to; the number of cattle the cattle trader brought to the livestock market; peak period of sale per year; the number and age/sex of cattle traded per month during each peak period using a 12 month recall; the period taken to sell the cattle. The markets were visited according to their respective market days. The following recordings were made for each livestock market; number, age and sex of cattle present; number of cattle sold; the frequency of cattle trade activities; accessibility; mobile telephone reception; number of cattle sold; number of local animal health providers present; and the estimated period of trade activity. Focus group discussions (Catley,

2012) with cattle traders, buyers and other traders in each market were carried out. The key informant interviews (Catley, 2012) involved discussions with local animal health providers and local council authorities. Local animal health providers were local government and private veterinarians and animal health assistants, while local council authorities were local council employees charged with the duty of collecting money from livestock traders from the gate. Discussions with local animal health providers revolved around activities they carried out, the most common animal diseases they treated and types of drugs they sold and their prices.

The market data was analyzed using <citation (package= "sna" and "linkcomm") (Butts, 2008; Kalinka and Tomancak, 2011) in R computer software 3.2.2 and SPSS version 16 (SPSS, 2007). The actor represented the market while the movement of cattle from one market to the other represented the connection between the markets. The movement of cattle was set as undirected since livestock traders mostly move back and forth in livestock markets and some go back with cattle to the village if they have not made any sales. The metrics of the network analyzed included: closeness, betweenness, density, centrality, size, diameter, clustering coefficient, centralization and positional analysis using network block modelling to determine structural equivalence. Also, communities were identified by examining the links. Using community link analysis, >citation (package= "linkcomm") (Kalinka and Tomancak, 2011) in R version 3.2.2, the following were analyzed: nested communities, relationship between communities, community centrality, community membership of actors and community modularity and connectedness.

3.7.2 Sampling parameters for herd modelling

The bio-economic herd simulation model developed by Shaw *et al*. (2014) was used to simulate the effect of the herd structure on exportation and importation of cattle in the herd. The herd model was chosen as it is the only herd model able to simulate the number of work oxen that would be required in the herd and the quantity imported. The parameters required for the herd model were; cattle population, herd composition by age and sex, basic input costs, value of cattle depending on age and sex, off-take rates and mortality. To allow for ease of tracking the number of cattle over the projected 20 years, the initial cattle population was set at 10,000 in the herd model.

The herd composition by age and sex was obtained from the field study data (as detailed in Table 2-13, Chapter 2) and secondary data from Shaw *et al* (2014) and Okello *et al*. (2015). Table 3-2 summarizes the parameters used in the herd model to simulate change in herd composition and estimate the number of draught cattle imported over a period of 20 years. A calving rate of 50%, based on the herd compositions observed in this study and Okello *et al*. 2015 and on the values used in Shaw *et al* (2014) was applied. Lastly, in order to mimic the current herd composition and livestock keeper preferences, it was assumed that 95% of young male cattle were allocated to draft as calculated for high oxen use systems in Shaw *et al*. (2014).

Table 3-2 Herd composition and production parameters used for the herd model

Age, sex and function	Starting herd composition[1] %	Mortality[2] %	Off-take[3] %
Female age 0 to 1	7	25	0
Female age 1 to 2	5.8	8	0
Female age 2 to 3	5.4	8	5
Female age 3 to 4	5.3	8	5
Female age 4 and over	27.2	8.5	9
Male age 0 to 1	7.2	25	0
Male age 1 to 2	3.4	8	0
Male age 2 to 3	0.5	8	2
Male age 3 to 4	0.5	8	5
Male age 4 and over	0.6	8.5	40
Work oxen age 3 to 4	10.6	8	0
Work oxen age 4 and over	26.5	9.5	13

[1] Based on the study population in the 'intervention group of households' prior to the intervention.

[2&3] Based on figures calculated from the survey in Okello *et al*. 2015, and completed with values from Shaw *et al*. 2014 and from the current study area

The total number of female and male cattle at the end of the year for each age cohort was calculated by multiplying the herd composition for each age cohort and the initial cattle population (10,000). Subsequently, the cow to adult male ratio was determined by dividing the total number of cows (females aged over 4 years) and the total number of adult males (adult males and draught male cattle aged over 4 years) at end of each year. The herd size for each year (year 1 to 20) was computed by summing up the total number of females and males for each year. Consequently, the growth rate was computed by dividing the herd size for each year with the set initial cattle population (10,000) minus 1. The number of draught cattle imported was computed by first setting the number of draught cattle required starting from year 1; then subtracting this from number of draught cattle (both young and adult males). As the young draft cattle are imported at some point during their second year, the resultant figure is then divided by 1 minus mortality of young males aged 2 to 3 divided by 200. The number of the cattle according to their age and sex cohort and herd size was used to estimate the herd composition at the end of year 20. The historical currency exchange rate for December 2014 when the intervention ended was used at rate of 1 United States Dollar (USD) to 2,778 Uganda shillings.

3.8 Results

3.8.1 Herd model

After inserting the parameters to the herd model, the model revealed that at the start the year (year 1) the total herd size was 9,810 falling to 6,164 at the end of year 20 as shown in Table 3-3. Also, the cow: adult male ratio at year 0 was 1.1 falling to 0.6 by the end of year 20 as shown in Table 3-3. The average herd growth rate was found to be minus 2.3%. At the start of the year (year 1), it was estimated that the number of draught cattle imported was 208 at the start of the year (year 1) rising to 300 at the of year 20; and the draught cattle were imported at an average rate of 1.9%.

Figure 3-1 shows the increase in draught cattle imported over the projected 20 years. The estimated herd composition at the end of year 20 was as summarized in

Table 3-4; and it was estimated that draught males would compose 44.6% of the herd at end of year 20, while the proportion of adult females would have reduced from 27.0 to 22.7% of the herd, which is the underlying reason for the cattle population decline. The model was rerun with lower calf death rates (20% for females and 17% for males, and a higher calving rate of 55%. Although the number of young draft males needing to be imported was lower under these assumptions (reaching just under 200, as opposed to 300), the overall herd size would still decline, by 1.3% per annum, and by the end of the period the proportion of adult females would have fallen from 27.0% to 23.9% of the herd.

Table 3-3 Herd model results

Year	Herd size at the end of the year	Cow: Adult male ratio	Growth rate (%)	Number of adult males aged 4+ required	Number of draught males imported
0	-	1.1	-	-	-
1	9,810	1.1	-1.9	3,050	208
2	9,485	1.1	-3.3	3,050	46
3	9,183	1.0	-3.2	3,050	73
4	8,960	1.0	-2.4	3,050	144
5	8,749	1.0	-2.3	3,050	163
6	8,533	1.0	-2.5	3,050	163
7	8,319	0.9	-2.5	3,050	171
8	8,113	0.9	-2.5	3,050	182
9	7,916	0.9	-2.4	3,050	196
10	7,727	0.9	-2.4	3,050	208
11	7,545	0.8	-2.4	3,050	219
12	7,368	0.8	-2.3	3,050	229
13	7,198	0.8	-2.3	3,050	239
14	7,034	0.8	-2.3	3,050	249
15	6,875	0.7	-2.3	3,050	258
16	6,723	0.7	-2.2	3,050	267
17	6,575	0.7	-2.2	3,050	276
18	6,433	0.7	-2.2	3,050	284
19	6,296	0.6	-2.1	3,050	292
20	6,164	0.6	-2.1	3,050	300

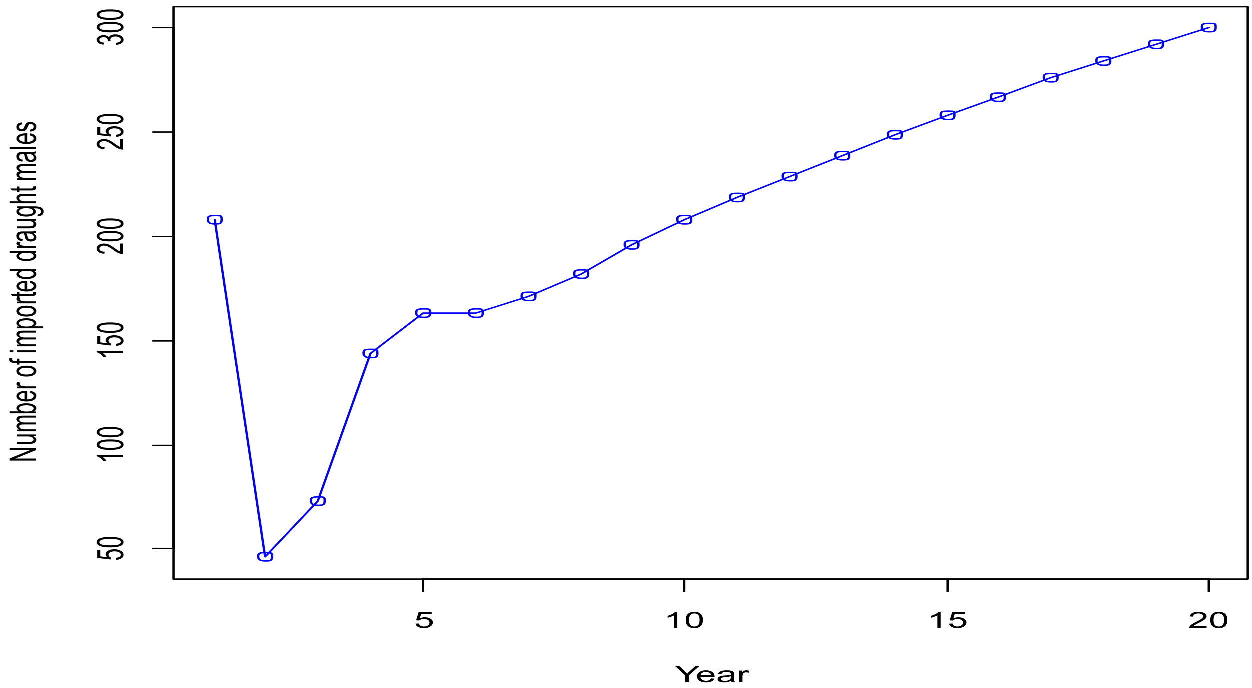


Figure 3-1 Draught males imported over a projected 20 year period

Table 3-4 Projected herd composition at the end of 20 years

Herd composition		
Age category (years)	**Female (%)**	**Male (%)**
0-1	5.44	5.89
1-2	4.23	4.58
2-3	4.03	4.37
3-4	3.64	0.20
4+	22.66	0.39
Draft male 3-4	---	8.68
Draft male 4+	---	35.90
Total	39.99	60.01

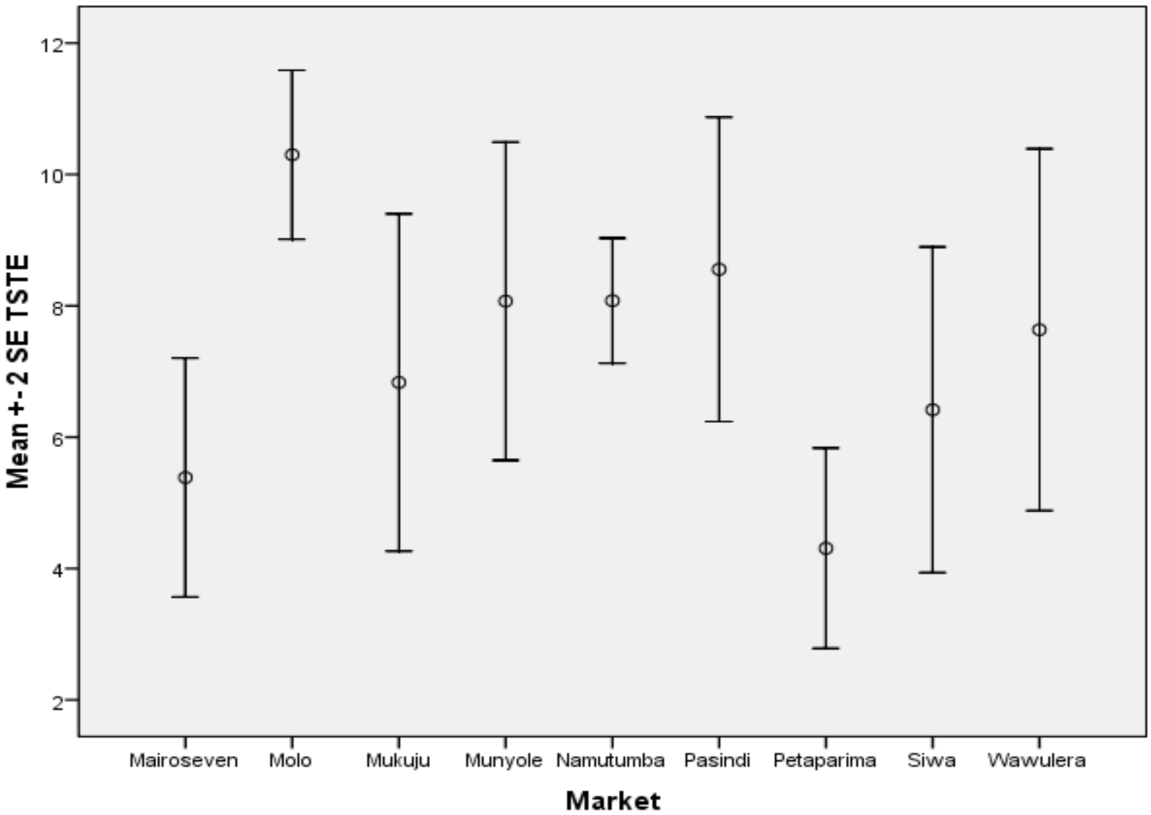
3.8.2 Cattle markets

The livestock markets were managed by the local council. Cattle traders were taxed a standard fee of USD 0.5 as movement permit. The livestock markets varied in size depending on their holding capacity and number of cattle traded; the largest markets were Namutumba and Molo. The smaller livestock markets such as Pasindi, Siwa, Munyole and Peta Parima only traded cattle while the larger livestock markets such as Namutumba and Molo traded cattle and other livestock such as poultry and goats. Also, it was found that each market operated once a week and traders attend them on rotational basis.

The semi-structured interviews revealed that a total of 1,565 cattle were present during the nine day visit; equivalent to an average of 135 cattle present in each livestock market per week ((computed as (1,565* 7 days/9 days)/ 9)). The number of cattle present and sold during the visit in each livestock market is summarized Table 3-1.). Figure 3-2 provides the mean number of cattle present in each livestock market. Cattle into Tororo district came from Namutumba (91 respondents), Soroti (82 respondents), Lira (13 respondents) and Mbale (10 respondents).

Table 3-1 Cattle traded in Namutumba and Tororo districts

Market	Female calves (0-1)	Young females (1-4 years)	Adult females (4+ years)	Males calves (0-1 years)	Young males (1-4 years)	Adult males (+ 4 years)	Total number of cattle traded	Total sold
Siwa	0	1	5	3	4	64	77	12
Peta parima	0	1	4	0	0	51	56	7
Mairo seven	0	0	5	0	3	62	70	8
Molo	0	3	14	0	2	393	412	31
Pasinde	0	0	8	0	0	146	154	16
Munyole	0	1	6	0	1	105	113	17
Mukuju	0	1	7	0	2	72	82	9
Wawulera	0	1	5	0	1	77	84	15
Namutumba	0	2	21	0	6	488	517	59



Total	0	10	75	3	19	1458	1565	174

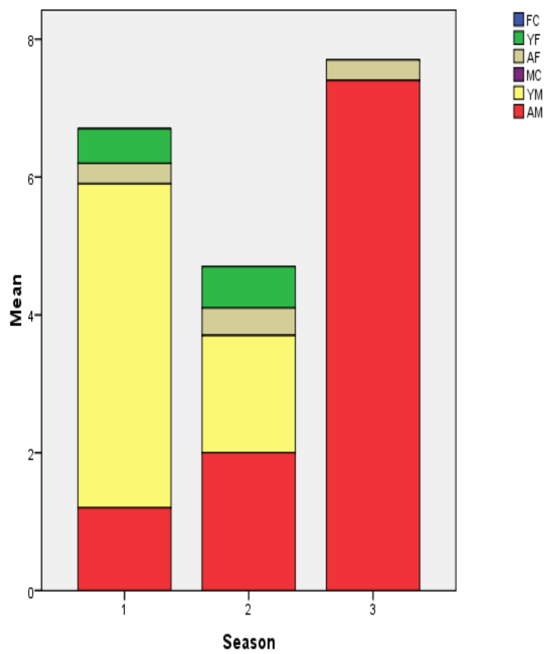
Figure 3-2 Average number of cattle traded in Namutumba and Tororo district

Data obtained from the questionnaires revealed that there are three cattle marketing seasons per year. The number of respondents who said that the first season was from January to February were 42 (21.3%); January to March, 121 (61.4%); January to April, 34 (17.2%). Respondents who said that the second season started from March to October were 42 (21.3%); April to October, 130 (65.9%); April to August, 10 and May to October, 15 (7.6%). Respondents who mentioned that the third season started from October to December were 171 (81%) and November to December, 26 (19%). Table 3-2 and

Figure 3-3 summarises the volume of cattle traded per season including the age and sex of cattle.

Table 3-2 Average number of cattle traded annually per season per trader

Season	Annual number of cattle traded per trader (mean and SD)						
	Female calves (0-1years)	**Young females (1-4 years)**	**Adult females (1-4 years)**	**Male calves (0-1 years)**	**Young males (1-4 years)**	**Adult males**	**Total number cattle traded**
1	0(0)	0.5 (0.9)	0.3 (0.9)	0 (0)	4.7 (3.1)	1.2 (1.9)	6.7 (3.2)
2	0(0)	0.6 (0.9)	0.4 (0.6)	0 (0)	1.7 (1.1)	2 (1.1)	4.7 (2.1)
3	0(0)	0 (0)	0.3 (0.6)	0 (0)	0 (0)	7.4 (4.1)	7.7 (4.2)
Total	0	1.1	1	0	6.4	10.6	19.1

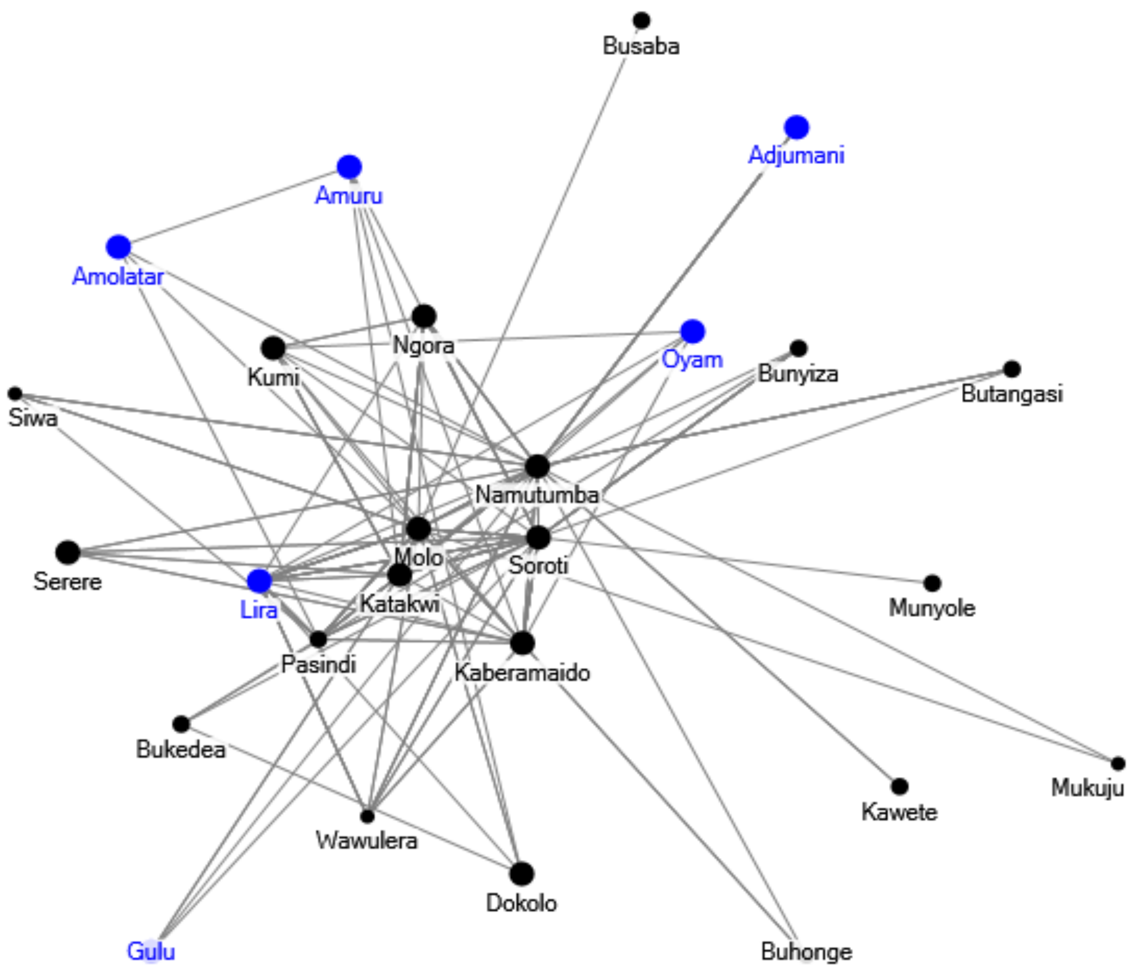


Legend: FC=female calves, YF=young females (heifers), AF=adult females, MC=male calves, YM=young males and AM=adult males

Figure 3-3 Type of cattle traded in each season

3.8.3 Network topology

The cattle trade network, as shown in Figure 3-4, was composed of a total number of 26 cattle markets, 325 dyads and 197 links; there were 37 unique and 160 duplicated links. The density and size of the network was 0.3 and 26 respectively. There was only one connected component in the network. By grouping the cattle markets using clusters and the Clauset-Newman-Moore algorithm the modularity of the network was 0.1. There were no isolated cattle markets in the network. Also, most of the cattle markets were weakly connected; with only a few being highly connected. The total degree of distribution was found to be highly skewed to the right. Table 3-3 summarises the results of the basic metrics. The elementary graphical indices showed that; density of the graph was 0.6; dyadic reciprocity, 1.7; edgewise reciprocity, 1.6; eigenvector of centralization, 0.3; and transitivity, was 0.4.



Legend: The black actors are livestock markets in south-east Uganda while the blue actors are from north-west Uganda.

Figure 3-4 Cattle trade network in northern and eastern Uganda

Table 3-3 Elementary metrics of the cattle trade network

Metrics	Maximum	Average	Minimum
a) Centrality indices			
1. Degree	19.0	5.9	1
2. Betweenness centrality	100.4	10.8	0
3. Closeness centrality	0	0	0
4. Eigenvector centrality	0	0	0
b) Clustering coefficient	1.0	0.5	0

The degree centrality score for each of the livestock markets is summarized in Table 3-4 and shown in Figure 3-5. With the highest centrality score of 110 (as shown in Table 3-4), Soroti had the highest number of links indicating that it had the highest movement of cattle in and out the district as shown in Figure 3-6. It was followed by Namutumba and Molo. Katakwi, Lira, Pasindi and Kaberamaido had a moderate flow of cattle in and out the district. Ngora, Wawulera, Kumi, Bunyiza, Serere, Siwa, Adjumani, Mukuju, Buhonge, Buhangasi, Dokolo and Amuru had a relatively low movement of cattle in and out of the district as shown in Figure 3-6.

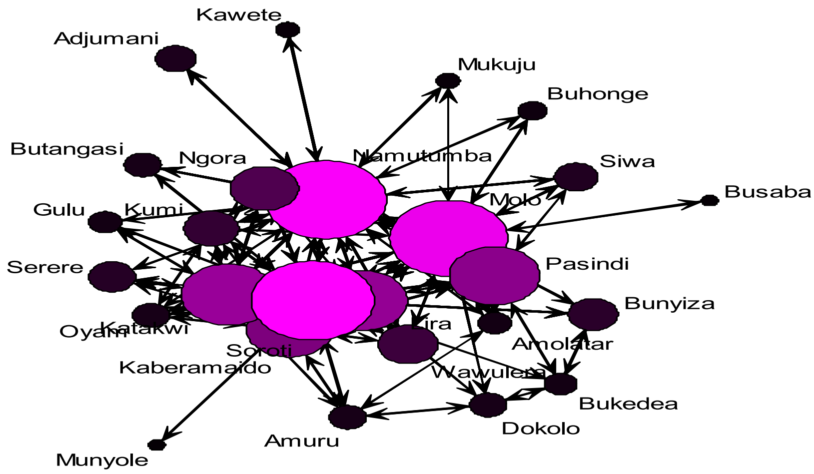


Figure 3-5 Plot of the centrality scores

NB: Size of the circle indicates the centrality score

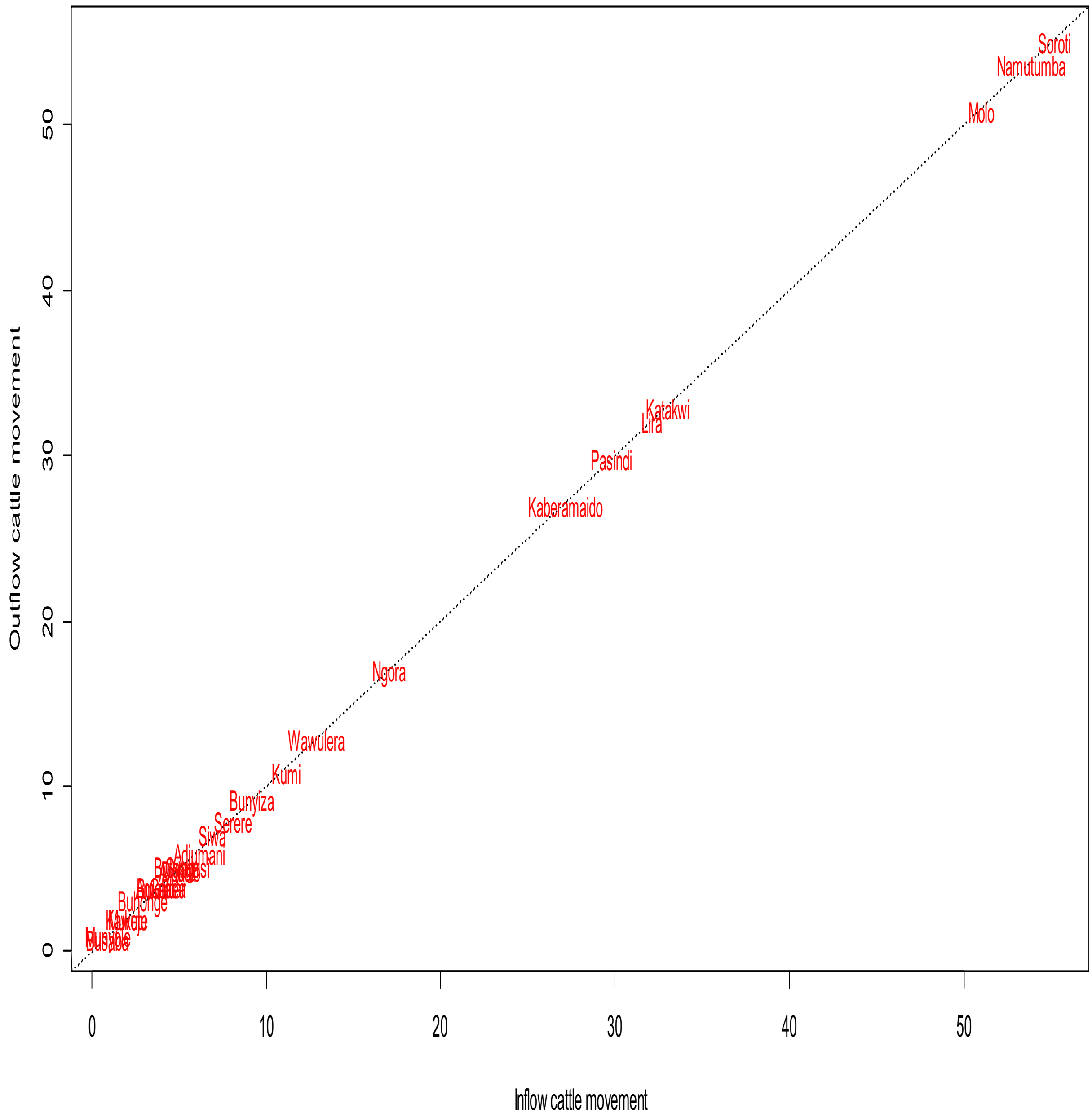


Figure 3-6: Flow of cattle within livestock markets in South-east and North-west districts of Uganda

The degree betweenness and closeness and the k-cores have been summarized in Table 3-4. Namutumba had the highest degree betweenness followed by Molo and Soroti respectively as shown Table 3-4. The degree closeness scores revealed that Namutumba had the highest degree of closeness followed by Soroti and Molo. The correlation between closeness and betweenness was found to be 0.8. The cattle markets with the highest k-core were Kaberamaido, Lira, Molo, Namutumba, Pasindi and Soroti as shown in Table 3-4. Plotting of k-core showed that there were several nesting cores. Because of the high number of nesting cores, nesting cores were limited to find out the main nesting cores by limiting the nesting membership to five as shown in Figure 3-7. Consequently it was found that members of the 5-core were Soroti, Molo, Katakwi, Kaberamaido, Lira, Wawulera, Pasindi, Namutumba, Oyam, Adjumani, Ngora, Serere and Siwa as shown in Figure 3-7. The cattle markets where spread of HAT was most likely to occur were Soroti, Namutumba and Molo as shown in Figure 3-8.

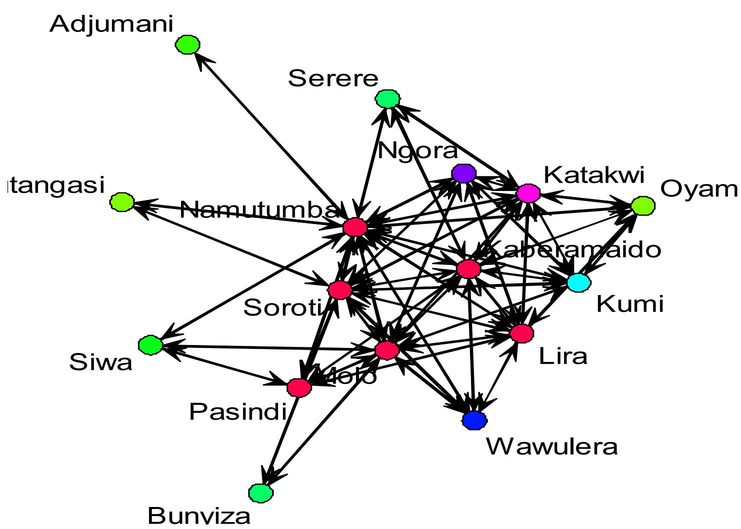


Figure 3-7 Diagram showing core cattle markets in the trade network

NB: The red circles represent the inner core markets, while blue, light blue and pink the intermediate and the green indicating the peripheral ones.

Table 3-4 Cattle trade network metrics for all the markets

Livestock market/District	Degree centrality	Betweenness centrality	Closeness centrality	K-cores
Adjumani	12	0	0.4	12
Amolatar	8	0.7	0.5	8
Amuru	10	1.1	0.4	8
Buhonge	6	0	0.4	6
Bukedea	8	0.5	0.4	8
Bunyiza	18	0.1	0.5	16
Busaba	2	0	0.4	2
Butangasi	10	0	0.5	10
Dokolo	10	1.5	0.4	8
Gulu	8	0	0.5	8
Kaberamaido	54	7.7	0.6	38
Katakwi	66	14	0.6	34
Kawete	4	0	0.4	4
Kumi	22	0.4	0.5	20
Lira	64	7.4	0.6	38
Molo	102	71.6	0.7	38
Mukuju	4	0	0.4	8
Munyole	2	0	0.4	2
Namutumba	108	101.4	0.8	38
Ngora	34	0	0.5	30
Oyam	10	0	0.5	10
Pasindi	60	8.7	0.5	38
Serere	16	0	0.5	16
Siwa	14	0	0.5	14
Soroti	110	67.2	0.7	38

Wawulera	26	0	0.5	26

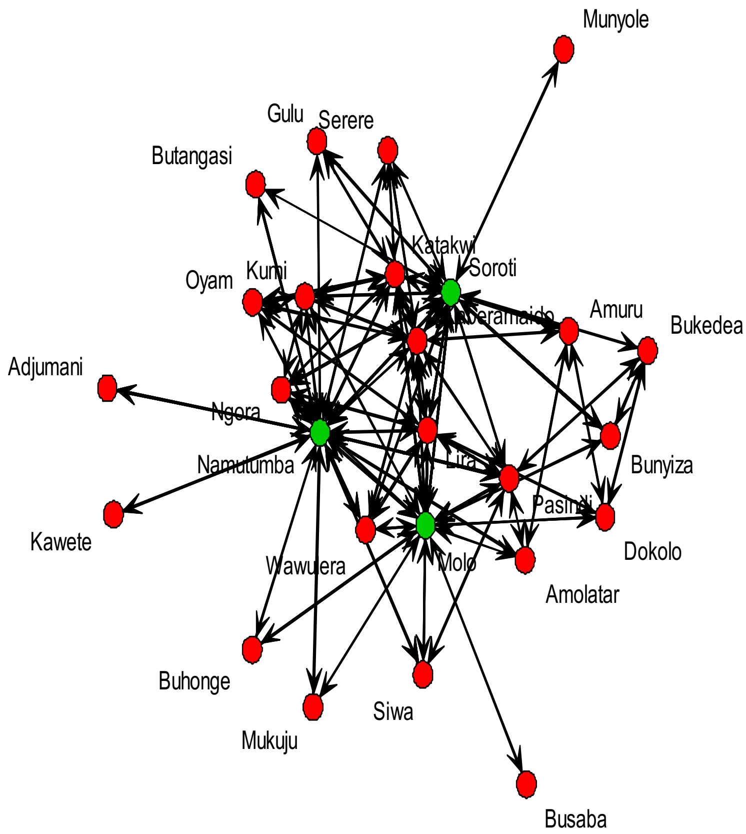


Figure 3-8 Cattle markets where spread of HAT is likely to occur

NB: The green circles indicate cattle markets where spread of HAT is most likely to occur in the network and the red ones are those that are not.

Actor partitioning using hierarchical clustering revealed that there were 4 clusters as shown in

Figure 3-9 Dendrogram of cattle markets according to their structural equivalence in the network

:

1. Adjumani, Amolatar, Amuru, Buhonge, Bukedea, Bunyiza, Busaba, Butangasi, Dokolo, Gulu, Kawete, Kumi, Mukuju, Munyole, Pasindi, Serere, Siwa and Wawulera.
2. Molo and Namutumba
3. Soroti
4. Kaberamaido, Katakwi, Ngora, Oyam, Kumi and Lira.

The hierarchical clustering was used to perform the structural equivalence block model. Network block modelling revealed that there was no single block that connected all others as shown in

Figure 3-10 and resulted in four blocks;

1. Adjumani, Amolatar, Amuru, Buhonge, Bukedea, Bunyiza, Busaba, Butangasi, Dokolo, Gulu, Kawete, Kumi, Lira, Mukuju, Munyole, Oyam, Pasindi, Serere, Siwa and Wawulera. These are shown as numbers 5 to 10 in

Figure 3-10.

2. Namutumba and Molo. These are shown as numbers 16 and 19 in

Figure 3-10.

3. Soroti. This is shown as numbers 25 in

Figure 3-10

4. Kaberamaido, Katakwi, Ngora, Kumi, Lira and Oyam. These are shown as numbers 14 to 12 in Figure 3-10.

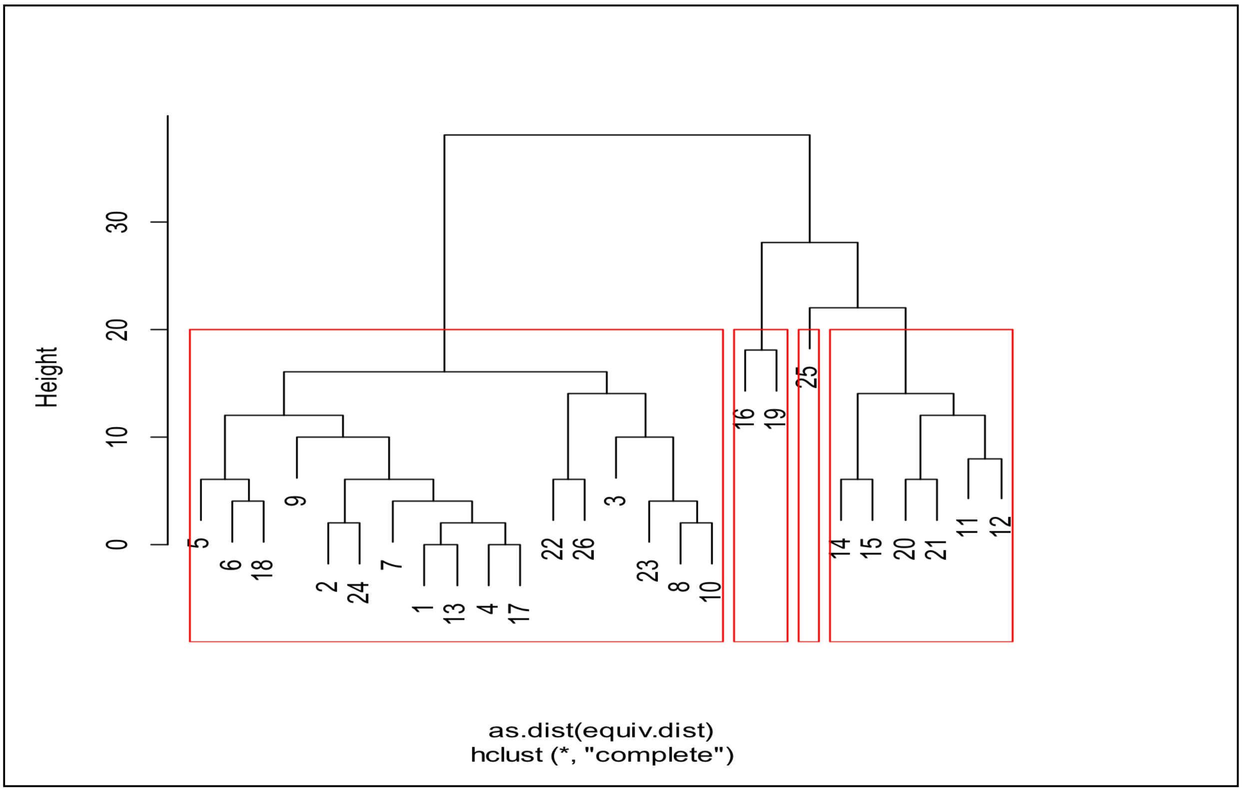


Figure 3-9 Dendrogram of cattle markets according to their structural equivalence in the network

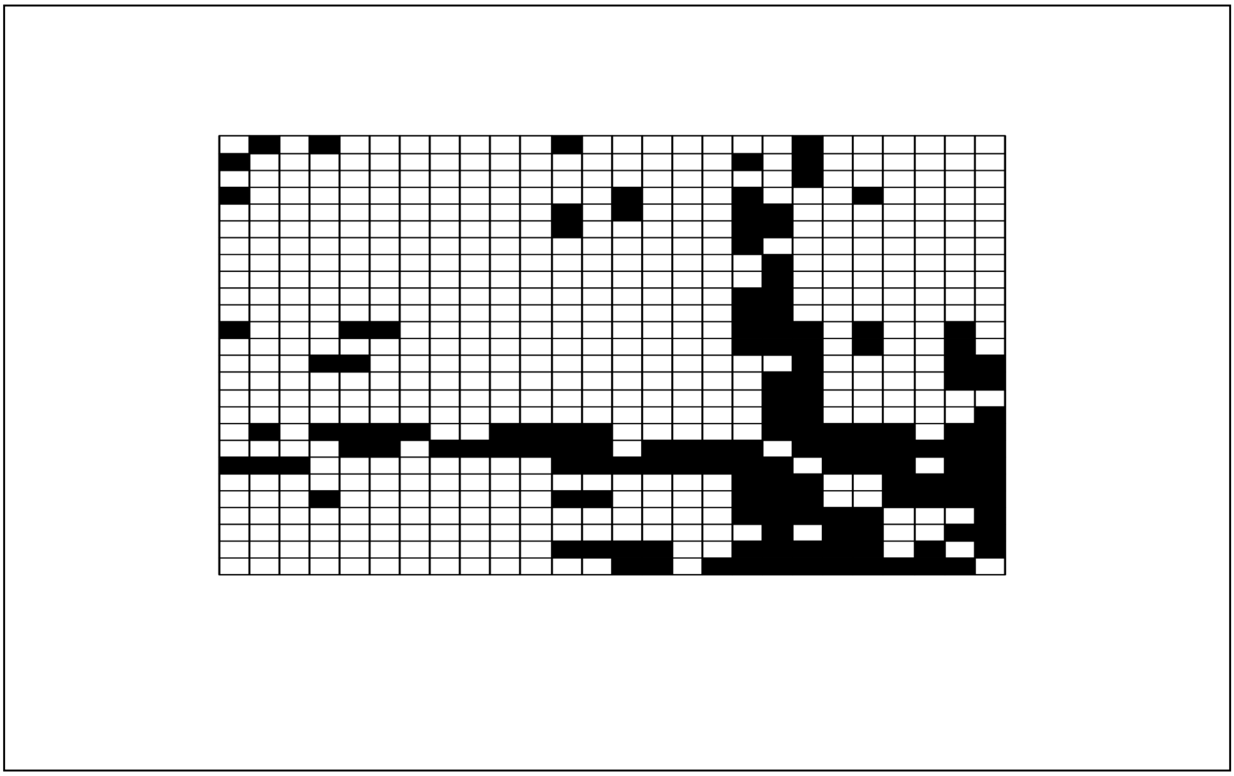


Figure 3-10 Block image of actors according to structural equivalence in the cattle trade network

NB; The white cells indicate absence of a link while the black cells show presence of a link

Extraction of link communities using a dendrogram, as shown in
Figure **3-11**, revealed that there were 5 communities in the network, as shown visually in Figure 3-12 and these were:

1. Amuru
2. Kaberamaido, Katakwi, Kumi, Lira, Molo, Namutumba, Ngora, Oyam, Pasindi, Soroti and Wawulera
3. Amolatar and Siwa
4. Serere and Gulu
5. Mukuju and Buhonge

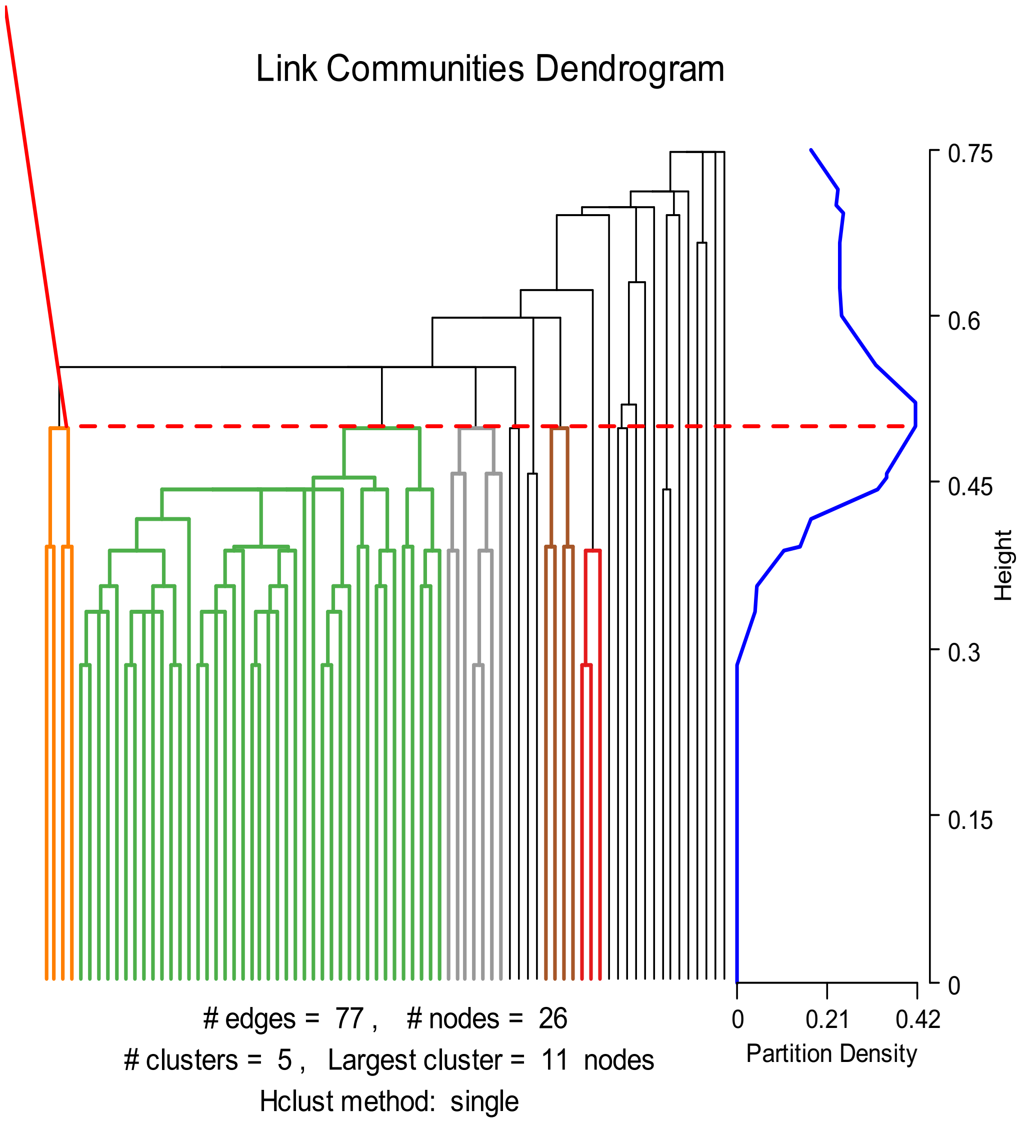


Figure 3-11 Output of extracting link communities from the cattle trade network

Also, using community membership matrix, it was found that the top connected markets were; Namutumba, Soroti, Kaberamaido, Katakwi, Molo, Amuru, Lira, Pasindi, Kumi and Ngora in that order as shown in Figure 3-143. Adjumani, Amolatar, Bukedea, Butangasi, Busaba, Bunyiza, Dokolo and Kawete livestock markets did not form part of any link community. Thus, livestock markets in south-east Uganda composed of 80% of the top connected actors in the cattle trade network. By limiting the actor community membership for the top connected actors to those actors belonging to three or more communities, Namutumba, Soroti, Kaberamaido, Katakwi and Molo emerged as the most connected markets.

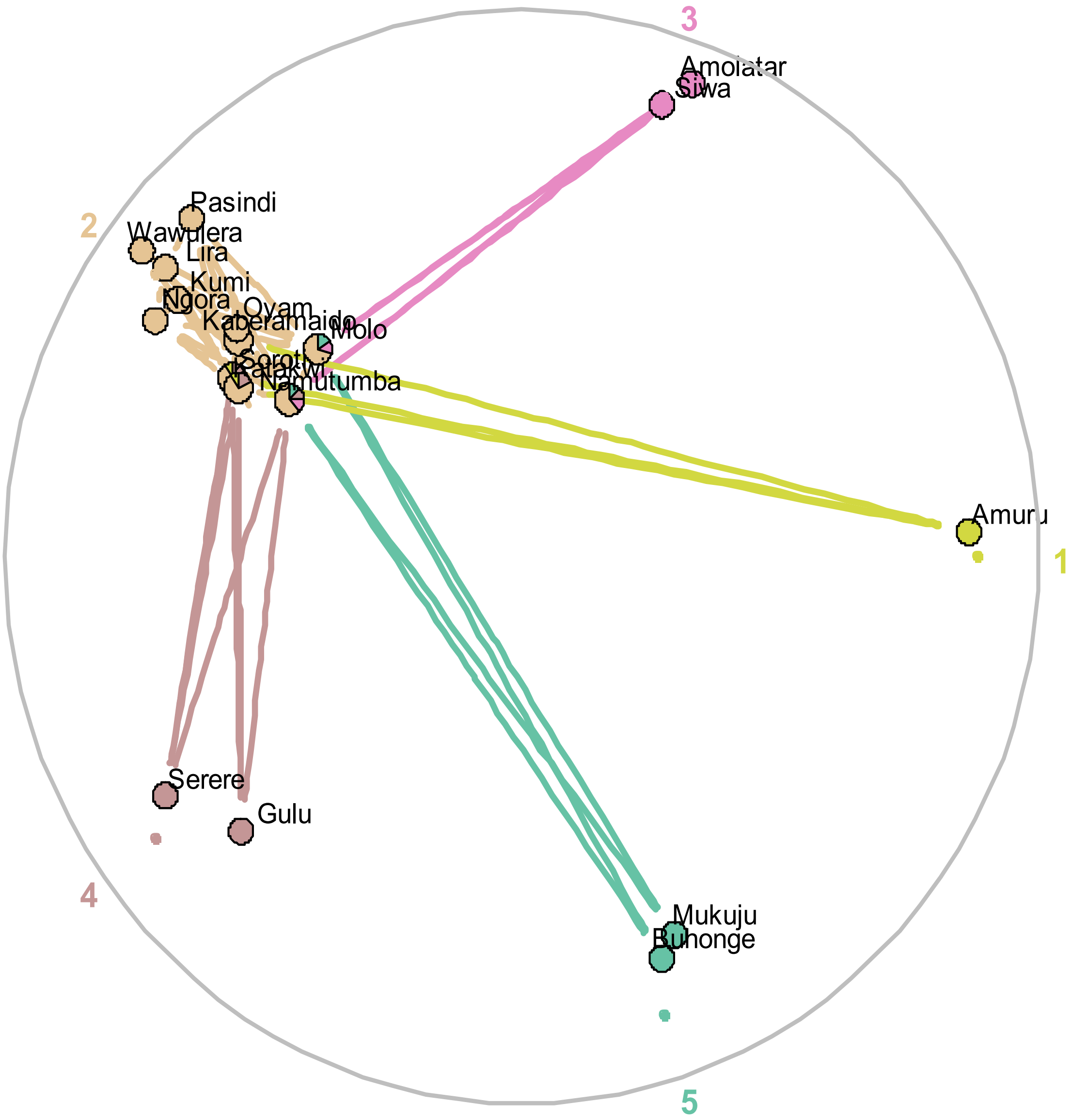


Figure 3-12 Visual display of the communities

NB; The pie-charts show the relative fraction of links a cattle market has in each community

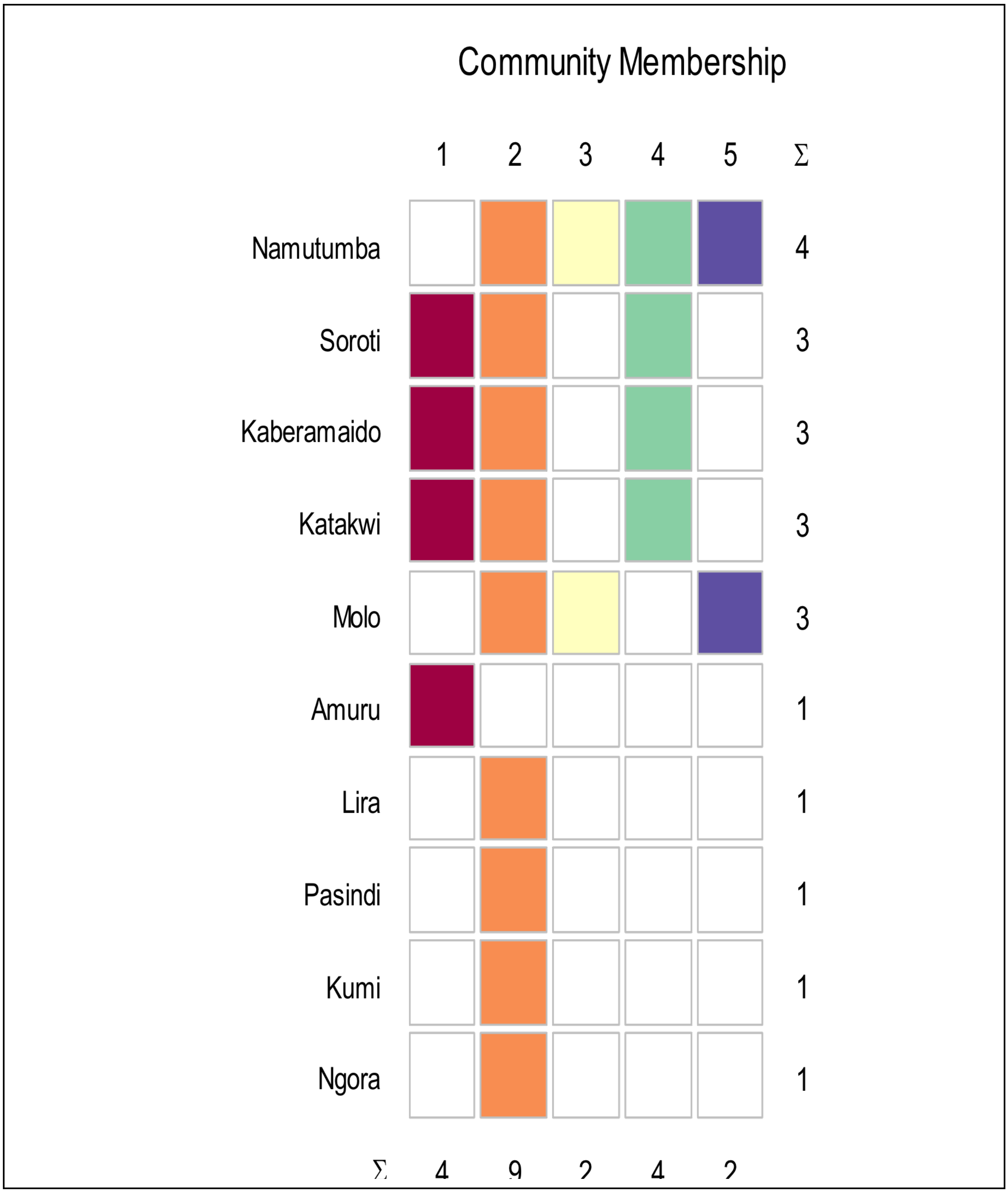


Figure 3-13 Community membership of the top connected markets

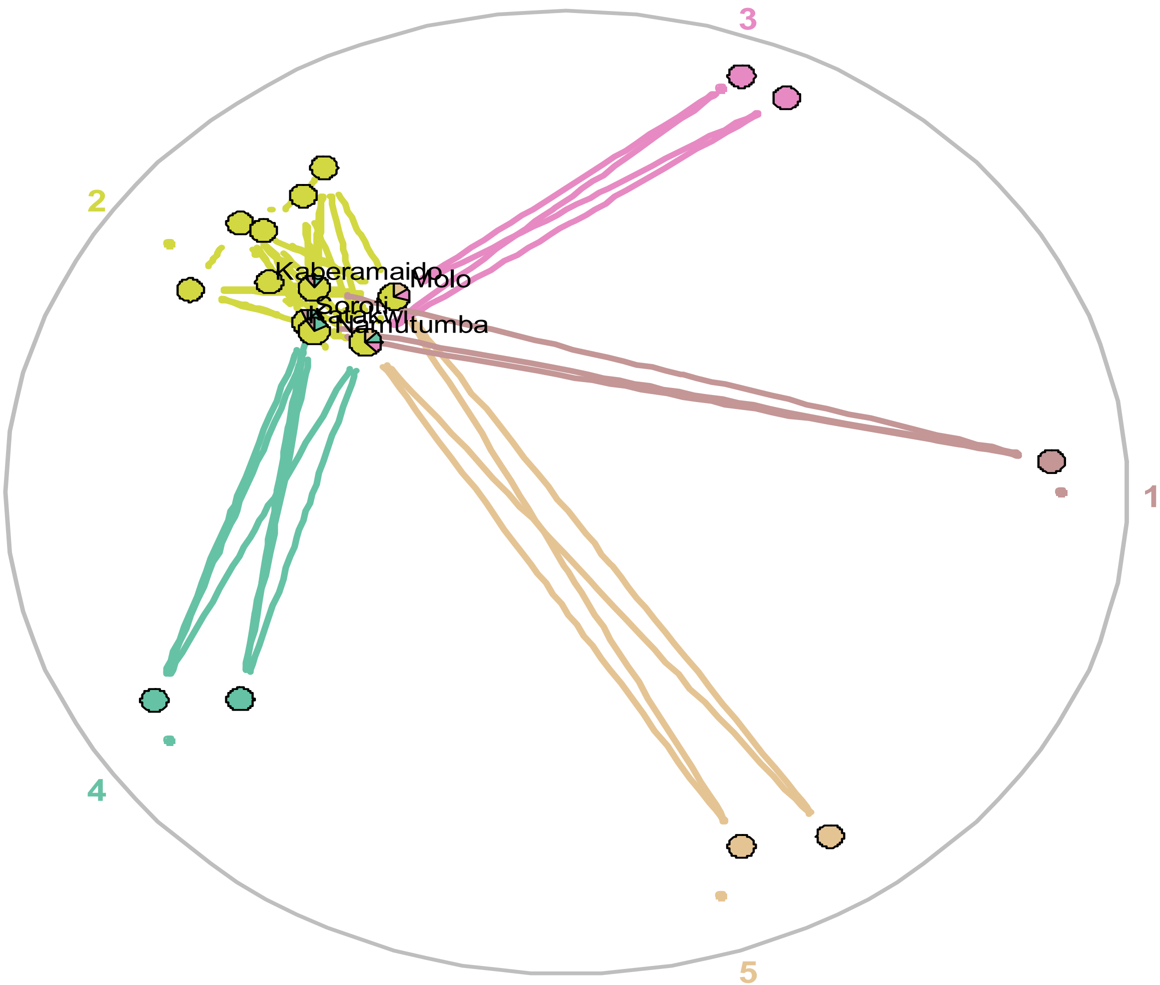


Figure 3-14 Visual display of top connected actors that connect to 3 or more communities.

NB: *The pie-charts show the relative fraction of links an actor has in each community*

Cattle markets can belong to multiple link communities; therefore it is possible to discover sets of markets that belong to a community that is entirely nested within a larger community of cattle markets. Analysis of the link communities revealed that there were no nested communities in the cattle trade network. Examination of the relationship between communities using Jaccard coefficient (based on the number of actors they share) revealed that there were two meta-communities. The first meta-community was composed of cattle markets in community three and five while the second one had markets in community one, two and four. Weighted community centrality using Jaccard coefficient for the cattle markets was as follows; Namutumba, 4.2; Molo, 3.3; Soroti, 3; Kaberamaido, 3; Katakwi, 3; Amuru,1; Lira, 1; Dokolo, 1; Pasindi. 1; Kumi, 1;Oyam, 1; Amolatar, 1; Serere 1; Gulu, 1; Buhonge, 1; Mukuju, 1; Siwa, 1 Bukedea, 0; Kawete, 0;Buhonge, 0; Adjumani, 0; Bunyiza, 0; and Butangasi, 0. Unweighted community membership results were as follows; Namutumba, 4; Molo, 3; Soroti, 3; and the rest was similar to the weighted community centrality. The community modularity of the 5 communities in the cattle trade work were as follows; community one, 0.3; community two, 1.5; community three, 0.4; community four, 0.3; and community 5, 0.5.

3.8.4 Sensitivity analysis

Sensitivity analysis to compare unweighted and undirected and weigheted and cattle trade network revealed that the are some differences depending on the of flow cattle. Differences were noted in the k-cores,cut-points, the top connected livestock markets and the elementary graphic metrics. The k-cores for each actor as twice as those of undirected network. However the significant difference was on cut-points; in the weighted and directed network, these were Katakwi, Lira and Also, the top connected actors in the directed network, as shown in the

Figure 3-155 were; Soroti, Molo Namutumba, Kaberamaido, Lira, Katakwi, Dokolo, Pasindi, Amolatar and Bunyiza.

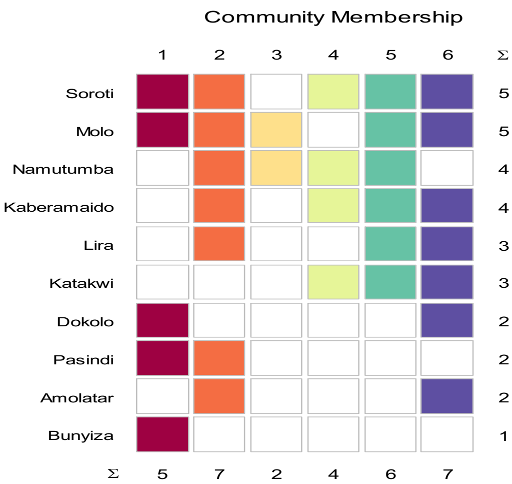


Figure 3-155 Top connected cattle markets in the directed and weighted network

Thus, Amuru, Kumi and Ngora which were among the top connected cattle markets in the undirected cattle network were not among the top connected cattle markets in the directed cattle network. Also, in the undirected cattle network, Namutumba was the top most connected actor as opposed to directed cattle network where Soroti and Molo were the top most connected actors. The elementary graphical indices of the directed and weighted cattle trade network were as follows; density of the graph, 0.3; dyadic reciprocity, 1.1; edgewise reciprocity, 1.2; and that the transitivity, was 0.3. However the eigenvector of centralization was the same as unweighted undirected network (0.3).

3.8.5 Other Findings

The herd structure where 37.1% of the total cattle herd were work oxen would require young draft cattle to be imported into the herd. However, a herd composition with less than 20% of the herd being male would relatively import very few young males. The number of respondents who stated that they mainly acquire cattle through livestock trade was 88.1%. Focus group discussions revealed that traders from mostly Lira district buy young males from south east Uganda and sell them to non-government organizations and other livestock farmers who train work oxen; they then buy back these animals after one and half years of 'training' them in draft work and sell them back to farmers in south east Uganda at a higher price. They typically bought one and half year old young males at USD 71.2 (95% CI: 54.7, 89.1) and sold them at USD 224 (95% CI: 182.7, 267.2) when they are three and half years, making a gain of USD 152.8, *ceteris paribus*. Untrained draft cattle at the same age would typically fetch USD 135.1 (95%C1: 109.2, 160.4) . Also it was found from the focus group discussions that there are typically two levels of cattle markets namely primary and secondary. The primary level cattle markets in Tororo district were; Siwa, Peta parima, Mairo seven, Pasinde, Munyole, Mukuju and Wawulera. Molo was the main secondary level cattle market in Tororo district. Also, Namutumba and Soroti cattle markets were the main secondary level cattle markets in Namutumba and Soroti districts respectively. Table 3-5 provides a summary of cattle prices by age/sex as obtained from focus group discussions.

Table 3-5 Typical mean price of cattle in the secondary livestock markets

Type of cattle by age/sex	Mean price bought from primary cattle markets (95% CI)	Mean price sold (95% CI)	Estimated gain (USD)
Calves	23.5 (18.2-28.5)	37.8 (36.1-39.5)	14.3
Young male untrained for draft work	71.2 (54.7-89.1)	135.1 (109.2-160.4)	63.9
Young male trained for draft work	143.7 (127-161.1)	224 (182.7-267.2)	80.3
Young female	48.6 (43.5,53.7)	108.1 (90.7-125)	59.5
Cow	162.1 (144.4-179)	207.7 (181.6-232.5)	45.6
Adult male	269.2 (252.7-286.8)	381 (275.8-495.2)	111.8

There were a total of nine animal health technicians selling drugs to livestock traders and farmers. They moved from one cattle market to other during market days generally on motorbike. Apart from selling livestock drugs, animal health technicians treated animals in the market. No spraying of cattle (with pesticides) took place in any of the markets we visited. The pestcides being sold sold in the cattle markets belonged to three groups namely; amidines, organophosphorus (chlorfenvinphos) and pyrethroids. The active ingredient in the amidine group of acarides was amitraz and these drugs included Milbitraz™, Norotraz™ and Amitix™ while the organophosphorus (chlorfenvinphos) group was composed of Supona™. The main active ingredients in pyrethroid group of drugs were cypermethrin, alpha-cypermethrin and deltamethrin. The cypermethrin sub-group of drugs were Tsetse-tick™, Cypermeth™ and Dipspray™; and Sypertix™ was the only alpha-cypermethrin being sold at the time of the study. Decatix™ was the only deltamethrin sold in the cattle markets. Table 3-6 summarises the types of drugs sold in the cattle markets including their active ingredient and average price and related 95% CI. It was also found that drugs used for controlling vector-borne diseases (trypanosomiaiss and tick-borne diseases) accounted for 62% of all the livestock drugs sold as shown in Figure 3-166.

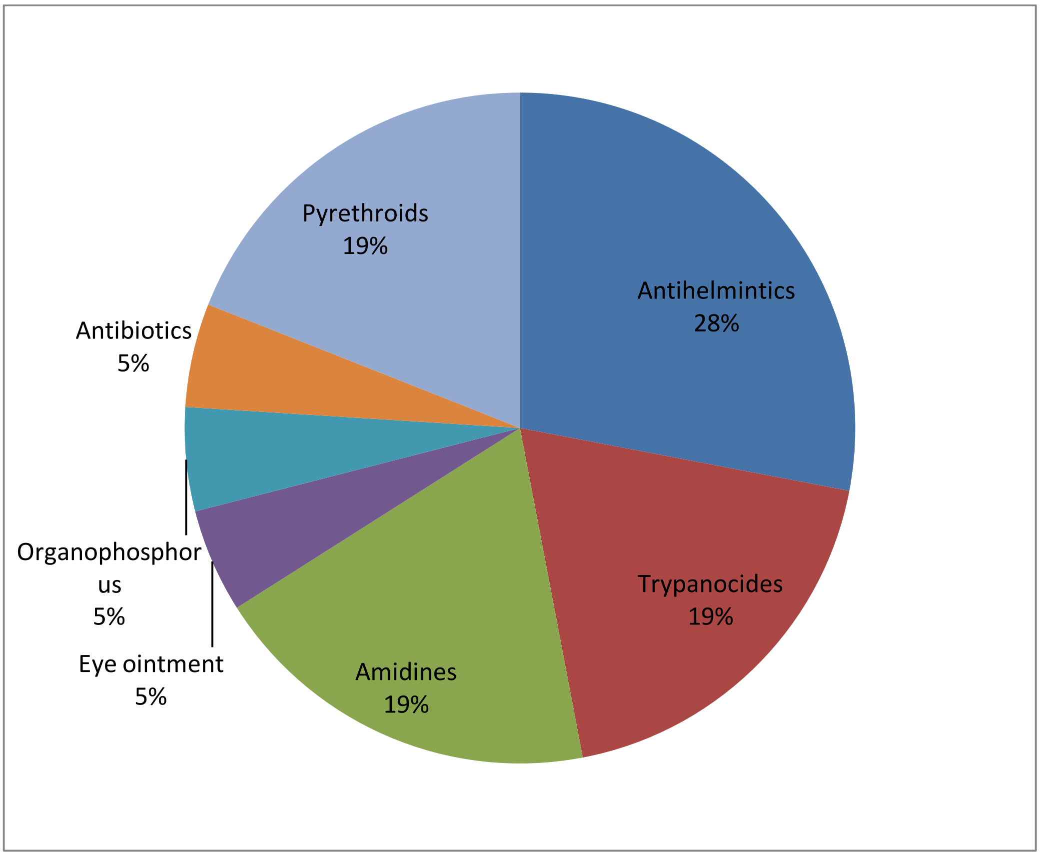


Figure 3-166 Market share of livestock drugs in livestock markets

According to information obtained through key informant interviews, drugs used for treatment of East Coast fever (parvaquones) were not available because they were expensive; 100 ml of parvaquone cost USD 13.6. Apart from selling drugs and treating cattle, animal health technicians also provided castration services. During the focus group discussions and key informant interviews, the animal health technicians indicated that the peak periods they sell their drugs are peak cattle market periods (season one and three) and during or after harvesting season. The semi-structured questionnaires revealed that there 30 (4.5%) repondents who indicated that they acquire their cattle through inheritance; 582 (88.1%) respondents through cattle markets; 69 (10.4%) respondents through buying from neighbors; 3 (0.4%) respondents through restocking programme; 3 (0.4%) respondents through exchange of goats for cattle; and 1 respondent through national Uganda social action fund programme.

Table 3-6 Livestock drugs sold in Namutumba and Tororo district markets

Type of drug	Drug	Active ingredient	Quantity	Mean price in USD with 95% CI
Trypanocides	Diminakel™	Diminazine aceturate (2.36g)	1 Sachet	0.6 (0.4,0.8)
	Veriben™	Diminazine aceturate (2.36g)	1 Sachet	1.2 (1.1,1.3)
	Novidium™	Homidium chloride (250mg)	1 tablet	0.2 (0.2,0.3)
	Samorin™	Isometamidium chloride (1g)	1 Sachet	1.4 (1.3,1.5)
Dewormers	Albendazole™ 2.5%	Albendazole	1 liter	5.4 (4.3,6.4)
	Albendazole ™10%	Albendazole	1 liter	8.3 (7.2,9.3)
	Alberfus™	Levamisole hydrochloride	1 liter	9.1 (8.3,9.9)
	Liverfus extra™	Levamisole hydrochloride	1 liter	13.5 (13,13.9)
	Liverfus ™	Levamisole hydrochloride	1 liter	8.6 (7.9,9.3)
	Wormicide™	Praziquantel (100mg)	100 ml	0.8 (0.7,1)
Antibiotic	Oxytet™	Oxytetracycline hydrochloride	100 ml	1.9 (1.4,2.4)
Acaricide	Milbitraz™	Amitraz	100 ml	2.6 (2.2,3)
	Norotraz™	Amitraz	100 ml	2.8 (2.5,3.1)
	Decatix™	Amitraz	100 ml	3 (2.3,4.7)
	Amitix™	Amitraz	100 ml	1.2 (1.2,1.3)
	Sypertix™	Alpha-cypermethrin	100 ml	3.5 (2.9,4.2)
	Tsetse-tick™	Cypermethrin	1 liter	32.5 (29.2,35.8)
	Cypermeth™	Cypermethrin	100 ml	4.8 (4.3,5.3)
	Dipspray™	Cypermethrin	100 ml	2.6 (2.1,3.1)
	Supona™	Chlorfenvinphos	250 ml	7.5 (6.5,8.5)
Eye ointment	Opticlox™	Cloxacillin	1 tube (5 g)	0.3 (0.2,0.4)

3.9 Discussion

The herd model revealed that the cattle herd size of cattle in south-east Uganda would decrease; since the growth rate was -2.3%. This is due to the high numbers of draught males and low numbers of female cattle; thus a low cow:adult male ratio. Draught males comprise 28.5% (considering only young draught males aged 3 to 4 years and adult draught males aged over 4 years) to 40% (including young males of an average age of 2.5 years being trained for draught) in south-east Uganda. The high oxen use in south-east Uganda leads to farmers replacing their draught males through purchasing. This is because the herd size and composition does not allow for sufficient regeneration of young males to replace the old draught males. Consequently, the reliance on cattle markets to replace draught male cattle lead to high movement of cattle within and between districts; posing a risk in the spread of HAT..

Cattle trade in south-east and northern Uganda can be summarised as having three patterns namely; short and high volume trade in young males; protracted and moderate volume trade in mixed types of cattle; and a short and high volume trade in adult males. The continual trade and movement of cattle in high volumes all year round has a potential epidemiological implication. This is because the risk of exposure of high volumes of cattle to tsetse flies during and after the rainy season is high; tsetse flies mostly emerge during and after rains when the ground is wet and the ambient temperature is right and the newly emerged tsetse flies (teneral flies) have to seek a bloodmeal (Welburn *et al*. 1992). It has also been established that the prevalence of *T. b. rhodesiense* is relatively high in cattle markets in south-east Uganda (Selby *et al*. 2013). Of equal epidemiological importance is the movement of young cattle from south-east Uganda northwards for 'training' in draught work and back. This is because on average the young males would spend around two and a half years in northern Uganda which is sufficient to spread sleeping sickness or any other disease if they were already infected in south-east Uganda; even though tsetse flies prefer larger cattle, it has been found that cattle age had a significant effect ($p<0.001$) on the likelihood of *T. brucei s.l* infection within cattle: cattle between 18-36 months (OR: 3.51, 95%CI: 1.63-7.51) and cattle over 36 months (OR: 4.20, 95%CI: 2.08-8.67) had significantly higher odds of *T. brucei s. l* infection than cattle under 18 months of age (von Wissmann *et al*. 2014). Therefore, although the volume of trade would be important in determining the risk factor of *rhodesiense* HAT spreading to north Uganda, the type of cattle being traded is of equal importance.

The inter-district cattle trade between south-east and northern Uganda is intensive and is potentially based on widespread use of cattle for draft work; the herd model revealed that there is need to bring in young males into the herd as the herd composition is mainly geared towards high work oxen use, which account for 37.1%of the herd. Furthermore, majority of farmers (88.1%) in Tororo acquire their cattle from HAT endemic districts (Namutumba and Soroti). Similar observations have been made in Madagascar where the cattle trade is based mostly on young males for draft work and sale of old draft cattle for slaughter; and that cattle trade was associated with spread of Rift Valley fever (Nicolas *et al*. 2013). Other studies found that there is a high oxen use in south east Uganda (Ocaido *et al*. 2005; Okello *et al*. 2015). A comparison of volumes traded in season one, which involves trade in mostly young males, and season three, which involves trade in adult male cattle, shows that volumes of adult male traded is slightly higher than that of young males. This difference is potentially due to high demand from a large pool of people; butchers, farmers and other traders; compared to season one where majority of buyers would be farmers and other traders.

The cattle network in this study can be categorised as connected and heterogenous; given most actors were weakly connected. The heterogeneity coupled with a low clustering coefficient, asymmetry and high skeweness found in this study are typical of scale-free networks (Barthelemy *et al*. 2004). The existence of two meta-communities is of epidemiological importance. Diseases are known to most likely spread more quickly in scale-free networks and existence of meta-communities or hubs within the network might further propagate spread of disease (Barthelemy *et al*. 2004). Studies done on poultry trade networks also showed that such networks are weakly connected and are scale free (Andriamanivo-Rasomoelina *et al*. 2014). Identification of Namutumba, Soroti and Molo livestock markets as the key markets that would spread diseases quickest was significant. If a disease was introduced thorugh these markets then it would spread quickly throught the entire network including the livestock markets in the north west of Uganda. This could be the case of diseases such as *rhodesiense* human Africa trypanosomiasis which is spread through cattle in Uganda. Also, in such instances, given the large number of cattle being traded all year round, the force of infection is bound to increase over time in north Uganda. Studies on the cattle markets have recommended treating cattle with a curative trypanocide in markets so as to clear them of the infection (Fèvre *et al*. 2001).The use of social network analysis is important in resilience management and determining which markets to prioritize given scarce resources in disease control, particularly for zoonoses.

It can be postulated that cattle markets that connect south-east and north-west Uganda would play a key role in the spread of diseases in future depending on the level of restoration of peace in north-west Uganda and south Sudan. It is expected that, following the postwar restocking programmes, farmers in northern Uganda will nevertheless continue demanding more cattle particularly draft cattle, which will typically come from south-east Uganda as they build their livelihoods after long periods of civil war that rocked Uganda. Thus there will be continuing flows of cattle in the districts between south-east and north-west Uganda leading to a stronger cattle network with potential nested communities.

Cattle marketing involved different layers of transaction. The first layer involved sourcing of cattle by small scale traders from household to household and sale of cattle by the farmers to the primary markets. The second layer involved mostly small and large scale traders; farmers did not have market information nor the negotiation capacities required for sale of cattle. Once the cattle traders acquired the animals, the majority of them moved the cattle on foot or on trucks for a long time from one market to the other and back depending on the season; and most traders and farmers would return back to villages with their unsold cattle; thus cattle movement was undirected. The undirected cattle movement and long periods of time traders had the animals before selling them would potentially expose the cattle to *rhodesiense* HAT. This meant that human and animal populations in areas where cattle were being sourced from would also be at risk of infection of HAT. Undirectional movement of cattle exposes a large group of animals and people to infection making disease control efforts difficult; and senstivity analysis revealed that the direction of cattle movement is an important factor in determining the key disease entry points in the cattle network.

The cattle network in this study was overhwelmingly dominated by the sale and movement of adult and young male cattle, which accounted for 89% of the animals sold by traders. Adult and young male were mostly traded due to a demand which was based on their biophysical characteristics and need for work oxen. Such charasteristics was not only important in terms of sale but risk management from the cattle trader point of view. This is because cattle traders are generally not concerned with the long term health of the cattle since they do not use them for production as opposed to farmers and would require animals that they do not have to invest in (healthcare wise). Given that *T. b. brucei* and *T. b. rhodesiense* do not generally affect the health of indigenous cattle, movement of large volumes of adult and young males would potentially increase the risk of creating a *rhodesiense* HAT foci in pathogen free areas. (Fèvre *et al*. 2006). Demand for certain types of cattle, attracts the presence of large scale traders, as they were not only found in the big livestock markets but also the in small markets. Large scale traders did not own all the cattle they brought to the market as they brought cattle from other cattle traders who could not make it to the market or were in other markets in and outside the district. Therefore the loose relationship between traders was significant in coordinating livestock movements and is an important factor in improving the strength of cattle trade as it increased the number of cattle brought to the market.

The study revealed that drugs to control tick-borne diseases (apart from *Theileria parva*/East Coast fever) and trypanosomiasis were available in the cattle markets; and that they each had an equal share of the market. In the neighboring district of Serere it was revealed that amidines and pyrethroids had an equal share of the livestock drug market (Bardosh *et al*. 2013). Lack of effective drugs to treat East Coast fever because of the associated high cost, leads to over reliance on cheap acaricides to control the disease. Unfortunately the cheap acaricides which are mostly amidines are not effective in controlling tsetse flies (Bardosh *et al*. 2013). Cattle traders are generally not concerned with the long term health of the animal but are strongly concerned with the immediate health of the cattle particularly the weight of the animal. It is therefore difficult for cattle traders to be incorporated in disease control programs as they do not themselves benefit from improved livestock productivity. Thus, large scale disease control would be better done at the farm level and in Namutumba, Molo and Soroti livestock markets (the main cut-off points in the cattle market). Also, the study revealed that although amidines are the cheaper than pyrethroids, the difference is not much but the perception of a lower price potentially played a big a role in marketing of livestock drugs. This study also revealed that treatment and prevention of disease was partially dependent on availability of money; and farmers would pay for treatment or prevention of diseases mostly during the harvesting season and gave draft cattle the priority on treatment as they brought in income compared to female cattle.

3.10 Conclusion

In this chapter the study set out to explore the linkages between herd dynamics, movement of cattle and a value chain processes of live cattle with the potential risk of spreading acute human African trypanosomiasis from the endemic south-east to northern Uganda districts. The herd model revealed that with the current herd composition, there is a greater demand for draft cattle in south-east Uganda since the number of cows and the fertility parameters are not sufficient to produce enough draft males to satisfy demand. Furthermore, in order to keep draft cattle numbers in the area constant, it is likely that gradually increasing numbers will need to be brought into the area over time. Also, demand for draft cattle is moderately high in northern Uganda. Consequently, there is movement of cattle back and forth between the two regions of Uganda with the old adult draft cattle and young males being the main cattle traded depending on the season. Demand for draft cattle and old male cattle for slaughter has led to moderately strong network of cattle markets with Kaberamaido, Katakwi, Molo and Soroti districts connecting most of the markets; thus acute HAT is most likely to be established in these districts. Although, Kaberamaido, Tororo and Soroti districts are known to harbor acute HAT, the study revealed that the disease could potentially be established in Katakwi district, more so if there is more cattle trade with South Sudan (Picozzi *et al*. 2005; Fèvre *et al*. 2005). Also, the study supported the policy of treating cattle with trypanocides in markets, particularly in the key markets where infection with acute HAT could spread from quickest. Hence this study contributed to a new approach of identifying key actors in the cattle market for purposes of prioritizing and reducing costs in disease control. The revelation that some of the young male cattle are brought from south-east Uganda and trained in northern Uganda regions for draft work (as part of value addition) and then sold back, indicates that this trade poses a constant risk of spread of acute HAT in northern regions over time.

3.11 Summary of key findings

(a) Demand for draft cattle a potential risk driver for spread of acute HAT

Given the close relationship between livestock market drivers and herd dynamics, a herd bio-economic simulation model was used to examine the herd dynamics in south-east Uganda in more detail. The study found that the herd composition of female:male cattle in this area was almost 1:1; 50.71% female and 49.29% male. The high number of males demonstrated the importance of draught animal traction to this part of the country, however the model also found that farmers were forced to import young male cattle at a rate of 1.96 per year in order to replenish adult draft cattle sold/died/sick, as the female population could not provide sufficient replacement young male cattle. Thus this study found the requirement for draft cattle through the importation of young male cattle and sale of adult males formed the main basis of the cattle trade network, through which acute HAT could spread within south-east Uganda districts and from south-east to northern Uganda.

Furthermore, the study found that there are three distinct cattle market seasons; January-April where young male cattle are mostly traded, May-August where both adult and young male cattle are traded and October-December, where adult male cattle are mostly traded. Value chain analysis revealed that some of the young males are bought from south-east Uganda and sold in northern Uganda for training in draft work, then sold back at a higher price in south-east Uganda, often at profits of up to 68%. This movement of young male cattle from acute HAT endemic regions in southeastern Uganda to the north poses a potential risk of disease spread.

(b) Commonly sold drugs in the cattle markets in south-east Uganda

Basic drugs for controlling trypanosomiasis and arthropod vectors are readily available in the cattle markets of southeastern Uganda, with drugs to control vector borne diseases (trypanosomiasis and tick-borne) composing 62% of the total drugs sold. The study found that the amidines and pyrethroids had an equal share of the market and this has also been observed by other authors (Bardosh *et al*. 2013). Also, the study found that amitix™ (amitraz) was half the cost of the cheapest pyrethroids (Dipsray™ - cypermethrin). The findings align with those from a previous study (Bardosh *et al* 2013) that proposed the availability of cheap acaricides could affect the control efforts against trypanosomiasis, given most farmers would prefer to buy cheaper drugs that impact the ticks they can plainly see on their cattle.

CHAPTER FOUR

4. ESTIMATING THE BURDEN OF *TAENIA SOLIUM* AND SOIL TRANSMITTED HELMINTHS IN NORTHERN LAO PDR

4.1 Introduction

Taenia solium cysticercosis and soil transmitted helminths (STH) are two of the seventeen neglected tropical diseases identified by the World Health Organization (WHO, 2010). The former is a major global public health concern, particularly in developing countries of Asia (Willingham and Engels D, 2006), sub-Saharan Africa (Preux *et al*. 2005) and Latin America (Bhattarai *et al*. 2012); however it has also been identified as a re-emerging issue in Europe (Gabriel *et al* 2015). Poverty, poor sanitation, lack of veterinary services, low-input animal production systems and cultural practices play a major role in the spread and maintenance of the disease (Okello *et al*. 2014: Bardosh *et al*. 2014). Human populations in the developed countries are also at risk of *T. solium* infections due to frequent travel or immigration to and from endemic countries (Schantz *et al*. 1992: Schantz *et al*. 2002). In humans the disease is caused by ingesting raw or undercooked pork infested with *cysticerci,* the larval form of *T. solium*, commonly known as pork tapeworm (Willingham and Engels D, 2006). In circumstances where people accidentally ingest the tapeworm eggs through infected feces, water or food which has been contaminated by infected fecal matter, then the larval stage may migrate to the brain causing a condition known as neurocyticercosis (NCC) (Ndumbazi *et al*. 2014). The neurological clinical manifestations of neurocysticercosis depend on the part of the brain infested by the larval stages; but seizures are the most common syndrome occurring in 66-90% of the cases (Capio and Hauser 2002; Garcia *et al*. 2003). Other symptoms include migraines, meningitis, blindness and hydrocephalus (Willingham and Engels D, 2006). It has been reported that neurocysticercosis is responsible for 20% to 50% of all late onset epilepsy globally (Rajkeshar *et al*. 2003; Willingham and Engels D, 2006). Apart from causing clinical manifestations, epilepsy can lead to social problems such as stigmatization and loss of work days (Praet *et al*. 2009). Epilepsy can effectively be treated using anti-epileptic drugs; however, access to such drugs, particularly in low income countries, which comprise more than 85% of the global burden, is poor hence there is a high treatment gap of more than 60% in such countries (Newton *et al*. 2012).

Soil transmitted helminths affect more than 2 billion people globally [Hotez *et al*. 2005). The most common STH are; hook worm (*Ancylostoma duodenale* and *Necator americanus*), round worm (*Ascaris lumbricoides*) and whip worm (*Trichuris trichiura*) (Booker *et al*. 2007). Populations infected with these diseases are at a risk of developing cognitive deficits (Bethony *et al*. 2012), iron deficiency anemia (in the case of hook worm) (Hotez *et al*. 2004), stunted growth and or physical unfitness particularly children in the case of roundworm (Crompton, 2001) and whip worms (Brundy, 1986).

4.2 Global Burden of *T. solium* and STH

A good understanding of the impact of prevalent diseases such as cysticercosis and STH on communities in resource-poor settings is important for Ministry of Health policy and planning. The most common approach for determining disease impact is through evaluating its burden in the human population (Murray *et al*. 1996). Burden of disease is a standardized conceptual framework for amalgamating available data on epidemiology, mortality and individual health status to envisage the level of health in a population and reasons of loss of health (Mathers, 2001). Thus, it can be used to quantify both the fatal and non-fatal effect of a disease or condition on the health of a population, as is done by the Global Burden of Disease and injury study (GBD) which develops comparable global estimates (commonly as DALY) of diseases and injuries affecting WHO member states (Murray *et al*. 1996). The consistency of the DALY calculation ultimately depends on the quality of the data collected (Devleesschauwer *et al*. 2014). Most data are extracted from field studies, literature reviews and expert opinions; such sources contain an innate level of uncertainty due to discrepancy in sampling, diagnostics or viewpoints among others (Devleesschauwer *et al*. 2013). To minimize such uncertainties, the resultant epidemiological parameters are mostly represented with their credibility or confidence interval, or as probability distribution as opposed to a distinct point estimate (Devleesschauwer *et al*. 2013). It has been recommended that a Monte Carlo simulation technique be used to include the stochastic nature in the DALY output; enabling appraisal of the level of uncertainty in the final DALY output and consequently better collation of health impact of different diseases or conditions (de Vocht *et al*., 2010).

Studies of the burden of *T. solium* at the regional or sub-district levels are limited; with only two studies done in Africa (Carabin *et al*. 2006; Praet *et al*. 2009), one in Latin America (Bhattarai *et al*. 2012), and no regional/sub-district studies in Asia. Similarly, whilst these studies have provided non-monetary and monetary estimates of *T. solium*, there are no estimates for Asia. In Mexico it was estimated that the DALY due to NCC and headaches was 23,020 (95% credible region (CR) 11,283-43,276) and 2,321 (95% CR 198-8758); with 0.25 DALY per 1,000 person years, of which 90% was estimated to be due to NCC. In central Africa it was estimated that NCC caused 9 (95%CR: 2.8-20.4) DALY per 1000 person-years and an overall monetary burden of cysticercosis of 10.3 million Euro, with 95.3% due to human cysticercosis and 4.7% porcine cysticercosis. A study on the monetary burden of cysticercosis was done in South Africa revealing that the total burden ranged from 18.6 to 34.2 million USD, with an estimated 73.1-85.4% of this overall burden due to treatment cost of human cysticercosis, and 14.6-26.9% representing cost of condemnation of pork infested with porcine cysticercosis (Carabin *et al*. 2006).

Similarly, there are limited studies at the regional or sub-district levels on the burden of STH. Worldwide, an estimated 819 million people (95% CI: 771.7 – 891.6) are infested with *A. lumbricoides*, 438.9 million people (95% CI 406.3 - 480.2) with hookworm and 464.6 million (95% CI 429.6 – 508.0) with *T. trichuris* (Pullan *et al* 2014). Also, of the 4.98 million YLDs attributable to STH, 65% were due to hookworm, 22% *to A. lumbricoides* and 13% to *T. trichiura,* with 67% of global STH infestations (68% global YLD) in Asia (Pullan *et al*. 2014).

4.3 Objectives of Chapter four

The main objective of this chapter was to:

- Evaluate the non-monetary and monetary burden of cysticercosis and STH in northern Lao PDR.

4.4 Materials and methods

4.4.1 Study area

The burden of disease analysis was conducted in 4 northern Lao provinces, namely, Phongsali, Luang Prabang, Huaphan and Oudomxay, with an estimated total population of 1,141,785 (Lao census, 2007). The population statistics at the time of research (2012-2014) was obtained from the 2005 Lao census, adjusted using the suggested inter-censal growth rate of 2.1% (Lao census, 2005). It is estimated that about 70% of the households in northern Lao PDR rear pigs, with the majority of these in low input, free range settings (Conlan *et al* 2008, Okello *et al*. 2015). Hygiene and sanitation levels are generally low, with research revealing that up to 83% of the population lack access to toilets in some areas (Bardosh *et al*. 2014), undoubtedly contributing to the polyparasitism endemic to this region (Ash *et al*. 2015; Conlan *et al*. 2008; Conlan *et al*. 2011, Surawinson *et al* 2011). Recent studies in Lao PDR revealed a hyper-endemic *T. solium* focus in one northern provincial village of almost 30% (Okello *et al* 2016), with a real possibility of other hyperendemic foci being present in other parts of the north where *T. solium* is endemic, particularly given the widespread existence of known risk factors such as the consumption of raw pork (Conlan *et al*. 2008; Conlan *et al*. 2011; Bardosh *et al*. 2014; Okello *et al*. 2016). Despite the high risk of neurocysticercosis (NCC), there is a dearth of diagnostic facilities offering tests such as computerized tomography (CT) and magnetic resonance imaging (MRI) in the country; adequate diagnosis and treatment of NCC is further hampered by the lack of trained neurologists in the country (Tran *et al*. 2008).

4.4.2 Epidemiological parameters for non-monetary cost estimation

A literature review was carried out to help determine the population, prevalence of epilepsy, proportion of NCC-attribute epilepsy, treatment gap and mortality due to NCC in Lao PDR. In instances where data were lacking, data from neighboring countries were used; the epidemiological data used to estimate DALYs, and their sources, are summarized in Table 4-1. The prevalence of epilepsy was estimated from the single study on epilepsy to date in Lao PDR, which estimated the prevalence to be 7.7 cases per thousand people (Tran *et al*. 2006). Currently, no information exists on the proportion of this attributable to NCC-associated epilepsy; therefore an attribution approach was used to estimate this from study data in Asia more generally, where it ranged from 0.2-50% of the epilepsy cases (Rajeshkhar *et al*. 2003). Data for the proportion of epilepsy patients seeking treatment (for determination of the treatment gap) was obtained from studies done in central Lao PDR (Odermatt *et al*. 2007; Tran *et al*. 2006), followed by a Monte Carlo simulation (R software v 3.2.0) and fitting distribution to the data to account for the fact that these studies were not done in the northern part of the country. Monte Carlo simulation is a computerized mathematical technique that allows uncertainty to be included in quantitative analysis. Mortality was determined from the Case Fatality Rate (CFR) of epilepsy in Lao PDR of 9-11% (Tran *et al*. 2008) , then secondly determining the CFR for the NCC cases as a product of CFR of epilepsy by proportion of epilepsy due to NCC (equation 5).

Data on STH prevalence in Lao PDR was obtained from survey data specific to the study area from 2005-2015. It was established that the prevalence of *A. lumbricoides* varied from 1.2-43%, hookworms 9-56% and Trichuriasis from 2.9-60.8% depending on the province under study (Conlan *et al*. 2012; Ash *et al*. 2014; Eom *et al*. 2014). Since data on the clinical sequelae of STH infestation was limited, it was assumed that sufferers experienced symptoms ranging from mild diarrhea or weight loss to severe cases such as wasting, abdomino-pelvic problems and severe anemia (hookworm only) and as a result, the disability weight (DW) used for the calculations also varied according to the severity. The DW was obtained from the WHO GBD 2004 as well as those used for global burden of STH study (Pullan *et al*. 2014). There is currently no specific data on mortality as a result of STH, therefore the global estimate of CFR of 0.08-0.0014% (Hotez *et al*. 2006) was multiplied by the prevalence to determine this (Equation 4 below). Table 4-1, Table 4-2, Table 4-3 and Table 4-4 provide a summary of all the parameters used in this study.

Table 4-1 Epidemiological parameters used for computation of the burden of NCC and STH

Parameter	Value or range of values	Distribution	Data source
Population	1,141,785	Fixed	Lao population census (2005)
Prevalence of epilepsy in Lao PDR	7.7 per 1,000	Fixed	Tran *et al*. 2006
Proportion of epilepsy due to NCC	0.25	Uniform (0.002-0.5)	Willingham *et al*. 2006; Rajkeshar *et al*. 2003
Prevalence of Hookworm pre-intervention (%)	0.46	Beta (0.45-0.47)	Conlan *et al*. 2012; Eom, 2014; Ash *et al*. 2015
Prevalence of *A. lumbricoides* pre-intervention (%)	0.12	Beta (0.12-0.13)	Conlan *et al*. 2012; Eom, 2014; Ash *et al*. 2015
Prevalence of *T. trichura* pre-intervention (%)	0.40	Beta (0.39-0.42)	Conlan *et al*. 2012; Ash *et al*. 2015
Case fatality ratio for NCC (%)	11	Beta (0.02-0.22)	Tran *et al*. 2006
Case fatality ratio for STHs	0.0014-0.08	Beta (0.000-0.001)	Hotez *et al*. 2006
Age of onset for age group 0-4 years	2	Fixed	UN, 2015
Age of onset for age group 5-14 years	9.5	Fixed	UN, 2015
Age of onset for age group 15-44 years	26.8	Fixed	UN, 2015
Age of onset for age group 45-59 years	50.7	Fixed	UN, 2015
Age of onset for age group over 60 years	69.4	Fixed	UN, 2015
Average duration for age group 0-4 years	1.4	Fixed	WHO,2004
Average duration for age group 5-14 years	2	Fixed	WHO,2004
Average duration for age group 15-44 years	3.6	Fixed	WHO,2004
Average duration for age group 45-59 years	2.8	Fixed	WHO,2004
Average duration for age group over 60 years	1.6	Fixed	WHO,2004

Table 4-2 Disability weights used for computing burden of *T. solium*

Parameter	Value	Distribution	Data source
Epilepsy disability weights for untreated people aged 0-4 years	0.420 (0.279-0.572)	Fixed	Salomon *et al*. 2012
Epilepsy disability weights for untreated people aged 5-14 years	0.420 (0.279-0.572)	Fixed	Salomon *et al*. 2012
Epilepsy disability weights for untreated people aged 15-44 years	0.420 (0.279-0.572)	Fixed	Salomon *et al*. 2012
Epilepsy disability weights for untreated people aged 45-59years	0.420 (0.279-0.572)	Fixed	Salomon *et al*. 2012
Epilepsy disability weights for untreated people aged over 60 years	0.420 (0.279-0.572)	Fixed	Salomon *et al*. 2012
Epilepsy disability weights for treated and seizure free people aged 0-4 years	0.072 (0.047-0.106)	Fixed	Salomon *et al*. 2012
Epilepsy disability weights for treated and seizure free people aged 5-14 years	0.072 (0.047-0.106)	Fixed	Salomon *et al*. 2012
Epilepsy disability weights for treated and seizure free people aged 15-44 years	0.072 (0.047-0.106)	Fixed	Salomon *et al*. 2012
Epilepsy disability weights for treated and seizure free people aged 45-59years	0.072 (0.047-0.106)	Fixed	Salomon *et al*. 2012
Epilepsy disability weights for treated and seizure free people aged over 60 years	0.072 (0.047-0.106)	Fixed	Salomon *et al*. 2012

Table 4-3 Disability weights used for computing burden of STH

Parameter	Value	Distribution	Data source

A. lumbricoides disability weights for untreated people aged for all ages	0.0296	Fixed	Pullan *et al*. 2012
T. trichura disability weights for untreated people for all ages	0.0296	Fixed	Pullan *et al*. 2012
Hookworm disability weights for untreated people for all ages	0.0041	Fixed	Pullan *et al*. 2012
A. lumbricoides disability weights for treated people aged for all ages	0.000	Fixed	UN GBD, 2004
T.trichura disability weights for treated people for all ages	0.000	Fixed	UN GBD, 2005
Hookworm disability weights for treated people for all ages	0.000	Fixed	UN GBD, 2006

Table 4-4 Average age of onset used for computation of the burden of NCC and STH

Age group	Average age at onset	Data source
All ages and sexes at 0-4 years	2	Bundy *et al*. 2004
All ages and sexes at 5-14 years	10	Bundy *et al*. 2004
All ages and sexes at 15-44 years	30	Bundy *et al*. 2004
All ages and sexes at 45-59 years	50	Bundy *et al*. 2004
All ages and sexes above 60 years	70	Bundy *et al*. 2004

The epidemiological parameters were calculated using R software v3.2.0 after coding in software Tinn for R (SourceForge version 5.1.1.0). The number of DALYs was calculated by adding the YLD and YLL as used by the GBD study (Murray *et al*. 1996):

$$YLL = N \times L$$

Where, YLL is the number of years lost due to mortality, N the number of deaths per year and L is the residual life expectancy as obtained from the Coale Demeny model life table West Level 26 and 25 (Coale *et al*. 1996).

$$YLD = I \times DW \times L$$

Where, YLD is the number of years lived with disability, I is the number of incident cases per year, DW is the disability weight and L is the average duration of disease until death or remission of the individual affected.

Thus DALY is calculated as:

$$DALY = YLL + YLD$$

For calculation of YLL, the observed life expectancies were compared to the Coale Demeny model life table West Level 26 and 25, which has a life expectancy of 80 for males and 82.5 for females (Coale *et al*.1996). The mortality rate due to NCC-associated epilepsy was estimated as the aforementioned product of the CFR of epilepsy in general in Lao PDR of 9-11% (Tran *et al*. 2006, 2008) and the estimated proportion of people with epilepsy (PWE) as a result of NCC. The formula for estimating mortality is shown in equation 5. The YLD was calculated by multiplying the number of years lived with disability (as extrapolated from the UN World Population Prospects 2012), by the GBD 2010 epilepsy disability weights (DW) (Salomon *et al*. 2012). Currently there are no NCC-specific DWs. The DALY obtained from this study - as in the case WHO GBD 2010 study - was incidence based, therefore the prevalence of epilepsy and STH was converted to incidence by multiplying it by the duration as shown in Equations 4 and 6 below:

$$I_n = Pn \times n / Dn \qquad (4)$$

$$M_n = Pn \times n \times Cn \qquad (5)$$

$$I_s = Ps \times Ds \qquad (6)$$

$$M_s = Ps \times Cs \quad (7)$$

Where, *In*= Incidence of NCC-associated epilepsy; *Pn* = Prevalence of NCC-associated epilepsy; n = Proportion of NCC-associated epilepsy cases; *Dn* = Duration of NCC-associated epilepsy; $_{Mn}$ = Mortality due to NCC-associated epilepsy; *Cn* = Case-fatality Rate of NCC-associated epilepsy; I_s= Incidence of STH; Ps = prevalence of STH; Ds = Duration of STH; M_s= Mortality due to STH; and Cs= Case-fatality Rate of STH.

4.4.3 Epidemiological and economic parameters for monetary cost estimation

Cost estimations of the monetary burden of NCC and STH, and losses from porcine cysticercosis, were assessed using a decision tree analysis adapted from Praet *et al* (2009) as shown in Figure 4-1. The monetary burden of NCC included the value of number of days persons with epilepsy are unable to work, which was estimated to be 267 based on data obtained from Praet *et al* (2009) and Krishnan *et al* (2004) and expenditure on treatment, where the most recent annual total cost of treating epilepsy in Lao PDR was USD 25.2 per person (Odermatt *et al*. 2007). The annual loss of income due to epilepsy was estimated from the Lao PDR minimum wage which is of USD 78.15 per person per month (ASEAN 2016). The monetary cost of STH was estimated from the overall percentage of the Lao PDR population seeking healthcare, which was 47.1% (Phomtavong *et al*. 2005) – given there is no current data on the health seeking behavior of STH patients more specifically in the country. The cost of antihelmintic drugs as purchased in the country was estimated to range from USD 0.03-1.00 (Phommasack *et al*. 2008; Okello, 2014).

The number of pigs in the study area was estimated at 35,200 (Lao Agricultural census, 2011). There is limited information regarding porcine cysticercosis in Lao PDR; one study reported that 1.7% of pigs slaughtered in northern Lao are cystic (Conlan *et al*. 2013) while another found that 2.15% of the pigs are condemned due to heavy infestation with cysticercosis and 1.67% condemned due to light infestation (Choudhury *et al*. 2013). This information was used to estimate the cost of porcine cysticercosis in the study area. Table 4-5 provides a summary of all the parameters used to estimate the monetary cost of *T. solium* and STH.

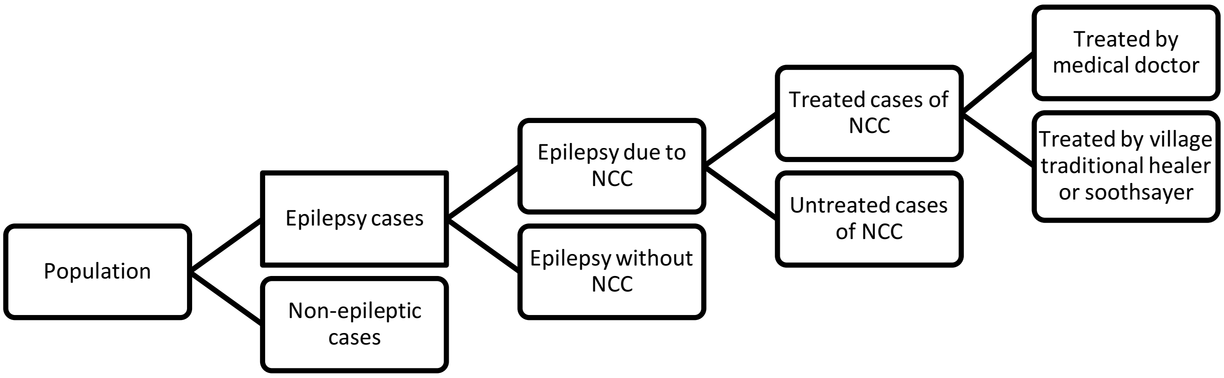


Figure 4-1 Decision tree for estimating the monetary burden of cysticercosis

Table 4-5 Parameters used to calculate monetary burden of cysticercosis and STH

Parameter	Value	Distribution	Data source
Annual cost of treating each case of epilepsy (USD)	25.2	Fixed	Odermatt *et al*. 2007
Loss of working time due to epilepsy per year (days)	267	Uniform (222-310)	Praet *et al*. 2009
Loss of productivity due to epilepsy (%)	25	fixed	Krishnan *et al*. 2004
Price of antihelmintic per tablet (USD)	0.5 (0.05-0.97)	Uniform (0.03-1)	Phommasack *et al*. 2008; Personal communication with Dr. Boulam
Estimated proportion of people with STH seeking treatment	0.47	Fixed	Phomtavong *et al*. 2005
Pig population	35,200	Fixed	Lao Agricultural census, 2011
Proportion of pigs condemned due to heavy cyst infestation	0.02	Fixed	Choudhury *et al*. 2013

Proportion of pigs condemned due to light cyst infestation	0.01	Fixed	Choudhury *et al*. 2013
Value of pork per kilo	3	Fixed	Field data

4.5 Results

An estimated 0.1% (2198/1141785) of the total population in these four provinces of northern Lao PDR is suffering from NCC-associated epilepsy. The total number of DALYs due to NCC-associated epilepsy was estimated to be 5,094 (95%CI: 25.6-28,940); with 446.4 (95%CI: 2.2-2536) DALY per 100,000 person years as shown in Table 4-6 and Figure 4-2. The DALYs attributed to YLL was 93.3%, with the remaining 6.6% due to YLD.

Table 4-6 Neurocysticercosis DALY Estimate

Type of DALY	Value	95% CI	% of DALY
YLL	4,780.0	23.1-28,090	93.3
YLD	314.4	0.4-2,114	6.7
Total DALY	5,094.4	25.6-28,940	100.0
DALY per 100,000 persons	446.4	2.2-2,536	-

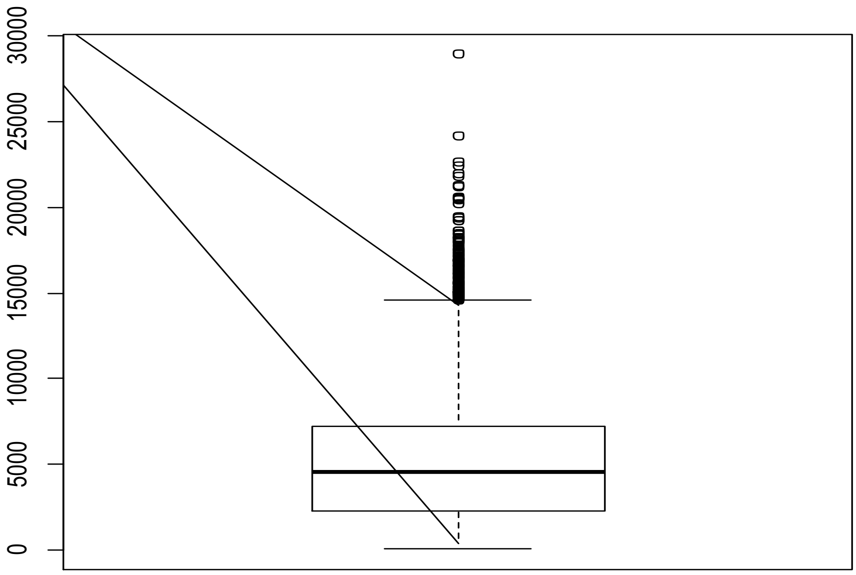


Figure 4-2 Box-plot of DALY due to NCC-associated epilepsy

It was estimated that the total DALY due to *A. lumbricoides* was 18,070 (95%CI: 8,670-25,473) with 1,583 DALY per 100,000 person-years. The YLL contributed 26% of the DALY total due to *A. lumbricoides* while the remaining 74% was the YLD. The DALY due to trichuriasis was 18,320 (95%CI: 8,975-26,080) with 1,605 DALY per 100,000 person years. The YLL contributed 22% of the total DALY due to trichuriasis while the remaining 78% was the YLD. The DALY due to hook worm was 5,094 (95%CI: 2,267-7,201) with 440 DALY per 100,000 person years. The YLL contributed 23% of the total DALY due to trichuriasis while the remaining 77% was the YLD.

The loss of productivity due to NCC-induced epilepsy was estimated at USD 4,283,073 and the cost of treating the disease USD 9,783; thus the total monetary cost of NCC was estimated to be USD 4,292,856. The value of condemned pork at slaughter due to heavy and light infestation with cysticercosis was estimated to be USD 80,256 and USD 20,064 respectively, resulting in a total loss of USD 100,320. The cost of antihelmintic treatment was USD 262,953. Subsequently the monetary cost of both cysticercosis and STH for the health sector was USD 4,555,809 and cost of the former to the agricultural sector was USD 100,320.

4.6 Discussion

This study is the first to estimate the burden and monetary cost of NCC in Lao PDR; and the first to estimate the dual burden of the co-existing parasitic diseases *T. solium* and STHs. Compared to similar studies on NCC burden undertaken in Cameroon and Mexico, the findings in this study reveal that the burden of NCC per person years was lower than in Cameroon, but higher than both Mexico and the 2004 Global Burden of disease estimates. The reasons for the higher numbers in Cameroon and Lao PDR could be that patients suffering from NCC-associated epilepsy in Mexico are more able/likely to receive treatment compared to those in Cameroon and Lao PDR.

In this study, the YLL composed 93.3% of the DALY estimate while the remaining 6.7% comprised of the YLD; similar to the case in Cameroon where the YLL constituted 85.1% and the YLD 14.9% of the total DALY (Praet *et al*. 2009). However in Mexico, the YLL and YLD comprised 28% and 72% of the total DALY respectively. This could partly be due to high mortalities caused by NCC-associated epilepsy; which was high in Cameroon (6.9%) and Lao PDR (11%) as opposed to Mexico where it was 1.5 per 100 000 (Praet *et al*. 2009; Tran *et al*. 2008; Bhattarai *et al*. 2012) . Globally, the 2010 WHO GBD study estimated the DALY per 100,000 from *T. solium* NCC and STH are 7(5-10) and 75(43-128), respectively (Murray *et al*. 2012). Consequently, the burden of cysticercosis and STH are relatively higher in Lao PDR compared to the global burden. Also, the finding that most of the monetary cost due to NCC-associated epilepsy is in the health sector is consistent with other studies (Carabin et. al 2006).

This study had some limitations, for example there are several disease outcomes from NCC-associated epilepsy such as headaches and vision loss which were not captured by this study. Therefore, the estimated total DALYs due to NCC-associated epilepsy described in this study could actually be under estimated. The monetary cost of *T.*

solium was very low as it was based on value of condemned pork; furthermore there were no pork screening processes in Lao PDR. Country or region explicit data on proportion of epilepsy attributed to NCC, treatment gap, STH mortality, healthcare expenditure and prevalence of porcine cysticercosis were also lacking, leading to reliance on information from the published literature, thus potentially either over or under-estimating the DALYs produced by this analysis.

4.7 Conclusion

This study provides the first NCC-associated epilepsy DALY estimate for the Asian region, focusing on northern Lao PDR. The monetary burden of NCC-associated epilepsy is high in the study area mostly due to cost of treatment and income lost due to inability to of NCC patients to work. Cost incurred by households in taking care of NCC-associated patients was not included in this study thus the monetary burden due to NCC could be much higher. Also, due to lack of meat inspection (thus pork condemnation) in the study area, the cost of *T. solium* in the agriculture sector could be higher. Given the high burden of (monetary and nom-monetary) of *T. solium* and STH it would be imperative to control both diseases as they tend to occur within the same foci in Lao PDR.

4.8 Summary of key findings

Monetary and non-monetary burden of T. solium and STH in northern Lao PDR

Assessment of the non-monetary burden of NCC due to epilepsy in northern Lao PDR was found to be higher than Latin America, but lower than findings from Africa. In northern Lao PDR, an estimated 5,094 (95% CI: 25.6-28,940) DALYs are lost annually due to NCC-associated epilepsy, with 446.4 (95% CI: 2.2-2,536) DALYs imposed per 100,000 person-years. In Mexico, it was estimated that a total of 25,341 (95% CR: 12,569–46,640) DALYs were approximated to be lost due to clinical presentation of NCC, with 0.25 (95% CR: 0.12–0.46) DALY lost per 1,000 person-years (equivalent to 25 DALYs lost per 100,000 person-years) of which 90% was attributed to NCC-associated epilepsy (Bhattarai *et al*. 2012). In West Africa, it was shown that the mean DALYs lost was 9.0 (95% CR 2.8–20.4) per 1,000 person-years (equivalent to 900 DALYs lost per 100,000 person-years) (Praet *et al*. 2009).

The non-monetary burden of STH in was found to be relatively low compared to sub-Saharan Africa and other regions of the world; except the *Ascaris lumbricoides* burden which was found to be higher in northern Lao PDR than the rest of the south-east Asia and sub-Saharan Africa. In northern Lao PDR, it was found that the mean DALYs lost due to *A. lumbricoides* was 38 (95% CR: 2.1–54.4) per 100,000 person-years. Other authors have estimated the burden of *A. lumbricoides* to be equivalent to 31-34 DALY per 100,000 person-years in south-east Asia and 29 DALY per 100,000 person-years in sub-Saharan Africa (Pullan *et al*. 2014). The hookworm burden in northern Lao PDR was found to be 53 DALY per 100,000 person-years compared to 114 and 210 DALY per 100,000 person-years in sub-Saharan Africa and the Pacific region respectively (Pullan *et al*. 2014). Also, it was found that the burden of trichuriasis was 51 DALY per 100,000 person-years compared to 49 and 77 DALY per 100,000 in the rest of south-east Asia and sub-Saharan Africa respectively (Pullan *et al*. 2014).

The current annual monetary burden of *T. solium* in northern Lao PDR was found to be USD 4,292,856 and USD 100,320 to the human health and agricultural sectors, respectively, thus a total cost of USD 4,393,176. Other studies in Africa have estimated the monetary impact of *T. solium* to be Euros 10,225,202 in West Cameroon and USD 18.6-34.2 million in South Africa to the agriculture sector (Praet *et al*. 2009; Carabin *et al*. 2006). The low monetary cost of *T. solium* in northern Lao PDR was due to lack of meat inspection; thus the cost of *T. solium* to the agriculture sector would likely to much higher. The study estimated the monetary burden of STH to be USD 262,952 in northern Lao PDR.

CHAPTER FIVE

5. A COST-EFFECTIVENESS ANALYSIS FOR THE INTEGRATED CONTROL OF *TAENIA SOLIUM,* SOIL TRANSMITTED HELMINTHS AND CLASSICAL SWINE FEVER

5.1 Introduction

Taenia solium taeniasis-cysticercosis is a zoonotic neglected tropical disease found throughout many parts of Asia, Africa and Latin America where pigs and humans co-exist in areas of poor sanitation and hygiene (Lightowlers, 2013). Consequently, there is growing requirement for advocacy for this disease and this is dependent upon the provision of the evidence of burden and demonstration that control is cost-effective (Okello *et al*. 2016). Therefore advocacy and improved policy dialogue can only come with improved methodologies for evaluation of the costs – and more importantly demonstrate the cost-effectiveness – of control interventions. Following this, there is a broad consensus that economic analysis of zoonoses should be based on the total societal benefits as compared to the total costs of controlling disease in humans and in animal reservoirs (Zinsstag *et al*. 2007).

The World Health Organization (WHO) has a declared objective of up scaling control and elimination of *T. solium* by 2020. It is one of the six diseases that have been identified as potentially eradicable by the International Task Force for Disease Eradication (Willingham and Angel, 2006). It recommends the following: effective control or elimination of *T. solium* on a national scale, inclusion of multifaceted control strategy in mass or target approaches, consideration of economic factors, better knowledge of the global burden of cysticercosis and assessment of the impact mass drug treatment on co-endemic parasitic diseases such as STH (Willingham and Angel, 2006).

To date, whilst models have suggested that a combined therapeutic approach in both pig and human hosts will result in the greatest sustained impact on parasite levels (Kyvssgaard *et al*. 2011), few research interventions have explored this concept in practice (Okello *et al*. 2016; Garcia *et al.* 2016). This chapter examines the economic aspects of a recently undertaken successful intervention in northern Lao PDR that treated both pigs and humans, resulting in a significant ($p < 0.0001$) *T. solium* reduction of 77.4% over a sixteen month period (Okello *et al*. 2015a). The holistic One Health intervention aimed to add value in both the human and pig interventions through simultaneously assessing collateral human health and pig production elements. For the human intervention, two rounds of human mass drug administration with albendazole 400 mg over three consecutive days resulted in the successful decrease of both *T. solium* and soil transmitted helminths (Ash *et al* 2015). In the pigs, vaccination against classical swine fever (CSF), an important porcine production-limiting disease in Southeast Asia (Blacksell *et al*. 2005) was built into the *T. solium* control package which included the anti-cysticercosis TSOL18 vaccine (Lightowlers, 2013) and oxfendazole at 30mg/kg (Pondja *et al*. 2012); the latter of which has also been shown to have a positive impact on gastrointestinal pig parasites (Okello *et al*. 2015a); thus improving pig growth rates and overall productivity.

5.1.1 Study Objectives

The aim of this study was to quantify the cost and benefits of the intervention, considering the various benefits to human and animal health alongside the monetary and non-monetary costs to project stakeholders (donors and beneficiaries) in order to determine the overall cost-effectiveness of integrated *T. solium* control in a smallholder setting in Southeast Asia. It is hoped this methodology and findings will help drive similar cost analyses for *T. solium* and other neglected tropical disease interventions, whilst simultaneously encouraging the consideration and inclusion of collateral benefits into control of other diseases under a true One Health approach.

5.1.2 Study area

The study was conducted in a Tai Dam village in Mai district, Phongsaly province in the northern region of Lao PDR (see Figure 1-3). The village consisted of 55 households and is mainly inhabited by the Tai Dam; one of the minority ethnic group (Bardosh *et al*. 2014). The Tai Dam are mostly found in northern Lao, Vietnam, Thailand and China (Bardosh *et al*. 2014). The Tai are mostly plain and valley dwellers and wet-rice growers compared to the rest of other linguistic groups in Lao PDR who practise swidden (slash and burn) cultivation and have strong beliefs in animal sacrifices, mostly using pigs, chickens and buffalo during ceremonies and festivities (Kashinaga *et al*. 2009). According to the Tai Dam, most of the ceremonies are done for house and village spirits, other spirits, New Year (e.g Pi May), during mourning, etc. (Kashinaga *et al*. 2009).

5.1.3 Data collection

A list of all the households was first developed. Afterwards, a semi-structured questionnaire was used to determine household characteristics, pig productivity and human health parameters (including reporting on epilepsy) in 49/55 (89.1%) of village households (refer to Appendix). The initial baseline survey, conducted in October 2013, included a 12 month recall to gather livestock productivity data regarding pig production. During the subsequent 16 month intervention described in detail by Okello *et al*. (2016), economic monitoring occurred via six monthly updates on changes in the village pig population (births, deaths, sales, purchases etc), human health parameters, and response to both the human and pig interventions which were concurrently undertaken.

5.2 Methodology for the Economic Evaluation of Intervention Costs and Benefits

Control and elimination of zoonotic diseases requires robust information on their effect on both human and livestock in order to enable policy formulation and allocation of resources. The study aimed to first evaluate the cost-effectiveness of controlling *T. solium* in both humans and pigs and soil transmitted helminths in people; secondly to allocate the costs of control between the health and animal sectors. Evaluating the cost-effectiveness of zoonotic disease control entails assessment of costs incurred by the society and the subsequent benefits attained. In this study, the total societal benefits of the intervention were estimated by determining the costs and benefits of disease control in both the human and animal sectors before and after the intervention. The conceptual framework used in this study was that zoonotic diseases affect both human and animals and their control generates benefits at a cost in a society (refer to Figure 1-1).

The societal view, where all resources were captured irrespective of who incurred them, was used for computation of the costs. This is unlike financial analysis where only private costs are assessed (Itty, 1997). The costs comprised of monetary and time expenditures borne by village inhabitants (private costs) as a result of symptoms or disease associated with *T. solium* or soil transmitted helminths - for example the costs of health seeking treatment (transport to and payment for health service) or drugs, - as determined by the questionnaire. The costs also include those incurred by the small holder farmers due to pig rearing which was subsequently captured using gross margin analysis as described later in the text. The project staff were consulted to generate a list of two cost centers, namely human and pig intervention, to which the costs incurred by project (public costs) were allocated using a micro-costing approach (Edejer *et al*. 2003). Using this method, costs were either allocated or aggregated to enable their analysis as a constituent of the overall project cost without double counting. Capital depreciation, as an overhead cost, was estimated for the cars using straight line method (Reynolds, 1961) and aggregated among the cost centers. The human intervention cost center included cost of albendazole tablets and the aggregated overhead costs such as capital depreciation and logistical costs. The pig intervention included the cost of oxfendazole, TSOL18 and CSF vaccine as well as aggregated overhead costs. The societal view was considered in assessment of the benefits of joint control of *T. solium* and STH. The benefits were divided into human non-monetary and monetary and pig monetary benefits.

5.2.1 Calculating the total benefit to humans

Disability adjusted life years (DALY) represent the non-monetary parameter of human disease burden, calculated through combining the years of life lost due to premature death (YLL) and years lived with disability (YLD) (Murray, 1994). The epidemiological parameters used for the incidence DALY calculations of NCC and STH (Schroder, 2012), were obtained using a combination of field data from individual interviews and secondary literature sources (as shown in Table 5-1), inputted into R software (version 3.2.2) . Given the accuracy of DALY estimates rely heavily on the information obtained for its computation, data attained from secondary sources were analysed using Monte Carlo simulation, and data fitted data to a distribution >citation (package = "fitdistrplus") (Delignette-Muller and Dutang, 2015), allowing for inclusion of the uncertainty in the DALY estimate within a given confidence level, as described by (Devleesschauwer *et al*. 2013). Attribution approach was used to estimate the incidence of NCC because the study did not confirm the epilepsy cases (Devleesschauwer *et al*. 2014). Initially, a door-to-door survey (Preux *et al*. 2005) was carried out to determine the number of epilepsy cases and then the prevalence was converted to incidence by multiplying it by the duration of the illness (Devleesschauwer *et al*. 2013). The proportion of epilepsy due to NCC was estimated using secondary data. The prevalence of the STH within the study site which had already been conducted in a separate study (Ash *et al*. 2015), was used together with other prevalence data collected in other provinces in northern Lao PDR; and these were then converted to incidence levels (Devleesschauwer *et al*. 2013). Table 5-1, Table 4-2 and Table 4-3 provide a summary of all epidemiological parameters that were used to estimate the non-monetary burden of *T. solium* and STH in a wider population (northern Lao PDR).

5.2.2 Calculating the total benefit to livestock

The animal arm of zoonotic disease burden in this case is represented by pig livestock production losses, incorporating the costs of livestock death and the effects of morbidity (for example lowered fecundity, weight loss leading to reduced sale price or carcass condemnation). Losses to the pig production enterprise were determined via a 'livestock production' segment of the questionnaire which evaluated the numbers of pigs bought, sold, died and born per household over the given time period.

Table 5-1 Epidemiological parameters used for computation of the burden of NCC and STH

Parameter	Value	Distribution	Data source
Population	1,141, 785	Fixed	Lao population census (2005)

Prevalence of epilepsy	8 per 1,000	Fixed	Study data
Proportion of epilepsy due to NCC	0.25	Uniform (0.002-0.5)	Willingham *et al*. 2006; Rajkeshar *et al*. 2003
Prevalence of Hookworm pre-intervention (%)	0.46	Beta (0.45-0.47)	Conlan *et al*. 2012; Eom, 2014; Ash *et al*. 2015
Prevalence of *A. lumbricoides* pre-intervention (%)	0.12	Beta (0.12-0.13)	Conlan *et al*. 2012; Eom, 2014; Ash *et al*. 2015
Prevalence of *T. trichura* pre-intervention (%)	0.40	Beta (0.39-0.42)	Conlan *et al*. 2012; Ash *et al*. 2015
Case fatality ratio for NCC (%)	11	Beta (0.02-0.22)	Tran *et al*. 2006
Case fatality ratio for STH	0.0014-0.08	Beta (0.000-0.001)	Hotez *et al*. 2006
Age of onset for age group 0-4 years	2	Fixed	UN, 2015
Age of onset for age group 5-14 years	9.5	Fixed	UN, 2015
Age of onset for age group 15-44 years	26.8	Fixed	UN, 2015
Age of onset for age group 45-59 years	50.7	Fixed	UN, 2015
Age of onset for age group over 60 years	69.4	Fixed	UN, 2015
Average duration for age group 0-4 years	1.4	Fixed	WHO,2004
Average duration for age group 5-14 years	2	Fixed	WHO,2004
Average duration for age group 15-44 years	3.6	Fixed	WHO,2004
Average duration for age group 45-59 years	2.8	Fixed	WHO,2004
Average duration for age group over 60 years	1.6	Fixed	WHO,2004

The second element contributing to the gross margin analysis was an evaluation of the expenditure on animal health, in terms of both time and money, borne by both livestock keepers (private expenditure) and the project (public expenditure); expressed as a component of the variable costs (see equation 8).The gross margin analysis was then calculated to determine the change in household income pre and post intervention (expressed as the net benefit) according to the standard formula:

$$\boldsymbol{Gross\ margin = [livestock\ ouput] - [variable\ cost]} \qquad (8)$$

Where, livestock output = [(animals and produce 'out') – (animals and produce 'in')] + change in herd value. The change in herd value is expressed as [closing valuation (the total number of pigs at the end of the year multiplied by their value) - opening valuation (the total number of pigs at the beginning of the year multiplied by their value)]. Variable costs include the costs of pig rearing incurred by the farmer plus any expenses of project participation (for example repair of pig pens). The value of condemned pigs was also calculated.

5.2.3 Extrapolation of findings to the broader northern Lao PDR

The total human population in the four Lao provinces was 1,141,785; comprising 572,211 females and 569,574 males as shown in Table 5-2 (Lao 2005 census). The age cohorts used in this study were ages; 0-4, 5-14, 15-44, 45-59, and over 60 years old.

Table 5-2 Human Population in Northern Lao PDR

Age (in years)	**Sex**	
	Female	**Male**
0 to 4	71,194	71,766
5 to 14	150,213	154,355
15 to 44	261,812	258,017
45 to 59	54,544	53,540
over 60	34,448	31,896
Total	572, 211	569,574

The number of pig rearing households rearing, total number of pigs in each province and the average number of pigs per household in each of the four provinces is shown in Table 5-3 (Lao agricultural census, 2011*)*. Computation of the gross margin per household entailed adjusting the income from the pig enterprise depending on the mean number of pigs per province; since gross margin is highly dependent on the herd size.

Table 5-3 Pig population in Northern Lao PDR

Province	Number of pig rearing households	Number of pigs	Average number of pigs per household
Huaphanh	28,900	98,800	3.4
Luang Prabang	26,900	113,100	4.2
Oudomxay	26,100	71,200	2.7
Phongsaly	22,800	68,100	3.3
Total	104,700	351,200	-

5.2.4 Analysing the total societal benefit of the intervention in relation to its total cost

The overall capacity of a public health intervention to prevent unwanted human health outcomes (such as mortality and prolonged morbidity as a result of disease presence) is indicated by the number of DALYs averted (Mathers, 2002). In this case, the total cost-effectiveness of the control programme, in relation to the total costs and benefits accrued in both the human and pig arms of the intervention, were initially arranged to obtain a figure expressed as a 'net benefit' defined as the total societal benefits obtained less the costs accrued for controlling the disease in both people and animals (equation 9). This net benefit figure was subsequently rearranged to obtain a net cost per DALY averted (equation 10); a measure of intervention cost-effectiveness.

$$N_b = D_a + E_s + L_b - P_c \quad (9)$$

$$N_c = (P_c - E_s - L_b)/D_a \quad (10)$$

Where N_b is the net benefit; D_a is the DALY averted, E_s the expenditure saved on human health (in USD), L_b is the livestock production benefit (in USD), P_c is the project cost (in USD) and N_c is the net cost per DALY averted.

The study used the cost-effectiveness thresholds launched by the 2003 World Health Report, which considered interventions with an incremental cost per DALY averted of less than three times a country's GDP per capita 'cost-effective' and less than one times GDP per capita as 'very cost-effective' (WHO, 2003; in Lao PDR the GDP per capita was USD 1,793 (World Bank, 2014). The old World Health Organization's cost-effectiveness threshold of USD 25 per DALY averted for 'very cost-effective' was also used (WHO, 2003).

5.2.5 Applying the separable cost approach

In addition, a separable cost approach (Gittinger, 1984; Roth *et al*. 2003) was used to determine the percentage share of the intervention cost accruing to the health and livestock sectors respectively. This method primarily focuses on monetary benefits, assessing project costs and monetary benefits in order that future intervention costs can be allocated according to the expected monetary benefits accrued by each sector as a result of disease freedom or control. In order to determine this, the monetary benefit-cost ratio is obtained (equation 11), ensuring a 1:1 ratio for each sector, followed by the percentage share of cost (equations 12 and 13).

$$M_{bcr} = L_b + E_s/P_c \qquad (11)$$

$$H_s = 100 \times E_s/T_b \qquad (12)$$

$$L_s = 100 \times L_b/T_b \qquad (13)$$

Where $_{\mathrm{Mbcr}}$ is the monetary benefit-cost ratio, L_b is the livestock production benefit (in USD, E_s the expenditure saved on human health (in USD), the health sector, P_c is the project cost (in USD), $_{\mathrm{Hs}}$ is the Health sector, $_{\mathrm{Tb}}$ is the total benefit (calculated as $D_a + E_s + L_b$) and L_s the livestock sector.

5.3 Results

5.3.1 Descriptive socioeconomic characteristics

There were a total of 55 households making up a population of 593 people in the village. A total of 49 households (89.1%) were interviewed; six households had travelled to Vietnam hence were not included in the study. Out of the 49 households, 41 (83.4%) did not have toilets and 8 (16.3%) had toilets. When asked about sources of income: rice was mentioned by 48/49 (98%) respondents; livestock rearing by 42/49 (86%) respondents, both rice and livestock rearing by 42 (86%) respondents, both rice and hunting by 2 (4%) respondents and other sources by 6 (12%) respondents. Also, the study revealed that there were 97 buffalo, 583 chickens, 135 ducks and 48 dogs in the village as shown in Figure 5-1.

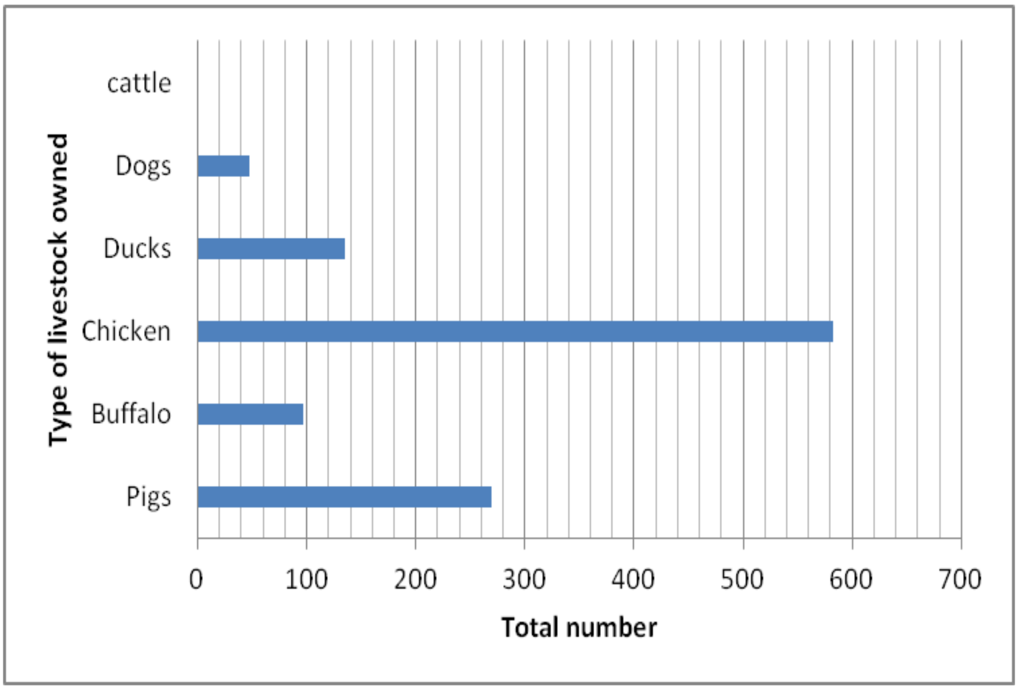


Figure 5-1 Livestock owned by farmers in Om Phalong village

At baseline there were a total of 270 pigs of which there were 28 (10%) boars; 64 (24%) sows; 53 (20%) weaners; 32 (12%) growers; 93 (34%) piglets as shown in Figure 5-2. Thus, the mean number of pigs per household pre-intervention was 5.2 (SD 4.9). By post intervention, pig numbers had increased by 53%, to a total of 414 pigs of which 27 (7%) were boars; 74 (18%) were sows; 34 (8%) were weaners; 182 (44%) were growers, a substantially higher proportion than before; and 97 (23%) were piglets in the village as shown in **Error! Reference source not found.**2, hence the mean number of pigs per household was 8.4 (SD, 6.1). Baseline pre-weaning mortality was 48.3% (185/386); post intervention this figure had dropped to 37/440 (8.4%). According to information obtained from key informant interviews, all pigs were left to roam freely, with the larger animals penned during the rice harvesting season. Also, key informant interviews revealed that the average weight of pigs was 22.9 kilograms (kg) and the price of pork per kg was USD 3.

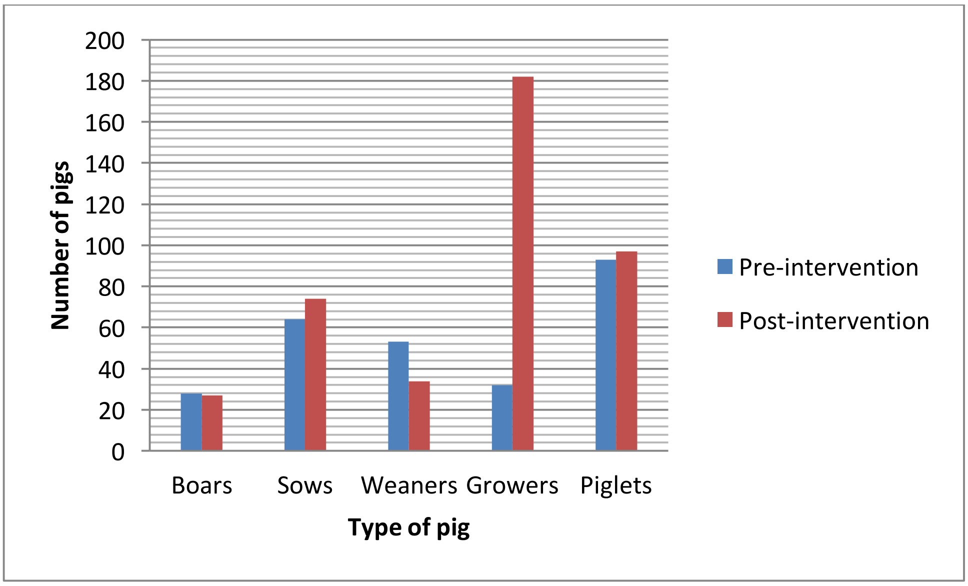


Figure 5-2 Number of pigs in the village before and after the intervention

5.3.2 Project costs for the combined human and pig intervention

(i) Overhead costs (fixed and recurring) incurred by the project

As during the first two rounds of control, in October 2013 and March 2014, the human and pig interventions were undertaken simultaneously the project expenditures for these rounds were combined, with the final administration (October 2014) treated as a single activity. The expenditures have been summarized in Table 5-4; the only capital cost was for vehicle depreciation, while the recurrent costs included drugs, vaccines, vehicle running and staff costs. The total capital and recurrent expenditure for the human intervention cost center was USD 5,291 and the pig vaccination cost center, USD 20,535. The pig cost center was further divided into namely; TSOL18 vaccination, deworming and CSF vaccination. The cost for each pig cost center is as shown in Table 5-4.

(ii) Direct financial costs incurred by the project

The human intervention consisted of two rounds of mass drug administration with an albendazole 400 mg triple dose protocol, previously described by Ash *et al* (2015) and one monitoring exercise. The direct financial costs incurred by the project for this activity were the cost of albendazole tablets (1,048 tablets each at 1 United States dollar) and the total number of human participants was 375 (Ash *et al*. 2015; Okello *et al*. 2016). The pig intervention consisted of a pig 'package' consisting of vaccination with CSF and TSOL18, plus administration of oxfendazole at 30 mg/kg, as described by Okello *et al* (2016). The pig intervention was administered three times (two pig vaccinations and one monitoring exercise) over the sixteen month intervention period, with direct financial costs including the cost of CSF vaccine and oxfendazole. The CSF vaccine was bought in bulk from the government veterinary laboratory based in Vientiane at total cost of USD 100 (833 doses at USD 1.2 per 10 doses); the total number of pig vaccinated for CSF 828 during the one year of the intervention. Although in this case the TSOL18 vaccine was donated, it has been included in this analysis at the expected wholesale costs (0.50 USD/dose) once it is registered on the commercial market in 2016 (Lightowlers, 2015). The results of the cost centers have been summarised in Table 5-44.

Table 5-4 Total public (project) costs of the human-pig intervention

Cost item	Human intervention (USD)	Pig intervention (USD)			Total amount (USD)	Break-down of total costs%
	MDA	TSOL18	Deworming	CSF		
a) Capital expenditures						
Vehicle depreciation	250	250	250	250	1,000	3.8
b) Recurrent expenditures						0
Field Staff remuneration during both human and pig treatment	1,378	1,378	1,378	1,378	5,512	21
Field Staff remuneration during pig treatment only	0	3,674	3,674	3,674	11,022	41.5
Field Staff remuneration during monitoring	148	148	148	148	592	2.2
Local facilitation fees	75	75	75	75	300	1.1
Total cost of MDA	1,048	0	0	0	1,048	3.9
Cost of CSF vaccine	0	0	0	100	100	0.3
Cost of TSOL18 vaccine	0	810	0	0	810	3.1
Cost of oxfendazole dewormer for pigs		0	366	0	366	1.4
Hiring of additional vehicle	315	315	315	315	1,260	4.8
Total fuel used	500	500	500	500	2,000	7.5
Questionnaire development, pre-testing and printing	38	38	38	38	152	0.6
Labouratory diagnostics	1,464	0	0	0	1,464	5.5
Miscellaneous	225	225	225	225	900	3.3
Total amount in USD	5,441	7,413	6,969	6,703	26,526	-

The cost of each activity (human MDA, pig vaccination with TSOL18, pig vaccination with CSF and pig deworming) was estimated using the figures obtained from the total human and pig population, number of visits and total cost of each activity as shown in Table 5-5. Based on these, the total cost of MDA per person was found to be USD 14 (computed as USD 5,441 divided by the total number of participants which was 375); and the total cost incurred during MDA and monitoring was per person per visit USD 5 (computed as USD 15 divided by 3). The total cost of vaccinating each pig per year using TSOL18 vaccine was USD 9 (computed as USD 7,413 divided by 828 pigs as they were vaccinated twice a year); and the total cost incurred per pig per visit during TSOL18 vaccination and monitoring was USD 3 (computed as USD 9 divided by 3). The total cost of deworming each pig was USD 8 (computed as USD 6,969 divided by 828 pigs) year); and the total cost incurred per pig per visit during deworming of pigs and monitoring was USD 3 (computed as USD 8 divided 3). The total cost of vaccinating pigs against CSF was USD 8 (computed as USD 6,703 divided by 828); and the total cost incurred per pig per visit during CSF vaccination was USD 3 (computed as USD 8 divided by 3), the specific visits related to CSF vaccination and monitoring). Table 5-6 summarises the total costs incurred for human and pig intervention as an activity.

Table 5-5 Parameters used to calculate total cost of each activity

Parameter	Value
Total number of participants	375
Total number of pigs	414
Total number of visits for pig vaccination	2
Total number of visits for MDA	2
Total number of monitoring visits	1
Total cost of MDA (in USD)	5,441
Total cost of pig deworming (in USD)	6,969
Total cost of pig vaccination with TSOL18 (in USD)	7,413
Total cost of pig vaccination with CSF (in USD)	6,703

Table 5-6 Total cost for each activity

Activity	Total cost	
	Per year (in USD)	**Per visit (in USD)**
MDA per person	14	5
TSOL vaccination per pig	9	3
Oxfendazole deworming per pig	8	3
CSF vaccination per pig	8	3

NOTE: The cost of TSOL18 regime per pig per year applied in this intervention was assumed to be protective for the lifetime of the pig (Lightowlers 2013), and as such does not need to be repeated in subsequent years.

5.3.3 Human health results

a) Non-monetary cost of NCC and STH

Door-to-door household surveys in the village revealed that approximately 0.8% of the inhabitant's self-reported suffering from epilepsy (3/375) based on a clinical description of seizures with or without mouth foaming. The clinical manifestations of epilepsy are well known in the village, named '*bah moo'* (crazy pig) in the local language based on the likeness of sufferers to salivating pigs; and the prevalence of epilepsy equated to 8 people per 1,000 pre-intervention before the intervention. After the intervention the prevalence of epilepsy in the village was 0.2% (1/375); equivalent to 2 people per 1,000. Based on the prevalence of epilepsy obtained from the village data, the number of people estimated to be suffering from epilepsy in the northern Lao region was 9,134 (computed as 1,141,785*8/1,000) before intervention. Thus, the number of patients with epilepsy due to NCC was estimated to be 2,404 before the intervention in northern Lao PDR. After entering all the parameters in R computer software, the DALY from NCC was estimated to be 5,282 (95% CI: 3.6-66,480) before the intervention; and the total DALY per 100,000 due to NCC-induced epilepsy was 462.6 before the intervention; using 3% discount rate and age weighting. It was assumed that there would be 2,284 people suffering from epilepsy (computed as 1,141,785*2/1,000); hence the estimated number of people that would suffer from NCC-induced epilepsy in northern Lao PDR was 580 post-intervention. The total DALY due to NCC was 1,742 (95% CI: 0-39 920) post-intervention; and the total DALY per 100,000 due to NCC-induced epilepsy was 153 post-intervention in northern Lao PDR, representing a 67% reduction in the disease burden. The epidemiological parameters of the STH were computed in R version 3.1.1 after coding, yielding the DALY figures pre- and post-intervention for each of the three diseases as shown in Table 5-7. Consequently the total DALYs averted was estimated to be 196,300 in northern Lao PDR, representing an overall reduction of 83.2% of the total disease burden due to NCC and STH.

Table 5-7 DALY averted for NCC and STH

Disease	DALY Pre-intervention	DALY Post-intervention	DALY averted	Percentage reduction in DALY burden
Trichuriasis	64,840	23,660	41,180	63.5
Hookworm	93,860	11,940	81,920	87.3
Ascariasis	72,020	2,360	69,660	96.7
NCC	5,282	1,742	3,540	67.0
Total	236,002	39,702	196,300	83.2

b) Patient's cost of NCC and STH

Data obtained from the door-to-door survey revealed that only 1 out of the 3 persons with epilepsy (PWE) seek healthcare from the traditional healer (soothsayer) spending USD 17 on treatment per year. The other two PWE did not seek any form of treatment. Based on this it was estimated that PWE seeking healthcare in northern Lao region was 33%; consequently the total number of NCC-associated epileptic patients that would seek treatment was calculated as 793 (computed as 33/100*2,404) before the intervention. Accordingly, it was estimated that PWE due to NCC would spend USD 13,481 on treatment (computed as 793*USD 17) per year before the intervention. By estimating that 33% of the NCC cases would seek healthcare, the number of NCC patients in northern Lao PDR seeking healthcare was estimated to be 191 (computed as 33/100*580). Consequently, the NCC patients would spend USD 3,247 (computed as 191*USD16.7) on healthcare post-intervention; resulting in a difference of USD 10,234 after intervention (computed as USD 13,481-USD 3,247).

According to the data obtained from the household surveys using one year recall, 210 out of 375 participants self-reported symptomatic diarrhea and anemia; and 40 out of the 210 (19%) diarrhea and anemia self reported cases sought health care; 6 from the medical doctor, spending an average of USD 0.6 each, and the rest from the village soothsayer, spending an average of USD 0.1 each. Using a uniform distribution, the mean expenditure incurred when seeking health (both from the medical doctor and soothsayer) was USD 0.3 (95% CI: 0.1-0.5). Data extrapolated from Ash *et al*. (2015) revealed that the mean prevalence of trichuriasis, hookworm and *ascariasis* was 53% (computed as 56%+43%+60%/3); consequently the number of individuals estimated to be affected by STH across the northern Lao PDR was estimated to be 605,146 (computed as 1,141,785*53/100). Also, it was estimated that the total expenditure on STH was USD 34,493 (computed as (605,146*19/100)*USD 0.3)) at pre-intervention within northern Lao PDR. After the intervention the prevalence of trichuriasis was 9.3%, hookworm, 1.9% and *ascariasis was* 18.5%; and the average prevalence of STH after intervention was 9.9% (Ash *et al*. 2015). Thus, the estimated number of people with STH would be 113,037 (computed as 1,141,785*9.9/100); and the expenditure on treatment of STH during health seeking would be estimated as USD 6,443 (computed as (113,036.7*19/100)*USD 0.3). Based on the difference in the amount of money spent on treating NCC and STH within the informal private health sector, the difference in health expenditure after the intervention was USD 28,050. Consequently, the total amount of health expenditure averted was USD 38,284 (computed as 10,234+28,050).

5.3.4 Pig intervention results

a) Pigs and pork products out

The value of pigs and pork products out constituted the sum total value in USD of all pigs sold, slaughtered or gifted to the village. At an average price of USD 37 per pig, 96 pigs were sold at a value of USD 3,519 in the 12 months leading up to the intervention. At an average price of USD 82 per pig, 102 pigs were sold at a value of USD 8,364. Similarly for pigs slaughtered, pre intervention slaughter numbers at baseline were 21 at a total value of USD 2,232, which at post intervention had risen to 46 at a total value of USD 3,856. Other pigs transferred out of the village herd, largely as a result of gifts for other reasons totaled 13, at a total value of USD 768 pre-intervention and largely consisted of younger pigs, increasing to 19 pigs and a value of USD 1,239 post intervention. Subsequently, the overall total increase in the value of pigs sold, slaughtered or gifted in the village over the 16 month intervention period was USD 6,980.

b) Pigs and pork products in

The value of pigs and pork products consisted of the sum total value of all pigs purchased or that came into the herd for other reasons, mostly received as gifts. In the 12 months leading up to the intervention, a total of 17 pigs (8 sows, 3 weaners and 6 growers) were purchased by the village households, at a total expenditure of USD 960. Post intervention analysis demonstrated that by the end of the intervention, the total value of 9 purchased pigs (5 sows, 1 weaner, 2 growers and 1 piglet) was USD 630. Eleven pigs (2 boars, 3 sows, 3 weaners, 1 grower and 2 piglets) were received as gifts pre-intervention, valued at USD 737, decreasing to gifts of 3 pigs (2 sows and I grower) worth USD 231 post intervention. Consequently, the overall total decrease in the value of pigs bought or gifted in the village over the 16 month intervention period was USD 837.

c) Gross margin from pig enterprise before and after the intervention

The change in herd value is expressed as the difference between the closing valuation (total number of pigs at the end of the year multiplied by their value) and the opening valuation (total number of pigs at the beginning of the year multiplied by their value). The baseline change in herd value of USD 1,901 had increased post-intervention to USD 5,024, resulting in a total increased pig production output of USD 10,939 over the course of the intervention. To obtain the gross margin from the pig enterprise, the herd value was added to the livestock output and the variable cost deducted from the resultant. The variable costs consisted of crush repairs, veterinary drugs and feed stuff. Before the intervention, the total variable cost was USD 67 decreasing to USD 27 after the intervention. The gross margin before the intervention was USD 6,697 and USD 17,556 after the intervention (a difference of USD 10,859); equivalent to USD 137 and USD 358 as the income gained from the pig enterprise before and after the intervention per household respectively as shown in Table 5-8. Subsequently it was deduced that the intervention increased the individual household income by 2.6 times the baseline amount (computed as USD 358/USD 137). Also, it was determined that the total losses from pig condemnation before intervention was USD 233 which dropped to USD 6 post intervention. Therefore, the total benefit across all the households from pig production was found to be USD 11,086 (computed as USD 10,859+USD 233-USD 6).

Table 5-8 Village pig gross margin analysis

Item	**Total income (USD)**	
	Pre-intervention	**Post intervention**
1. Pigs and pork products 'out'		
Total value of sold pigs	3,519	8,364
Total value of slaughtered pigs	2,232	3,856
Total value of pigs given as gifts, or stolen/disappeared	768	1,239
Subtotal: Value of pigs/pork products 'out'	6,519	13,459
2. Pigs and pork products 'in'		
Total value of purchased pigs	960	630
Total value of pigs received as gifts	737	231
Subtotal: Value of pigs/pork products 'in'	1,697	860
3. Change in herd value		
Closing valuation	14,372	19,395
Opening valuation	12,471	14,372
Overall change in herd value	1,901	5,024
Livestock output	6,723	17,623
4. Variable cost to farmers	26	67
5. Total gross margin	6,697	17,556
6. Average HH income from pig enterprise	137	358

The gross margin from the pig enterprise was extrapolated to northern Lao PDR by multiplying the equivalent total gross margin per household (as summarized in Table 5-8) and the total number of households with pigs in each province (refer to Table 5-3). Afterwards, the respective total gross margin for each province was multiplied by 2.6 to estimate the total gross margin after the intervention; resulting in a total gross margin of USD 9,398,720 before and USD 24,432,580 after the intervention as shown in Table 5-9; a difference of USD 15,033,860. According to the village data, the annual off-take was 24% after the intervention and 1 out 51 (1.9%) slaughtered pigs was condemned at home by their owners. Extrapolation of the same within four provinces in northern Lao revealed that the total number of pigs slaughtered was 84,488 or 1,934,775.2 kg (computed as 84,488*22.9 kg) of pork; it was estimated that 19 347.7 kg would be condemned valued at USD 58,043 (computed as USD 19 347.7*USD 3).

Table 5-9 Annual pig gross margin analysis in northern Lao PDR

Province	Number of pig rearing households	Total gross margin pre-intervention across all households (USD)	Total gross margin post-intervention across all households (USD)
Huaphan	28,900	2,586,550	6,725,030
Luang Prabang	26,900	2,975,140	7,733,750
Oudomxay	26,100	1,855,710	4,823,280
Phongsaly	22,800	1,981,320	5,150,520
Total	104, 700	9,423,600	24,432,580

Consequently, the difference in the value of condemned pork before and after the intervention was estimated to be USD 23,990. Also, it was found that the total benefit of controlling *T. solium* in the agricultural sector was USD 15,115,893 (Computed as benefit of reduced pork condemnation of USD 23,990 plus increased household income of USD 15,057,850).

5.3.5 Extrapolated project cost

By estimating the deworming coverage to be 63% (375/593*100), hence 622,960 of eligible participants (taken as more than 4 years instead of 6 years for ease of calculation), the total annual cost that would be incurred by deworming people (MDA) across all the provinces was estimated to be USD 8,721,440 (computed as 622,960 * USD 14). In the agricultural sector, the cost of vaccinating pigs using TSOL18, CSF and deworming was estimated to be; USD 3,055,440, USD 2,704,240 and USD 3,301,280 respectively; totaling USD 9,060,960. Consequently, the total project cost was estimated to be USD 17,782,400 for the simultaneous control of *T. solium*, STH and CSF in northern Lao PDR.

5.3.6 Determining the total cost-effectiveness of the intervention

By subtracting the livestock benefits (increased gross margin from pig enterprise and decreased value of condemned pork) and the averted cost in health expenditure from the project cost, the total benefit from vaccinating pigs using TSOL18, deworming pigs using oxfendazole, vaccinating pigs against CSF and MDA in people using albendazole was USD 2,686,266 (computed as USD 17,782,400-15,057,850-38,284) as shown in Table 5-20. Subsequently, the net cost-effectiveness of simultaneously controlling *T. solium,* CSF and STH was USD 14 per DALY averted; this reduced to USD 11 per DALY averted using the separable cost method.

The study revealed that by computing only the control of *T. solium* (without integrating STH) and including only *T. solium* and STH in the computation of cost-effectiveness of the intervention; the net cost-effectiveness of these approaches would be USD 2,461 per DALY averted and USD 44 respectively as shown in Table 5-20. By using TSOL18, pig deworming and MDA (including *T. solium* only), the net cost-effectiveness would be USD 4,250; and by using the same regime but including STH as well, the net DALY averted would be USD 76.

By comparing the cost per DALY averted for each intervention approach with the Lao PDR GDP per capita as a measure of cost-effectiveness, it was found that the most cost-effective approaches (less than USD 1,793, Lao PDR GDP per capita) were simultaneous control of *T. solium* and STH, simultaneous TSOL18 vaccination, pig deworming and control of *T. solium* and STH and simultaneous TSOL18 vaccination, pig deworming, MDA (*T. solium* and STH) and CSF as shown in Table 5-31; these approaches were also 'very cost-effective' (i.e less than USD 598-less than three times Lao PDR GDP per capita). The least cost-effective approaches (more than USD 1,793, Lao PDR GDP per capita) were simultaneous control of *T. solium* and STH and simultaneous TSOL18 vaccination, pig deworming and control of *T. solium* only as shown in Table 5-31.

Table 5-20 Net cost-effectiveness of the various intervention approaches

Item	Intervention approach				
	Human intervention		Human and pig intervention		
	Control of *T. solium* only using MDA	Simultaneous control of *T. solium* and STH	Simultaneous TSOL18 vaccination, pig deworming and control of *T. solium* only	Simultaneous TSOL18 vaccination, pig deworming and control of *T. solium* and STH	Simultaneous TSOL18 vaccination, pig deworming, MDA (*T. solium* and STH) and CSF
a) Project cost (USD)	8,721,440	8,721,440	15,078,160	15,078,160	17,782,400
b) Livestock benefits (agricultural sector) (USD)	-	-	23,990	23,990	15,057,850
c) Health expenditure averted (health sector) (USD)	10,234	38,284	10,234	38,284	38,284
d) Sub-total (**a** *minus* **b** *minus* **c**) (USD)	8,711,206	8,683,156	15,043,936	14,957,843	2,686,266
e) DALYs averted (health sector)	3,540	196,300	3,540	196,300	196,300
f) Net cost per DALY averted (**d/e**) (USD/DALY)	2,461	44	4,250	76	14

Table 5-31 Cost-effectiveness of the intervention approaches compared with GDP per capita

Intervention approach	Cost effectiveness		
	Very cost effective (<USD 598)	Cost effective (USD 598 - 1,793)	Least cost effective (>USD 1,793)
Control of NCC only using MDA	No	No	Yes
Simultaneous control of T. solium and STH	Yes	Yes	No

Simultaneous TSOL18 vaccination, pig deworming and control of T. solium only	No	No	Yes
Simultaneous TSOL18 vaccination, pig deworming and control of T. solium and STH	Yes	Yes	No
Simultaneous TSOL18 vaccination, pig deworming, MDA (T. solium and STH) and CSF	Yes	Yes	No

Cross sector analysis revealed that by using TSOL18 vaccine, oxfendazole in pigs and MDA (considering NCC only) to control *T. solium*, the health sector will contribute 31.7% of the total share of intervention; and by considering both NCC and STH in the intervention using the same approach, the health sector will contribute 63.8% of the total share of contribution; the agricultural sector will contribute 68.2% and 36.1% of to the total share of contribution towards the intervention respectively as shown in Table5-12. By using TSOL18 vaccine, oxfendazole and MDA (including both NCC and STH) to control *T. solium*, the health and agricultural sectors will contribute 0.2% and 99.7% to the total funds required for the *T. solium* intervention as shown in Table 5-12.

Table 5-42 Separable cost analysis for the health and agricultural sectors

Sector	**Intervention approach**				
	Control of NCC only using MDA	**Simultaneous control of NCC and STH**	**Simultaneous TSOL18 vaccination, pig deworming and control of NCC only**	**Simultaneous TSOL18 vaccination, pig deworming and control of NCC and STH**	**Simultaneous TSOL18 vaccination, pig deworming, MDA (NCC and STH) and CSF**
Health sector contribution (in %)	100	100	31.75	63.85	0.25
Agricultural sector contribution (in %)	0	0	68.25	36.15	99.75

Total %	0	0	100	100	100

5.4 Discussion

Information obtained from the semi-structured questionnaire revealed that smallholder pig rearing is an important farming activity in the study area and the intervention improved pig productivity. This is because the average number of pigs reared per household was increased from 5.2 to 8.4 after one year of the intervention. Furthermore, vaccinating pigs with CSF reduced pre-weaning mortality from 48.3% to 8.4%. However an increase in pig population would indirectly increase the risk of *T. solium* in the village and beyond; and vaccinating pigs with TSOL18 and deworming ensured that the risk of acquiring *T. solium* was low; given the culture of eating raw meat in the study area (Bardosh *et al*. 2014; Okello *et al*. 2016).

According to information obtained from the semi-structured questionnaires, only a few households (19.4%) have access to toilets hence the risk of contaminating the environment with infective *Taenia* eggs is high in the villages in northern Lao PDR. Similarly, other authors reported that only 17% of the households in Phongsaly province owned toilets (Bardosh *et al*. 2014). Furthermore, one of the main reasons for keeping pigs is in order to be able to slaughter them at home for religious ceremonies and eating raw pork meat on these occasions exposes people to T. solium. Similar observations have also been by other authors (Bardosh *et al*. 2014; Okello *et al*. 2014).

The finding that the burden of NCC in northern Lao region was 462.6 DALY per 100,000 person-years (equivalent to 4.6 DALY per 1,000 person-years) was significant; and this was similar to findings in Chapter 4 (446.4 DALY per 100,000 person-years) which evaluated the burden of *T. solium* and STH in northern Lao PDR. This is because there is currently no study on the burden of NCC in Asia. Studies done in West Cameroon (in Africa) and Mexico (in Latin America) revealed that DALY per 1,000 persons was 9 and 0.25 respectively (Praet *et al*. 2009; Bhattarai *et al*. 2012). Thus, the burden of *T. solium* in northern Lao PDR is lower than in West Cameroon but higher as compared to Mexico. Unlike the study done in Africa, the data in the current study was stratified according to age and sex groups. This was similar to the approach used in Mexico although urban and rural stratification was also included. Since majority of the northern Lao PDR population live in the rural areas just like would be in Africa, the burden of NCC is higher in northern Lao PDR and West Cameroon unlike Mexico. However, the burden of NCC in northern Lao PDR is potentially higher than what the study revealed due to exclusion of other symptoms of epilepsy such as vision loss and headaches. Due to high prevalence of STH in the study area, the burden of STH was equally high although it does not cause high mortality.

Since some zoonotic diseases such as *T. solium* affect both humans and livestock, the total burden of such diseases should be evaluated (Carabin *et al*. 2005). Although methods to estimate the costs of zoonotic disease due to both livestock productivity (Tschopp *et al*. 2012) and humans are available (Narrod *et al*. 2012), there is currently still no completely satisfactory conceptual framework for analyzing the total societal burden of zoonotic diseases; that is the combined costs of disease from both the humans and animals. Analysis of the total societal burden of *T. solium* and hence the total societal burden of its control, revealed that the most cost-effective approach in controlling *T. solium* was combined MDA of people, pig vaccination against the disease and CSF and deworming. Other cost-effective approaches were MDA targeting both NCC and STH and combined MDA (targeting both NCC and STH) and pig vaccination against *T. solium*. The least cost-effective intervention approaches were predicted to be; combined MDA (targeting only NCC) and pig vaccination against *T. solium*; and MDA targeting NCC only. Therefore inclusion of approaches that are effective against STH and CSF plays a major role in determining cost-effectiveness in regions where *T. solium*, STH and CSF are endemic or hyper-endemic. To achieve high cost-effectiveness, pig vaccination against *T. solium* could be done together with CSF or a bivalent vaccine ('One Health vaccine') developed for regions where CSF is endemic. Delivery of combined *T. solium* and CSF vaccination has the potential of being sustainable if the pork value chain, and particularly meat inspection, is developed. *T. solium* unlike CSF does not typically affect pig productivity hence it will be difficult to convince farmers to pay for vaccine particularly in regions, such as northern Lao PDR, where meat inspection is not routinely done. In regions where CSF is not endemic, diseases or management practices that cause pig mortality, pre-weaning mortality in particular, should be controlled or modified so as to achieve a higher survival rate, thus increasing the livestock benefits.

Although Albendazole was the drug for control of *T. solium* and STH in this study, there are other drugs that can be used to control the former only using targeted approach or MDA. These are niclosamide and praziquantel. The former is the drug of choice when controlling *T. solium* because it is not absorbed in the intestines, reducing the chances of initiating neurological symptoms, if latent NCC exists in the same patient, unlike the latter (Pearson and Hewlett, 1985; Flisser *et al*. 1993). Whereas MDA with praziquantel has been administered for schistosomiasis in most areas of Africa, no controlled safety data on its use in cysticercosis-endemic regions yet exists (Gilman *et al*. 2012).

The separable cost analysis revealed that there is need for sharing resources between agricultural and health sectors since; inclusion of STH and CSF played a major role in determining the share of contribution from each sector. Joint sector disease control is a critical part of enhancing household health, wealth and overall well being; since the biggest beneficiaries are the affected households. Unfortunately, integrated sectoral approaches are rare, even though there is need for such to tackle societal problems. One of, if not the main underlying reason is who should fund what. However, the presence of societal health problems at hand should be the guiding principle of integrated actions, rather than individual/separate approaches, as they are much more cost-effective as demonstrated by this study.

This study has limitations; first the data used to simulate and estimate the cost-effectiveness of simultaneously controlling *T. solium*, STH and CSF may not be representative to the entire northern Lao region. Therefore further studies are needed to establish the *T. solium*, STH and CSF prevalent regions in northern Lao PDR. An earlier study on the hyper-endemic *T. solium* hot spot in northern Lao could serve as starting point in establishing such hot spots (Okello *et al*. 2014). Second, when looking at the aggregated societal benefits and the net monetary benefit including all livestock and monetary human health benefits, high livestock benefits may mean that monetary benefits exceed monetary costs. This leads to the counter-intuitive result where the net cost per DALY averted becomes negative. This is a difficult result to interpret, or rank. It also could have the unwanted effect of skewing the allocation of cost entirely towards the livestock sector, since livestock benefits outweigh costs. This would be a particularly unhelpful outcome, as the strength of the interventions illustrated above is that they deal with both the human and the livestock disease reservoir simultaneously. The separable costs approach avoids this difficulty, by effectively taking the DALYs out of the equation when allocating costs between sectors. Third, the total number of DALYs due to NCC was probably underestimated since only the NCC-associated clinical presentation of epilepsy was included.

5.5 Conclusion

Because of the difficulty of changing cultural habits of eating raw pork and lack of toilets, control of *T. solium* in the northern Lao PDR depends heavily on education, vaccination of pigs against the disease and MDA; to reduce the disease prevalence. However, sustainable control of *T .solium* would require its simultaneous control with CSF. This is because, unlike *T. solium*, CSF massively affects pig productivity and cause high mortality; subsequently farmers will be more willing to pay for its control. Furthermore, it would be more cost-effective to control both *T. solium* and STH.

5.6 Summary of key findings

Cost-effectiveness of integrated control of T. solium, STH and CSF in northern Lao PDR

Taenia solium can be controlled through human intervention only or through both human and pig interventions (Kyvssgaard *et al* 2007). Investigation of the cost-effectiveness of a *T. solium* control programme via a human MDA intervention targeting only this parasite revealed the net cost per DALY averted to be USD 2,461. However, this would significantly drop to USD 44 if planned interventions used an MDA protocol simultaneously targeting both *T. solium* and STH, which is close to the WHO standard of USD 25 for 'extremely good value for money interventions' (WHO, 2003) and well below the current standard for 'very cost effective 'of the 1 year's per capita GDP (less than USD 598). Exploration of the cost-effectiveness of simultaneously controlling *T. solium* in humans (through mass drug administration) and pigs (through TSOL18 vaccination and deworming) found the net cost per DALY to be USD 4,250. It was estimated that the cost-effectiveness of simultaneously controlling *T. solium* in humans and pigs as well as STH would be USD 76. However, simultaneous control of CSF, STH and *T. solium* in humans and pigs would result in net cost per DALY of USD 14; which fell to USD 11 if the separable cost method was applied. Subsequently, simultaneous control of CSF, STH and *T. solium* in humans and pigs was classified as 'very cost effective' since it was less than one times Lao PDR GDP per capita (USD 598).

CHAPTER SIX

6. GENERAL DISCUSSION AND CONCLUSION

6.1 Introduction

This final chapter summarizes the key research findings of this thesis and presents the general conclusions based on these. Furthermore, the strengths and limitations of this study are considered and suggestions for further research into economic analysis of zoonotic diseases are presented. This chapter concludes with recommendations for four categories of stakeholders in control zoonotic diseases: policy makers, researchers, local animal health providers and farmers.

Many issues need to be considered when analysing disease control options in humans and/or animals. These issues can be divided along analytical frameworks ranging from the cost-benefits to livestock productivity (agricultural sector) and/or human health (health sector); integrating these cost/benefits into a single cost effective unit, and the control of zoonoses from the perspective of both beneficiaries and donors. However, few studies have integrated these various approaches to determine the 'added value' of controlling zoonoses in the agricultural sector (Zinsstag *et al*. 2015). Consequently, the economic studies presented in this thesis focused on the benefits of controlling zoonoses in the agricultural - or both agricultural and health – sectors through two case studies undertaken in Uganda and Lao PDR.

6.2 Chapter Overview of Study Objectives and Methodology

The literature review in chapter 1 examined the current governance systems/policies regarding zoonoses control in Uganda and Lao PDR, summarised the various economic analysis methods for zoonotic diseases, and gave an overview of the epidemiology and current control methods targeting trypanosomiasis and *T. solium.* Chapter 1 also laid out the overall aim and key objectives of the case studies:

i) Uganda – to determine the household-level benefits of using RAP to control trypanosomiasis, and examine the cattle trade networks to ascertain the inter-district risk of HAT spread and highlight potential control options.

ii) Lao PDR – to estimate the joint burden of *T. solium* and STH in the north of the country, and subsequently estimate the cost effectiveness of simultaneous integrated control of these two diseases and CSF.

The key aim in Chapter 2 was to identify the net annual change in income per bovine due to RAP. Secondary objectives were to determine statistically significant differences in annual household income before and after the RAP intervention (paired t-test) and between RAP and non-RAP households (ANOVA); estimate the proportion of cattle to be sprayed to control trypanosomiasis and confer adequate benefits to farmers from the donor's perspective (marginal analysis), estimate the cost of RAP from the farmer's perspective and describe the differences and similarities between households/villages with high and low prevalence of *Trypanosomiasis brucei sensu lato*. This was done via a baseline survey (n=660 households), from which a secondary longitudinal survey was conducted on RAP-participating households, designated as 'intervention group of households' (n=660). Exploratory data analysis using multiple correspondence analysis determined the difference and similarities between inclusion and exclusion villages as defined by the intervention protocol. Subsequent logistic regression was carried out to establish the key predictors of *T. brucei s.l.* infection; resulting in the identification of key characteristics of high prevalence villages. Gross margin analysis determined the income gained from cattle after 12 and 18 months of the intervention to establish changes in income due to RAP. This income data was then combined with the overhead cost of RAP ('project costs') to establish the regime that resulted in the highest net returns via marginal analysis, whilst also establishing the cost of RAP from the farmers' perspective.

The objective of Chapter 3 was to examine the potential risk of HAT spread from south-east to northern Uganda through the cattle trade networks, and to establish the main economic driver of the spread of HAT in south-east Uganda. In this study, social, market and value chain analysis methodologies provided the underlying theoretical framework for understanding risk of disease spread through networks via semi-structured cattle trader interviews (n=119), focus group discussions, key informant interviews and bio-economic herd simulation modelling.

Chapter 4 estimated the combined burden of *T. solium* and STH in northern Lao PDR, consequently developing an analytical framework for establishing the benefit of simultaneous control of *T. solium*, STH and CSF as described in Chapter 5. In this study, stochastic modelling of disability-adjusted life years (DALY) was carried out on the estimated population (n=1,141,785) using various parameters from the literature, whilst the monetary burden of *T. solium* was estimated using decision tree analysis.

Using inputs from Chapter 4, Chapter 5 estimated the potential cost effectiveness of simultaneously controlling *T. solium*, STH and CSF as a group. In this study, village level prevalences of NCC-associated epilepsy (estimated via a door-to-door screening approach) and STH (provided by a concurrent epidemiological study) were projected to the larger northern Lao population to estimate the dual burden of *T. solium* and STH using stochastic modelling, supplemented by data sources from the broader research project and various parameters from the literature. On the pig production side, the difference in annual household income before and after village-level CSF vaccination was computed using gross margin analysis, then projected to the larger pig population in northern Lao PDR (n=351,200). A micro-costing technique was used to divide the cost centres of the human and pig intervention (at the village level) into two, which was then used to estimate the project cost incurred to each sector should the intervention be scaled out over the broader northern Lao region. Finally, in order to determine the most cost-effective intervention option(s), the project cost, health expenditures, DALY-averted and livestock benefits from CSF vaccination was divided into two broad approaches (human-only and human *plus* pig) in order to calculate the net cost per DALY averted of each approach (Figure 6-1).

The human intervention was further divided into i) MDA choice to control *T. solium* only, and ii) MDA choice for simultaneous control of *T. solium* and STH. The human *plus* pig intervention approach was further divided into i) TSOL18 + oxfendazole + MDA (*T. solium* control only), ii) TSOL18 + oxfendazole + MDA (*T. solium* and STH control), and iii) TSOL18 + oxfendazole + MDA (*T. solium* and STH) + CSF vaccination. The study used the thresholds launched by the 2003 World Health Report, which considered interventions with an incremental cost per DALY averted of less than three times a country's GDP per capita (USD 1,793 for Lao PDR) 'cost-effective' and less than one times Lao PDR GDP per capita (USD 598) as 'very cost-effective'. The World Health Organization's cost-effectiveness threshold of USD 25 per DALY averted for 'very cost-effective' was also used (WHO, 2003).

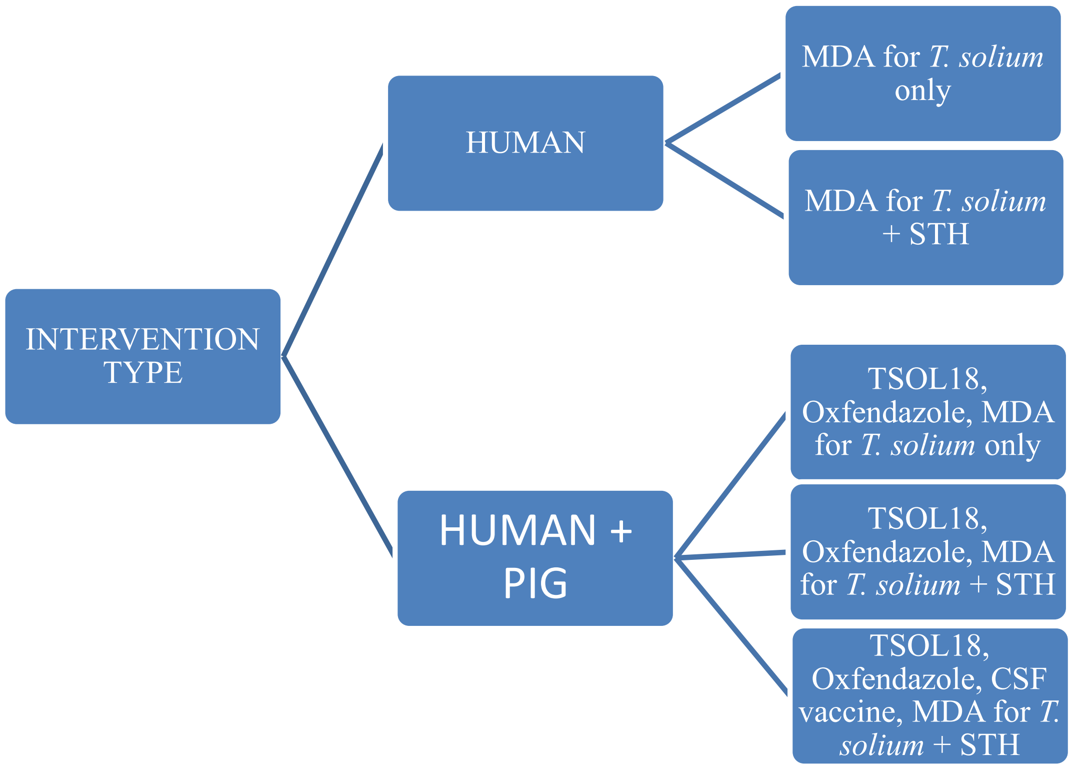


Figure 6-1 Calculation of cost-effectiveness of various intervention options for *T. solium* control

6.3 General conclusions

The general conclusions can be categorized into the evaluation of costs and benefits of RAP, cattle trade networks and herd models in south-east Uganda, burden of *T. solium* and STH in northern Lao PDR and cost-effectiveness of simultaneously controlling *T. solium*, STH and CSF in northern Lao PDR region. Although the conclusions in this section are presented as solitary units, they can only be interpreted properly and understood in combination with the information presented in the chapters of this thesis.

6.3.1 Evaluation of the cost and benefits of RAP (Chapter 2)

- Use of RAP to control trypanosomiasis leads to high returns in households and income per head of adult bovine through reduced cattle mortality and increased work output of draft cattle.
- The results of this study support a policy of preventing the spread of acute HAT infection by spraying at least 25% of the cattle population, as well as treatment of cattle using double dose diminazine aceturate in key cattle markets in south east Uganda.
- Use of RAP is likely to increase food security through increasing draught cattle work output and acreage cultivated.
- The cost of RAP from the farmer's perspective is very low in subsidised projects such as this where drugs and spray-persons are provided, with most expenses incurred by the farmer associated with time/labour costs of taking cattle for spraying and purchasing ropes.
- Although the cost of RAP to farmers is low, most farmers still do not understand the principles behind the control method and preferentially purchase cheaper acaricidal drugs that do not impact the tsetse vector.

6.3.2 Evaluation of the cattle trade networks and herd model (Chapter 3)

- Farmers in south-east Uganda replenish their draft cattle herd by importing young males from other districts due to low numbers of female cattle.

- Demand for young males and older draft cattle in both south and northern Uganda has resulted in high movement of cattle between the two regions; thus the risk of acute HAT spreading to northern Uganda is very high.
- Northward movement of untrained young males from the south-east to northern Uganda and back again 18 months later poses a further risk of disease spread.
- High use of draft cattle results in the establishment of more regular cattle markets; thus, accelerated and sustained cattle movement increases the risk of disease spread.
- Social network analysis revealed a high risk of disease spreading very quickly within the cattle network if the disease starts in Namutumba, Soroti or Molo cattle markets because of the existence of communities (super spreaders).
- Currently, there is no single cattle market or community of cattle markets that connect all other markets.

6.3.3 Evaluation of the burden of T. solium and STH in northern Lao PDR (Chapter 4)

- The study is the first estimate of the DALY associated with NCC in south-east Asia. However, the value of DALY estimate associated with NCC is likely to be an underestimate because other clinical manifestations of NCC such as headaches and vision loss were not included
- The non-monetary burden estimates in the study suggests that healthy lives are being lost to NCC and STH in northern Lao PDR.
- The non-monetary burden of *T. solium* is high in south-east Asia compared to Latin America but lower when compared to DALY estimates from Africa.

6.3.4 Evaluation of the cost-effectiveness of simultaneously controlling T. solium, STH and CSF in northern Lao PDR (Chapter 5)

- This is the first study to provide the empirical evidence of the added value of integrated health interventions that involve public health and transboundary livestock diseases.

- Simultaneous control of *T. solium*, STH and CSF is the most cost-effective approach compared to targeting the diseases singly; emphasizing the benefit of integrated health interventions.

6.4 Strengths and limitations of the studies

6.4.1 Strengths

a) Broader applicability of the research methodologies

The research methodologies in assessing benefits of controlling zoonotic diseases in the livestock sector alone, and both livestock and health sectors, can widely be applied. Unlike human health, animal health cannot be assessed by non-monetary burden of disease methods because animals cannot determine their own life span. Subsequently, the benefit of controlling zoonotic diseases can be assessed using gross margin analysis; especially in mixed crop-livestock systems where cattle are mostly kept for draft work, as demonstrated in Chapter 2. Gross margin analysis was also used to determine the livestock benefits from the pork enterprises in northern Lao PDR (Chapter 5). The resultant annual profit from the cattle or pork enterprises can then be stochastically modeled together with human parameters to establish the cost-effectiveness of the intervention, as done in Chapter 5. Furthermore, stochastic modelling of DALY can be done in scenarios where there is lack of data, which is common with neglected tropical diseases. However, conversion of DALY to dollars could be useful whenever budgetary decisions are determined by monetary costs and when such inputs are required for cost–benefit analyses.

b) Diverse research tools

In the study reported in Chapter 3, analysis tools from social network analysis, market analysis, value chain analysis and bio-economic herd modelling were used to establish the risk of acute HAT spreading to northern Uganda. This was based on the premise that there is a close relationship between farm-level herd dynamics and subsequent livestock movement. Use of a theoretical framework that draws from these various disciplines might improve the results and understanding of the pattern with which acute HAT spreads. In the study reported in Chapter 2, elementary econometrics and other statistical tools were used to improve the gross margin results. In the study reported in Chapter 4 and 5, analysis tools from statistics, livestock and health economics were used to determine the burden of *T. solium* and STH and cost-effectiveness of simultaneously controlling them.

c) Integrated health evaluation framework

Earlier studies have mostly evaluated zoonotic diseases singly, providing either monetary or non-monetary estimates of burden and very few that have empirically studied the cost-effectiveness of controlling zoonotic diseases. Chapter 5 demonstrates how several diseases can be included in the computation of intervention cost-effectiveness. The framework developed in Chapter 5, where both neglected tropical diseases and transboundary animal diseases are simultaneously analysed, sets a precedent for the added value of carrying out integrated health interventions that include livestock production diseases.

d) Large sample sizes and high coverage

In Chapter 2, a total of 660 households out of a possible 886 households (75%) were followed for 18 months with cattle exits and entries updated every six months. In Chapter 3, all the cattle traders (n=199) were interviewed. In northern Lao PDR, 49 households out of a possible 55 (89%) were followed up for 1 year (n=375) with pig exits and entries updated every 6 months. The large sample sizes and high coverage reduced the occurrence of bias and type I or II error. However, large sample size can affect data quality.

6.4.2 Limitations

a) Considerations concerning comparison with other studies (Chapter 2)

Studies reported in Chapter 2 were done at the household level using gross margin analysis, which makes it difficult to compare with results from other countries. In contrast, cost-benefit analyses resulting in a benefit-cost ratio/net present value/internal rate of return can be more easily applied across countries to compare the benefits of disease control across a broader region. Moreover, it is difficult to allocate labour using gross margin analysis, as these do not include overhead costs which could be quite substantial.

b) Inadequate sampling (Chapter 3)

Although all the cattle traders in south-east Uganda were interviewed, there was a clear need to also interview cattle traders in northern Uganda. This could have provided clearer movement patterns of cattle especially from northern Uganda to south-east Uganda.

c) Lack of primary data (Chapter 4 and 5)

In the studies reported in Chapter 4 and 5, there was over reliance on secondary data due to a general lack of information on *T. solium* and STH occurrence in northern Lao PDR. Therefore there is a possibility that these studies could have overestimated or underestimated the monetary and non-monetary burden of *T. solium* and STH. Furthermore village data was used to extrapolate the cost-effectiveness of simultaneously controlling *T. solium*, STH and CSF; there is a need for further randomized community-based trials to test the cost-effectiveness of these interventions over broader geographical areas and larger populations of humans and pigs.

6.5 Suggestions for Further Research

In this thesis, several innovative research tools were applied or developed. In Chapter 2, gross margin analysis and a subsequent before/after and with/without matrix was used to determine the annual change in income among RAP and non-RAP households. However, due to the aforementioned limited value of gross margin analysis at a broader national or regional level, there is now a need to examine the benefit of RAP at a higher level using a cost-benefit analysis which can be used to compare RAP with other trypanosomiasis control methods such as traps, targets, aerial spraying, ground spraying and sterile insect technique. Chapter 2 also established the cost of RAP to farmers; however, further research is required on the combination of these results with the overhead costs as reported by Muhanguzi *et al* (2015) to determine the total cost of RAP.

The study in Chapter 3 integrated several analytical tools, however there now exists a need to develop an analytical framework that combines herd dynamics at the farm level and livestock dynamics. Also, cattle trade networks and risk management of acute HAT still require a combined analytical framework, for example through micro-chipping/GPS collaring of traded cattle to determine their movement patterns, and taking blood samples of cattle in the markets over a period of time to establish *T. b. brucei* prevalence. Moreover, analysis of the cattle trade network in Uganda should include cattle/livestock markets in northern Uganda.

The study reported in Chapter 4 used stochastic modelling of DALY to determine the burden of *T. solium* and STH. However, more information on the true prevalence of NCC in northern Lao PDR is required to accurately assess the burden of *T. solium* in this way. It would be interesting to assess the burden of *T. solium* and STH using the new recommendations of DALY computing which uses prevalence rather than incidence and abandons age-weighting. Moreover, refined reference life tables, disability weights and comorbidity adjustments could be used to refine the DALY estimates (Hotez *et al*. 2014); this also applied to Chapter 5 calculations of the stochastic DALY estimation. Intervention modelling in chapter 5 should be attempted over a given period of time (usually 20 years), requiring stochastic modelling of the integrated control of *T. solium*, STH and CSF including cross-sector economic analysis (Roth *et al*. 2003).

The overall study on economic control of zoonotic diseases provided a good framework for analyzing integrated health approaches. However, it was very difficult to assign benefits to a specific control method using integrated analytical framework; becoming even more difficult with more levels of integration. For example, use of MDA in humans and TSOL18 vaccine in pigs to control *T. solium* since the latter reduces the risk of exposure (to humans) to the disease. As for spreading cost, micro-costing technique was found to be useful.

6.6 Conclusion and Final Recommendations

Possible implications of the study to the agricultural and health sectors are discussed in this section. Recommendations are made for various stakeholders including policy makers, researchers, farmers and local animal health providers.

6.6.1 Agricultural and public health policy

Earlier authors have postulated that control of zoonoses is difficult because zoonotic diseases fall between livestock and health sectors leading to weak policies. Furthermore control of zoonoses is majorly done during pandemics due to securitization (Okello *et al*. 2014). It has also been found that a lack of information of the impact of zoonotic diseases on livestock productivity poses a challenge in developing comprehensive policies of controlling zoonoses (Mableson *et al*. 2014). This study (chapter 2) provided empirical evidence that zoonotic trypanosomiasis can be controlled using RAP, resulting in substantial benefits to both individual farmers and broader society at a low cost due to reduced mortality and improved cattle productivity, consequently increasing food security. This study also supported the finding that spraying 25% of the village cattle using is sufficient to prevent clinical HAT re-infection of cattle, leading to potentially less people being infected (Muhanguzi *et al*. 2014). Therefore use of RAP to control acute HAT (by spraying 25% of village cattle population) within the cattle reservoir and improve the overall cattle productivity - and subsequently food security - is one of the recommendations from this study. However, in circumstances where 25% of the village cattle population cannot be established, the study recommends spraying only draught cattle using a privatized system. Also, the study would recommend inclusion of information about use of cattle (what farmers use their cattle for) during national census; such information will indicate the potential risk of acute HAT occurring in regions with high work oxen.

Using network analysis, the findings in Chapter 3 supports the relatively new Ugandan government policy of pre-movement spraying cattle in livestock markets (Wendo, 2002). The study however goes further to suggest a methodology for how to prioritise cattle markets for spraying in the face of limited resources, for example recommending spraying of cattle in Namutumba, Soroti and Molo in southeastern Uganda rather than all cattle markets and thus potentially saving costs.

The Lao PDR study reported in Chapter 3 and 4 shows that healthy lives are being lost to *T. solium* and STH, demonstrating the cost effectiveness of integrated human interventions targeting both *T. solium* and STH using a common drug. The study therefore recommends integrating the simultaneous control of *T. solium* and STH, and encourages further integration of with existing CSF control programme to improve sustainability; unlike CSF, *T. solium* does not affect pig productivity, therefore farmers would be more willing to control CSF, especially given the lack of economic penalty for cystic pork due to the general lack of meat inspection in the country.

6.6.2 Collaborative research on integrated health interventions and a value chain approach to zoonoses risk management

An understanding of the added value of integrated health approaches can be useful to create awareness on the importance of collaborative research amongst varying disciplines and sectors such as veterinarians, medical doctors, economists, social scientists and pharmaceutical companies. This is because zoonotic diseases occur at the human-animal-environment interface, and the benefits of their control extend beyond the reaches of this interface alone. However, in order to capitalize on these benefits, innovative, cost-effective and sustainable implementation strategies are required. For example, it would be more cost-effective and sustainable to develop a bivalent vaccine by combining TSOL18 vaccine with a CSF vaccine to control both *T. solium* and CSF (Chapter 5).

Second, the method of social network analysis, herd modelling, value chain and market analysis in Chapter 3 also gives a good example of the types of collaboration and methodological approaches that can uncover disease risks and spread patterns, which helps 'untangle' the complexity of determining disease risk drivers along the cattle value chains. For example, veterinarians, epidemiologists and computer informatics could work together to determine the risk of spread of acute HAT in Uganda and neighboring countries. Value chain approaches to zoonoses risk management could also applied in northern Lao PDR and neighboring countries such as China and Vietnam to understand the risk of *T. solium* spreading to these countries.

6.6.3 Zoonosis control awareness for farmers and local animal health providers

Farmers and local animal health providers are the chief implementers of disease control strategies at the ground level; therefore it is critical that they have sufficient knowledge about the impact of the zoonoses and the control methods. Furthermore, insufficient knowledge about zoonoses could exacerbate the spread of the disease. For example, it was revealed that local animal health providers in southeastern Uganda could be using impure isometamidium chloride to control trypanosomiasis, and most farmers do not understand the rationale behind RAP. It is therefore recommended that local animal health providers be made aware on the dangers of impure drugs particularly in relation to the risk of drug resistance that could lead to acute HAT epidemics; this study recommends anti-microbial research to determine the current efficacy of trypanocides being used in Tororo district. In general, more effective extension services to teach farmers on RAP – and the importance of appropriate drug therapy more generally – could benefit the southeastern Uganda HAT endemic areas. In northern Lao PDR it is imperative to educate farmers on sanitation and hygiene as well as the benefits of simultaneously controlling *T. solium*, STH and CSF. This is particularly in important when future interventions are planned to control *T. solium* through vaccinations to improve the farmers' willingness to pay.

6.6.4 Participation of farmers and other stakeholders in zoonotic disease control

It was observed that farmers in Uganda and Lao PDR did not adequately participate in determining what the priority zoonotic diseases. This is partly due to heavy reliance on donor funding to control endemic zoonotic diseases. Furthermore, endemic zoonotic diseases are not always the priority of most governments in developing countries. In relation most farmers are not adequately aware what zoonotic diseases are. Thus it is recommended that farmers and other stakeholders should be included in identifying and control of priority zoonotic diseases. This can be achieved through setting up a platform to encourage engagement of farmers, donors and other stakeholders in mainstreaming zoonotic disease control.

REFERENCES

Abaru DE. 1985. Sleeping sickness in Busoga, Uganda, 1976–1983. *Tropical Medicine and Parasitology*; 36:72–76.

Abel PM *et al*. 2004. Retaking sleeping sickness control in Angola. *Tropical Medicine and International Health*; 9:141–148.

Adam Y *et al*. 2013. The sequential aerosol technique: a major component in an integrated strategy of intervention against riverine tsetse in Ghana. *PLoS Neglected Tropical Diseases*, 7:3:e2135.

Aguirre AA, Ostfeld RS, Tabor GM, House C and Pearl MC. 2002. Conservation medicine: ecological health in practice. Oxford University press.

Agyemang K, Dwinger RH, Jeannin P, Leperre P, Grieve AS, Bah ML and Little, DA. 1990. Biological and economic impact of trypanosome infection in N'Dama cattle managed in The Gambia. *Animal Production*; 50: 383-389.

Agyemang K, Little DA., Mattioli R, Sonko E and Janneh L. 1993. Effects of trypanosome infection and postpartum live weight change on resumption of reproductive activity in N'Dama cows. *Theriogenology*; 39: 985-995.

Ahn YY, Bagrow JP and Lehmann S. 2010. Link communities reveal multiscale complexity in networks. *Nature*; 466: 761–764. doi:10.1038/nature09182.

Ahmedin J and Hugh-Jones ME. 1995. Association of tsetse control with health and productivity of cattle in the Didessa Valley, western Ethiopia. *Preventive Veterinary Medicine;* 22: 29-40.

Ajala MK and Adesehinwa AOK. 2007. Roles and efficiency of participants in pig marketing in northern part of Nigeria. *Journal of Central European Agriculture*; 8(3): 311–326.

Albert M, Wardrop NA, Atkinson PM, Torr SJ and Welburn SC. 2015. Tsetse Fly (G.f. fuscipes) Distribution in the Lake Victoria Basin of Uganda. *PLoS Neglected Tropical Diseases* 9(4):e0003705. doi:10.1371/ journal.pntd.0003705.

Allsopp R and Hursey BS. 2004. Insecticidal control of tsetse. In The Trypanosomiases (Maudlin, I.*et al*., eds), pp.491-507, CABI Publishing.

Alston JM, Norton GW and Pardey PG. 1995. Science under scarcity. Cornell University Press, Ithaca and London.

American Veterinary Medical Association (AVMA). 2008. One Health: A new Professional Imperative*,* One Health Initiative Task Force: Final Report http://www.avma.org/onehealth/ (Accessed online 4th October 2016).

Anderson NE, Mubanga J, Fevre EM, Picozzi K, Eisler MC, Thomas R, Welburn SC. 2011. Characterisation of the wildlife reservoir community for human and animal trypanosomiasis in the Luangwa Valley, Zambia. *PLoS Neglected Tropical Diseases*; 5:e1211.

Arndt C. 1995. Grazing patterns of different land-use intensities in the Ghibe Valley, southwest Ethiopia -- analysis of herd following data. Universität Gesamthochschule Kassel, Witzenhausen, Germany.

Arndt K. 1996. Effects of increasing land-use intensity generated by tsetse-control on resource allocation and property institutions in Gullele, south-west Ethiopia. Universität Gesamthochschule Kassel, Witzenhausen, Germany.

ASEAN. 2014. Minimum wages levels across ASEAN.

http://www.aseanbriefing.com/news/2013/04/16/minimum-wage-levels-across-asean.html. Accessed 6/4/2014.

Ash A, Okello A, Khamlome B, Inthavong P, Allen J and Thompson RAC. 2015. Controlling *Taenia solium* and soil transmitted helminths in a northern Lao PDR village: Impact of a triple dose albendazole regime. *Acta Tropica*. http://dx.doi.org/10.1016/j.actatropica.2015.05.018

Ashford RW. 1997. What it takes to be a reservoir host. *Belgian Journal of Zoology*; 127:85–90.

Atun R, de Jongh T, Secci F, Ohiri K and Adeyi O. 2010. Integration of targeted health interventions into health systems: a conceptual framework for analysis. *Health Policy and Planning*; 25: 104–111.

Bain JS. 1968. Industrial organization, 2nd ed. New York: John Wiley and Sons.

Bajardi P, Barrat A, Natale F, Savini L and Colizza V. 2010. Dynamical Patterns of Cattle Trade Movements. *PLoS ONE* 6(5): e19869. doi:10.1371/journal.pone.0019869.

Balyeidhusa ASP, Kironde FAS and Enyaru JCK. 2012. Apparent lack of a domestic animal reservoir in gambiense sleeping sickness in northwest Uganda. *Veterinary Parasitology*;187:157–167.

Baptist R. 1992. Derivation of steady-state herd productivity. *Agricultural Systems*; 39(3): 253-272.

Barabási AL and Bonabeau E. 2003. Scale-free networks. *Scientific American*; 288(5): 60-69.

Bardosh K, Inthavong P, Xayaheuang S and Okello AL. 2014. Controlling parasites, understanding practices: The biosocial complexity of a One Health intervention for neglected zoonotic helminths in northern Lao PDR. *Social Science & Medicine*; 120: 215-223.

Barennes H, Tran DS, Latthaphasavang V, Preux PM and Odermatt P. 2008. Epilepsy in Lao PDR: From research to treatment intervention. *Neurology Asia;* 13: 27–31.

Barrett MP, Burchmore RJS, Stich A, Lazzari JO, Frasch AC, Cazzulo JJ and Krishna S. 2003. The trypanosomiasis. *The Lancet*; 362: 1469-1480.

Barrett MP. 2001. Veterinary link to drug resistance in human African trypanosomiasis? *The Lancet*; 358: 603-604.

Bassett TJ. 1993. Land use conflicts in pastoral development in northern Côte d'Ivoire: in T.J. Bassett and D.E. Crummey (eds.), Land in African Agrarian Systems. Madison, WI: University of Wisconsin Press, pp. 131-154.

Basuno E, Yusdja Y and Ilham N. 2010. Socio-economic impacts of avian influenza outbreaks on small-scale producers in Indonesia. *Transboundary and Emerging Diseases*; 57(1-2):7-10. doi: 10.1111/j.1865-1682.2010.01121.x.

Batchelor NA, Atkinson PM, Gething PW, Picozzi K, Fèvre EM, Kakembo ASL and Welburn SC. 2009. Spatial predictions of Rhodesian human African trypanosomiasis (sleeping sickness) prevalence in Kaberamaido and Dokolo, two newly affected districts of Uganda. *PLoS Neglected Tropical Diseases*; 3:e563.

Bauer B, Gitau D, Oloo FP and Karanja SM. 2006. Evaluation of a preliminary title to protect zero-grazed dairy cattle with insecticide-treated mosquito netting in western Kenya. *Tropical Animal Health and Production*; 38(1):29–34.

Bausch D and Cline BL. 1995. The impact of control measures on urinary schistosomiasis in primary school children in northern Cameroon: a unique opportunity for controlled observations. *American journal of tropical medicine and hygiene*; 53(6):577-580.

Bauer B *et al*. 2011. Managing tsetse transmitted trypanosomosis by insecticide treated nets: an affordable and sustainable method for resource poor pig farmers in Ghana. *PLoS Neglected Tropical Diseases*; 5(10):e1343.

Bauer B *et al*. 1995. Successful application of deltamethrin pour-on to cattle in a campaign against tsetse flies (*Glossina* spp.) in the pastoral zone of Samorogouan, Burkina Faso. *Tropical Medicine and Parasitology*; 46:183–189.

Bechir M, Schelling E, Wyss K, Daugla DM, Daoud S, Tanner M and Zinsstag J. 2014. An innovative approach combining human and animal vaccination campaigns in nomadic settings of Chad: experiences and costs. *Medicine tropicale (Mars): revue du Corps de santé colonial*; 64:497-502.

Berentsen PBM, Dijkhuizen AA and Oskam AJ. 1992. A dynamic model for cost-benefit analyses of Foot and Mouth disease control strategies. *Preventive Veterinary Medicine*; 12: 229-245.

Berrang Ford L *et al*. 2006. Sleeping sickness in Uganda: revisiting current and historical distributions. *African Health Sciences;* 6:223–231.

Berrang Ford L *et al*. 2010. Sleeping sickness in southeastern Uganda: a spatio-temporal analysis of disease risk, 1970–2003. *Vector Borne and Zoonotic Diseases*; 10:977–988.

Berrang-Ford L, Lundine J and Breau S. 2011.Conflict and human African trypanosomiasis. *Social Science and Medicine*; 72: 398–407.

Berrang Ford L. 2007. Civil conflict and sleeping sickness in Africa in general and Uganda in particular. *Conflict and Health*; 1:6.

Bell DC, Atkinson JS and Carlson JW. 1999. Centrality measures for disease transmission networks. *Social Networks; 21(1)*: 1–21.

Bethony J, Brooker S, Albonico M, Geiger SM, Loukas A, Diemert A, Hotez PJ. 2006. Soil-transmitted helminth infections: ascariasis, trichuriasis and hookworm. *Lancet*; 367: 1521–1532.

Bhattarai R, Budke CM, Carabin H, Proan˜o JV, Flores-Rivera J, *et al*. 2012. Estimating the Non-Monetary Burden of Neurocysticercosis in Mexico. *PLoS Neglected Tropical Diseases*; 6(2): e1521. doi:10.1371/journal.pntd.0001521.

Bhattarai R, Carabin H and Budke C. 2003. The Burden of Cysticercosis. In: Novel aspects on cysticercosis and neurocysticercosis, edited by Sibat HS.2013. InTech. ISBN 978-953-51-0956-3.

Blacksell SD, Khounsy S, Boyle DB, Gleeson LJ, Westbury HA and Mackenzie JS. 2005. Genetic typing of classical swine fever viruses from Lao PDR by analysis of the 5' non-coding region. *Virus Genes*; 31(3):349-355.

Blacksell SD. 2010.Classical swine fever and emerging diseases in southeast Asia. Australian Center for International Agricultural Research, proceedings number 94. ISBN: 1 86320 286 2

Boehlje, MD and Eidman, VR. 1984. Farm Management. John Wiley and Sons. New York. United States of America.

Borgatti SP, Carley K and Krackhardt D. 2006. Robustness of centrality measures under conditions of imperfect data. *Social Networks*; 28: 124–136.

Booker S, Clements ACA and Bundy DAP. 2006. Global epidemiology, ecology and control of soil-transmitted helminth infections. *Advanced Parasitology*; 62: 221–261. doi:10.1016/S0065-308X(05)62007-6

Bourn DM. 1978. Cattle, rainfall and tsetse in Africa. *Journal of Arid Environments;* 1:49-61.

Bouyer J *et al*. 2010. Control methods in trypanosomosis. In: LeFèvre PC *et al*., eds. *Infectious and parasitic diseases of livestock.* Paris, Lavoisier: 1927–1959.

Bouyer J *et al*. 2006. Tsetse control in cattle from pyrethroid footbaths. *Preventive Veterinary Medicine*; 78(3–4): 223–238.

Bouyer J *et al*. 2010. Stratified entomological sampling in preparation for an area-wide integrated pest management program: the example of *Glossina palpalis gambiensis* (Diptera: Glossinidae) in the Niayes of Senegal. *Journal of Medical Entomology*; 47:543-552.

Brandl FE. 1986. The use of a herd simulation model for the estimation of direct economic benefits of tsetse control - application to the pastoral zone of Sideradougou, Burkina Faso. *Revue de la Elevage et Medicine Veterinaie en Pays Tropicale* 38(4): 364-370.

Brandl FE. 1988. Farming and resource economics in the tropics. Vol. 1 Economics of Trypanosomiasis Control in Cattle. Wissenschaftsverlag: Kiel, Germany, pp 220.

Brightwell R *et al*. 1987. A new trap for *Glossina pallidipes*. *Tropical Pest Management*; 33:151–189.

Brightwell R, Dransfield RD and Kyorku C. 1991. Development of a low-cost tsetse trap and odour baits for *Glossina pallidipes* and *G. longipennis* in Kenya. *Medical and Veterinary Entomology*; 5:153–164.

Bruce D and Nabarro D. 1903. Progress report on sleeping sickness in Uganda. *Reports of the Sleeping Sickness Commission of the Royal Society*; 1:11–88.

Buxton PA. 1955. The natural history of tsetse flies. An account of the biology of the genus *Glossina* (Diptera). London, H.K. Lewis.

Brun R, Blum J, Chappuis F and Burri C. 2010. Human African trypanosomiasis. *Lancet*; 375: 148–59.

Bucheton B, MacLeod A and Jamonneau V. 2011.Human host determinants influencing the outcome of *Trypanosoma brucei gambiense* infections. *Parasite Immunology*; 33:438–447.

Buckingham K. 1993. A note on HYE (Healthy Years Equivalent). *Journal of Health Economics;* 11: 301-309.

Bundy DAP and Cooper ES. 1989.Trichuris and trichuriasis in humans. *Advances in Parasitology*; 28:107–173. [PubMed: 2683614].

Bundy DAP, Chan MS, Medley GF, Jamison D, Savioli L. 2004. Intestinal Nematode Infections. In: Murray CJL, Lopez AD, Mathers CD, editors. Global Epidemiology of Infectious Disease. WHO: 243-300.Global Burden of Disease Volume IV.
http://whqlibdoc.who.int/publications/2004/9241592303.pdf

Butts CT. 2008. Social network analysis with sna. *Journal of statistical software*; 24(6): 1-51.

Camara M *et al*. 2006. Genetic and morphometric evidence for population isolation of *Glossina palpalis gambiensis* from Loos islands, Guinea. *Journal of Medical Entomology*; 43:853–860.

Camus E.1995. Evaluation of trypanosomiasis and brucellosis control in cattle herds in Ivory Coast. *Agriculture and Human Values*; 12(2): 90-94.

Carabin H, Krecek RC, Cowan LD, Michael L, Foyaca-Sibat H, Nash T and Willingham AL. 2006. Estimation of the cost of Taenia solium cysticercosis in Eastern Cape Province, South Africa. *Tropical Medicine and International Health*; 11(6): 906–916.

Carabin H, Budke CM, Cowan LD, Willingham AL and Torgerson PR. Methods for assessing the burden of parasitic zoonoses: echinococcosis and cysticercosis. 2005. *Trends in Parasitology*; 21(7): 327-346.

Carpio A, Escobar A, and Hauser WA: Cysticercosis and Epilepsy: A Critical Review. 1998. *Epilepsia,* 39(10): 1025- 1040.

Castellani A. 1903. Presence of *Trypanosoma* in sleeping sickness. *Reports of the Sleeping Sickness Commission of the Royal Society*; 1:3–10.

Cecchi G *et al*. 2009. Towards the *atlas* of human African trypanosomiasis. *International Journal of Health Geographics*; 8: 15.

Challier A. 1982. The ecology of tse-tse (*Glossina* sp.) (Diptera, Glossinidae): a review (1970–1981). *Insect Science and its Application*; 3:97–143.

Christy C. 1903. The distribution of sleeping sickness, filarial perstans, etc, in east equatorial Africa. *Report of the Sleeping Sickness Commission of the Royal Society;* 2:2–8.

Clauset A., Moore C and Newman MEJ. 2008. Hierarchical structure and the prediction of missing links in networks. *Nature*; 453: 98–101.

Cleaveland S, Kaare M, Tiringa P, Mlengeya T and Barrat J. 2003. A dog rabies vaccination campaign in rural Africa: impact on the incidence of dog rabies and human dog-bite injuries. *Vaccine*; 21 (17-18): 1965-1973.

Cline BL and Hewlett BS. 1996. Community-based approach to schistosomiasis control. *Acta Tropica*; 61(2):107-119

Coale AJ and Demeny P .1966. Regional Model Life Tables and Stable Population, Princeton University Press, Princeton, N.J. 1966.

Conlan J, Khounsy S, Inthavong P, Fenwick S, Blacksell S and Thompson RCA. 2008. A review of taeniasis and cysticercosis in the Lao People's Democratic Republic. *Parasitology International*; 57: 252–255.

Conlan JV, Khamlome B,Vongxay K, Elliot A, Pallant L, Sripa B, Blacksell SD, Fenwick S and Thompson RCA. 2012. Soil-Transmitted Helminthiasis in Lao PDR: A Community-Wide Cross-Sectional Study of Humans and Dogs in a Mass Drug Administration Environment. *American Journal of Tropical Medicine and Hygiene*; 86(4): 624–634.doi:10.4269/ajtmh.2012.11-0413.

Conlan JV, Sripa B, Attwood S and Newton PN. 2011. A review of parasitic zoonoses in a changing southeast Asia. *Veterinary Parasitology*; 182:22–40.

Commission on Epidemiology and Prognosis, International League Against Epilepsy. 1993. Guidelines for Epidemiologic Studies on Epilepsy. *Epilepsia;* 34(4):592-596.

Conlan J, Khounsy S, Inthavong P, Fenwick S, Blacksell S and Thompson RCA. 2008. A review of taeniasis and cysticercosis in the Lao People's Democratic Republic. *Parasitology International*; 57: 252–255.

Conlan JV, Khamlome B,Vongxay K, Elliot A, Pallant L, Sripa B, Blacksell SD, Fenwick S and Thompson RCA. 2012. Soil-Transmitted Helminthiasis in Lao PDR: A Community-Wide Cross-Sectional Study of Humans and Dogs in a Mass Drug Administration Environment. American *Journal of Tropical Medicine and Hygiene*; 86(4): 624–634.doi:10.4269/ajtmh.2012.11-0413.

Crompton DWT. 2001. Ascaris and ascariasis. *Advances in Parasitology*; 48:285–375. [PubMed:11013758]

Danon L, Ford AP, House T, Jewell CP, Keeling MJ, Roberts GO, Ross JV and Vernon MC. 2011. Networks and the epidemiology of infectious disease. *Interdisciplinary perspectives on infectious diseases*; 2011:284909.
http://dx.doi.org/10.1155/2011/284909

Davis S, Aksoy S and Galvani A. 2011.A global sensitivity analysis for African sleeping sickness. *Parasitology*; 138:516–526.

Dean TJ, Joel GB, Anthony RM, George AMC, David BE, Prabhat J, Anne M and Philip M. 2006. Disease Control Priorities in Developing Countries, 2nd edition. The World Bank and Oxford University press. ISBN-10: 0-8213-6179-1. http://www.ncbi.nlm.nih.gov/books/NBK11728/

Debertin D.L, 2012. Agricultural Production Economics second edition. New Jersey: MacMillan Publishing Company . ISBN: 0-02-328060-3.

Deckers N and Dorny P. 2010. Immunodiagnosis of Taenia solium taeniosis/cysticercosis. *Trends in Parasitology*; 26(3): 137-144. doi: 10.1016/j.pt.2009.12.008

Deckert A, Gow S, Rosengren L, Léger D, Avery B, Daignault D, Dutil L, Reid-Smith R and Irwin R. Canadian Integrated Program for Antimicrobial Resistance Surveillance (CIPARS) Farm Program: results from finisher pig surveillance. 2010. *Zoonoses Public Health*; 57 (1): 71-84. doi: 10.1111/j.1863-2378.2010.01356.x.

Delgado C, Hazell P, Hopkins J and Kelly V, 1994. Promoting Intersectoral Growth Linkages through Agricultural technology and Policy Reform. *American Journal of Agricultural Economics*; 76(5): 1166-1171.

Delignette-Muller ML and Dutang C. 2015. fitdistrplus: An R Package for Fitting Distributions. *Journal of statistical software*; 64(4): 1-34.

Delgado C, Rosegrant M, Steinfeld H, Ehui SKand Courbois C. 1999. Livestock to 2020: the next food revolution. Food, Agriculture, and the Environment Discussion paper 28. International Food Policy Research Institute.

Devleesschauwer B, Havelaar AH, de Noordhout CM, Haagsma JA, Praet N, Dorny P, Duchateau L, Torgerson PR, Oyen HV and Speybroeck N. 2014. DALY calculation in practice: a stepwise approach. *International Journal of Public Health*; 59(3): 571-574. DOI 10.1007/s00038-014-0553-y.

Devleesschauwer B, McDonald S, Haagsma J, Praet N, Havelaar A and Speybroeck N (2013). DALY: The DALY Calculator - A GUI for stochastic DALY calculation in R. R package version 1.2.0. http://cran.rproject.org/package=DALY

de Silva NR, Chan MS and Bundy DAP. 1997. Morbidity and mortality due to ascariasis: re-estimation and sensitivity analysis of global numbers at risk. *Tropical Medicine and International Health*; 2(6): 519–528.

Dijkhuizen AA, Renkema JA and Stelwagen J. 1991. Modelling to support animal health control. *Agricultural Economics*; 5: 263-277.

Dijkhuizen AA, Huirne RBM and Jalvingh AW. 1995. Economic analysis of animal diseases and their control. *Preventive Veterinary Medicine*; 25: 135-149.

Ding D, Hong Z, Wang W, Wu JZ, De Boer HM, Prilipko L and Sander JW. 2006. Assessing the Disease Burden Due to Epilepsy by Disability Adjusted Life Year in Rural China. *Epilepsia,* 47(12):2032–2037.

Doran M and Van den Bossche P. 1999. An assessment of the socio-economic impact of bovine trypanosomosis and its control in the southern African region. Paper presented at the 25th meeting of the ISCTRC, Mombasa, Kenya, October 1999.

Dorny P, Brandt J, Zolia A and Geerts S. 2003. Immunodiagnostic tools for human and porcine cysticercosis. *Acta Tropica*; 87:79-86.

Dransfield, R. and Brightwell, R. 2004. Community Participation in Tsetse Control: the Principles, Potential and Practice. In Maudlin, I., Holmes, P., Miles, M. (Eds.) The Trypanosomiases. CABI Publishing Wallingford, pp. 533–546.

Duncan JW and Strogatz SH. 1998. Collective dynamics of 'small-world' networks. *Nature;* 393: 440-442. doi:10.1038/30918.

Dujardin JP, Kaba D and Henry AB. 2010. The exchangeability of shape. *BMC Research Notes*; 3:266.

Dukes TW. 2000. That other branch of medicine: an historiography of veterinary medicine from a Canadian perspective. *Canadian Bulletin of Medical History*; 17:229–243.

Dutton JE. 1902. Note on a *Trypanosoma* occurring in the blood of man. *British Medical Journal*; 2177:881–884.

Eisler MC, Torr SJ, Coleman PG., Machila, N and Morton JF. 2003. Integrated control of vectorborne diseases of livestock — pyrethroids: panacea or poison? *Trends in Parasitology*; 19: 341–345.

Eom KS, Yong TS, Sohn WM, Chai JY, Min DY, Rim HJ, Jeon HK, Banouvong V, Insisiengmay B and Phommasack B. 2014. Prevalence of Helminthic Infections among Inhabitants of Lao PDR. *Korean Journal of Parasitology;* 52(1): 51-56.

Evison C and Kathuria KDS. 1984. A review affixed wing aerial spraying against *Glossina morsitans* in Zambia during the period 1968-1978. Ministry of Agriculture and Water Development, Lusaka. 15 pp.

Faria JC. 2012. Resources of Tinn-R GUI/Editor for R Environment.UESC, Ilheus, Brasil.

FAO. 2003. Veterinary Public Health and control of zoonoses in developing countries, Summary of comments and discussion from the FAO/WHO/OIE Electronic Conference, FAO Corporate Document Repository.

FAO. 2016. Country pasture/forage profile, Uganda.
http://www.fao.org/ag/agp/agpc/doc/counprof/PDF%20files/Uganda_English.pdf

Feldman U. 2004. The sterile insect technique as a component of area-wide integrated pest management of tsetse. In: Maudlin, I.,Holmes, P.H., Miles, M.A. (Eds.), The trypanosomiases. Oxfordshire, CABI Publishing, pp. 565-582.

Feron A, d'Ieteren GDM., Durkin J, Itty P, Kakiese O, Maehl JHH, Mulungo M, Nagda SM, Paling RW, Pelo M, Rarieya JM, Sheria M, Thorpe W and Trail JCM. 1987. Productivity of ranch N'Dama cattle under trypanosomiasis risk: In ILCA / ILRAD (eds.) Livestock Production in Tsetse Affected Areas of Africa. Nairobi, pp. 246-250.

Fetrow J, Madison JB and Galligan DT. 1985. Economic decision making in veterinary practice: a method for field use. *Journal American Veterinary Medical Association*; 186: 792-797.

Fèvre EM, Coleman PG, Odiit M, Magona JW, Welburn SC and Woolhouse ME. 2001. The origins of a new *Trypanosoma brucei rhodesiense* sleeping sickness outbreak in eastern Uganda. *Lancet*; 358:625–628.

Fèvre EM, Coleman PG, Welburn SC and Maudlin I. 2004. Reanalyzing the 1900–1920 sleeping sickness epidemic in Uganda. *Emerging Infectious Diseases*; 10:567–573.

Fèvre EM, Picozzi K, Fyfe J, Waiswa C, Odiit M, Coleman PG and Welburn SC. 2005. A burgeoning epidemic of sleeping sickness in Uganda. *Lancet*; 366:745–747.

Fèvre EM, Bronsvoort BM, Hamilton KA and Cleaveland S. 2006. Animal movements and the spread of infectious diseases. *TRENDS in Microbiology*; 14(3): 125-131.

Flisser A. 1992. Neurocysticercosis in an Orthodox Jewish community in New York City. New England Journal of Medicine 327, 692–695.

Ford J. 1971. The role of the trypanosomiasis in African ecology. A study of the tsetse fly problem. Oxford, Clarendon Press.

Ford J, Nash TAM and Welch JR. 1970. Control by clearing of vegetation. In: Mulligan HW, ed. *The African trypanosomiases*. London, George Allen and Unwin :543–563.

Forget G and Lebel J. 2001. An ecosystem approach to human health. *International Journal* of *Occupational and Environmental Health;* 7:3-36.

Food and Agriculture Organization of the United Nations. 2011. A value chain approach to animal diseases risk management-Technical foundations and practical framework for field application. Animal Production and Health Guidelines. No. 4. Rome.

Forrer A, Vounatsou P, Sayasone S, Vonghachack Y, Bouakhasith D, Utzinger J, *et al*. 2015. Risk Profiling of Hookworm Infection and Intensity in Southern Lao People's Democratic Republic Using Bayesian Models. *PLoS Neglected Tropical Diseases;* 9(3):e0003486.

Fortunato S. 2010.Community detection in graphs. *Physics Reports* ;486: 75–174.

Fournet F, Traore S and Hervouet JP. 1999. Effects of urbanization on transmission of human African trypanosomiasis in a suburban relict forest area of Daloa, Cote d'Ivoire. *Transactions of the Royal Society of Tropical Medicine and Hygiene*; 93:130–132.

Fox RGR, Mmbando SO, Fox MS and Wilson A. 1993. Effect on herd health and productivity of controlling tsetse and trypanosomiasis by applying deltamethrin to cattle. *Tropical Animal Health and Production*; 25: 203-214.

Freeman LC. 1996. Some antecedents of social network analysis. *Connections*; 19: 39–42.

Frisvold G and Ingram K. 1995. Sources of agricultural productivity growth and stagnation in sub-Saharan Africa. *Agricultural Economics*; 13: 51-61.

Funk S, Nishiura H, Heesterbeek H, Edmunds WJ and Checchi F**.** 2013**.** Identifying transmission cycles at the human–animal interface: the role of animal reservoirs in maintaining gambiense human African trypanosomiasis. *PLoS Computational Biolology; 9:* e1002855.

Gabre-Madhin E. Z. 2001. Market institutions, transaction costs and social capital in Ethiopian Grain Market, IFPRI Research Report 124, Washington, DC: IFPRI.

Galligan DT, Marsh WE and Madison JB. 1987. Decision making in veterinary practice: expected value and risk as dual utility scales. *Preventive Veterinary Medicine*; 5: 79-86.

García HH, Gonzalez AE, Evans CAW, Gilman RH and Cysticercosis Working Group in Peru. 2003. *Taenia solium* cysticercosis. Lancet; 362(9383): 547–556.

Garcia HH, Gonzalez AE, Tsang VCW, O'neal SE, Llanos – Zavalaga F, Gonzalvez G, Romero J, Rodriguez S, Moyano LM, Ayvar V, Diaz A, Hightower A, Craig PS, Lightowlers MW, Gauci CG, Leontsini E and Gilman RH. 2016. Elimination of Taenia solium Transmission in Northern Peru. *The New England Journal of Medicine*; 374(24): 2335-2344.

Gausi JK, Safalaoh AC, Banda JW and Ng'ong'ola DH. 2004. Characterization of the smallholder poultry marketing systems in rural Malawi: A case study of Malingunde Extension Planning Area. *Livestock Research for Rural Development*; 16 (97).

Gavidia CM, Verastegui MR, Garcia HH, Lopez-Urbina T, Tsang VCW, Pan W, *et al*. 2013. Relationship between Serum Antibodies and *Taenia solium* Larvae Burden in Pigs Raised in Field Conditions. *PLoS Neglected Tropical Diseases* 7(5): e2192. doi:10.1371/journal.pntd.0002192.

Geerts S, Holmes PH, Diall O and Eisler MC. 2001. African bovine trypanosomiasis: the problem of drug resistance. Trends in Parasitology; 17(1): 25-28.

Geerts S and Holmes PH. 1997. Drug management and parasite resistance in animalt rypanosomiasis in Africa. Proceedings of the 24th Meeting of the International Scientific Council for Trypanosomiasis Research and Control (ISCTRC), Maputo, Mozambique, OAU/ISTRC, pp. 371-385.

Geerts S and Holmes PH. 1988. Drug management and parasite resistance in bovine trypanosomiasis in Africa. Rome: FAO, *PAAT Tech Sci Ser* : 1.

Gemechu G, Tibebu and Alemayehu K.1997. "Community-based tsetse and trypanosomiasis control pilot programme using deltamethrin insecticide in Konso, Southern Ethiopia," FRP Technical Pamphlet No. 16. FARM Africa. Addis Ababa: Ethiopia.

Gibbs EPJ .2005. Emerging zoonotic epidemics in the interconnected global community. *Veterinary Record;* 157:673-679.

Gilbert MC, Jenner J, Pender D, Rogers J, Slingenbergh and Wint W. 1999. "The development and use of the Programme Against African Trypanosomiasis Information System(PAATIS)." Paper presented at the 25th meeting of the ISCTRC, Mombasa, Kenya, October 1999.

Gilman RH, Gonzalez AE, Llanos-Zavalaga F, Tsang VCW and Garcia HH. 2012. Prevention control of *Taenia solium* taeniasis/cysticercosis in Peru. Pathogens and Global Health; 106(5): 312-318.

Gittinger JP. 1982. Economic Analysis of Agricultural Projects. Baltimore and London: Johns Hopkins University Press, 2nd edition.

Goodman HL. 1961. Snowball sampling. *Annals of Mathematical Statistics;* 32: 148–170.

Gonzalez AE, Falcon N, Gavidia HH, Tsang VC, Bernal T, Romero M and Gilman EH. 1997. Treatment of porcine cysticercosis with oxfendazole: a dose-response trial. *Veterinary Records*; 141:420-422

Gonzalez AE, Falcon N, Gavidia HH, Tsang VC, Bernal T, Romero M and Gilman EH. 1998. Time-response curve of oxfendazole in the treatment of swine cysticercosis. *American Journal of Tropical Medicine and Hygiene*; 59: 832-836.

Gonzalez AE, Garcia HH, Gilman RH, Tsang VCW. 2003. Control of Taenia solium. *Acta Tropica*; 87: 103-109.

Gooding RH and Krafsur ES. 2005. Tsetse genetics: contributions to biology, systematic and control of tsetse flies. *Annual Review of Entomology*, 50:101–123.

Goodwin LG. 1970. The pathology of African Trypanosomiasis. *Transactions of the Royal Society of Tropical Medicine and Hygiene*; 64(6): 797-812.

Gould RV.1987. Measures of betweenness in non-symmentric networks. *Social Networks*; 9: 277–282.

Goutex JP and Lancien J. 1986. Le piege pyramidal a tsetse (Diptera: Glossinidae) pour la capture et la lutte. Essais comparatifs et description de nouveaux systemes de capture [The pyramidal tsetse (Diptera: Glossinidae) trap for capture and control. Comparative tests and description of new capture systems]. *Tropical Medicine and Parasitology;* 37:61–66.

Govereh J. 1999. Impacts of animal disease control on migration, livestock adoption and farm capital accumulation: Zambezi Valley, Zimbabwe. Ph.D. dissertation, Michigan State University, East Lansing, Michigan.

Grebaut P, Bena JM, Manzambi EZ, Mansinsa P, Khande V, Ollivier G, Cuny G and Simo G. 2009. Characterization of sleeping sickness transmission sites in rural and periuban areas of Kinshasa (Republique Democratique du Congo). *Vector-Borne and Zoonotic Diseases*; 9:631–636.

Gre´pin KA and Reich MR. 2008. Conceptualizing Integration: A Framework for Analysis Applied to Neglected Tropical Disease Control Partnerships. PLOS Neglected Tropical Diseases; 2 (4): e174. doi:10.1371/journal.pntd.0000174.

Haan C and Umali D. 1992. Public and private sector roles in the supply of veterinary services. *World Bank.* http://www.rrojasdatabank.info/12agrisym/agrisym133-145.pdf

Habtemariam T, Ruppanner R, Riemann HP and Theis JH. 1983. Evaluation of trypanosomiasis control alternatives using an epidemiologic simulation model. *Preventive Veterinary Medicine*; 1: 147-156.

Hall DC, Ehui S and Delgado C. 2004. The livestock revolution, food safety, and small-scale farmers: why they matter to us all. *Journal of Agricultural and Environmental Ethics*; 17(4-5): 425–444.

Hanneman RA and Mark R. 2005. Introduction to social network methods. Riverside, CA: University of California, Riverside (published in digital form at http://faculty.ucr.edu/~hanneman/)

Hardstaff JL, Häsler B and Rushton JR. 2015. Livestock trade networks for guiding animal health surveillance. *BMC Veterinary Research*; 11:82. DOI 10.1186/s12917-015-0354-4.

Harimanana A, Chivorakul P, Souvong V, Preux PM and Barennes H. 2013. Is insufficient knowledge of epilepsy the reason for low levels of healthcare in the Lao PDR? *BMC Health Services Research*; 13:41.

Haydon DT *et al*. 2002. Identifying reservoirs of infection: a conceptual and practical challenge. *Emerging Infectious Diseases*; 8:1468–1473.

Haythornthwaite C. 1996. Social network analysis: An approach and technique for the study of information exchange. *Library & Information Science Research*; 18(4): 323–342.

Heckathorn DD. 1997. Respondent-driven sampling: a new approach to the study of hidden populations. *Social Problems*; 44(2): 174-199.

Heider F.1946: Attitudes and cognitive organization. *Journal of Psychol*ogy ; 21: 107–112.

Hendrichs J *et al*. 2005. Strategic options in using sterile insects for area-wide integrated pest management. In: Dyck VA, Hendrichs J, Robinson AS, eds. *Sterile insect technique. Principles and practice in area-wide integrated pest management*. Dordrecht, Springer :563–600.

Herbert Kyeyamwa , Wim Verbeke , Stijn Speelman , John Opuda-Asibo & Guido Van Huylenbroeck . 2008. Structure and Dynamics of Livestock Marketing in Rural Uganda: Constraints and Prospects for Research and Development. *Journal of International Food&AgribusinessMarketing*; 20(4):59-89.

Hirch BT, Prange S, Hauver SA and Gehrt SD. 2013. Raccoon Social Networks and the Potential for Disease Transmission. *PLoS One*; 8(10): e75830.

Hobbs JE. 1997. Measuring the importance of transaction costs in cattle marketing. *American Journal of Agricultural Economics*; 79: 1083-1095.

Holmes PH.1997. New approaches to the integrated control of trypanosomiasis. *Veterinary Parasitology*; 71: 121-135.

Holtzman JS and Kulibaba NP. 1994. Livestock marketing in pastoral Africa: policies to increase competitiveness, efficiency and flexibility. In I. Scoones (Ed.), Living with uncertainty. New directions in pastoral development in Africa. London Intermediate Technology Publications Ltd (pp. 79–94).

Hopkins TK and Wallerstein I. 1986. Commodity chains in the world-economy prior to 1800. *Review (Fernand Braudel Center)*; 10 (1): 157-170.

Hotez PJ, Brooker S, Bethony JM, Bottazzi ME, Loukas A and Xiao S. 2004. Hookworm Infection. *New England Journal of Medicine*; 351:799-807.

Hotez PJ, Alvarado M, Basa´n˜ez MG, Bolliger I, Bourne R, *et al*. 2014. The Global Burden of Disease Study 2010: Interpretation and Implications for the Neglected Tropical Diseases. *PLoS Neglected Tropical Diseases;* 8(7): e2865. doi:10.1371/journal.pntd.0002865.

Hubálek Z. 2003. Infectious Diseases: Anthroponoses, Zoonoses, and Sapronoses. *Emerging Infectious Diseases*; 9(3): 403-404.

Huberman BA and Adamic L. 1999. Growth dynamics of the World-Wide Web. *Nature*; 401: 131

Hyunh TTT, Aarnink AJA, Drucker A and Verstegen MWA. 2006. Pig Production in Cambodia, Lao PDR,Philippines, and Vietnam: A Review. *Asian Journal of Agriculture and Development;* 3(1-2*):* 69-90.

Jahnke HE. 1974. The Economics of controlling tsetse flies and cattle trypanosomiasis examined for the case of Uganda. Forschungsberichte der africa-studienstelle 48, IFO – Intitut für Wirtschaftsforschung, Weltforum Verlag, Munich, Germany, 359 pp.

Jahnke HE, Tacher G, Keil P and Rojat D. 1988. Livestock production in tropical Africa, with special reference to the tsetse-affected areas. In: ILCA/ILRAD, Livestock Production in Tsetse Affected Areas of Africa. Nairobi: ILCA/ILRAD.

James R, Croft DP, Krause J. 2009. Potential banana skins in animal social network analysis. *Behavioural Ecology and Sociobiology*, 63(7): 989-997.

James AD. 1987. Principles and problems of benefit-cost analysis for disease control schemes. In: KS Howe and JP McInemey (Editors), Disease in Livestock: Economics and Policy. EUR 11285 EN, Commission of the European Communities, Brussels, pp. 69-77.

James AD and Carles AB .1996. Measuring the productivity of grazing and foraging livestock. *Agricultural Systems;* 52: 271-291.

Jeon HK, Yong TS, Sohn WM, Chai JY, Min MY, Rim HJ, Insisiengmay B and Eom KS. 2013. Human Neurocysticercosis Case and an Endemic Focus of *Taenia solium* in Lao. *Korean Journal of Parasitology; 51 (5): 599-602.*

Jeong H, Tombor B, Albert R, Oltvai ZN and Barabási AL. 2000. The large-scale organization of metabolic networks. *Nature;* 407: 651–654.

Jordan AM. *Trypanosomiasis control and African rural development*. London, Longman, 1986.

Jordan AM, 1993. Tsetse-flies (Glossinidae). In: Lane RP, Crosskey RW, eds. *Medical insects and arachnids*. London, Chapman and Hall, 1993:333–388.

Kabasa JD. 2007. Public–private partnership works to stamp out sleeping sickness in Uganda. *Trends in Parasitology*; 23(5):191–192.

Kajunguri D, Hargrove JW, Ouifki R, Mugisha JY, Coleman PG and Welburn SC. 2014. Modelling the use of insecticide-treated cattle to control tsetse and Trypanosoma brucei rhodesiense in a multi-host population. *Bulletin of Mathematical biology*; 76(3):673-696. doi: 10.1007/s11538-014-9938-6.

Kaplinsky R and Morris M. 2000. A handbook for value chain research. IDRC. https://www.ids.ac.uk/ids/global/pdfs/VchNov01.pdf

Kalinka AT and Tomancak P. 2011. linkcomm: an R package for the generation, visualization, and analysis of link communities in networks of arbitrary size and type. *Bioinformatics*; 27(14):2011-2012.

Kaw BC. 2003. Nipah virus outbreak in Malaysia. *Journal of Clinical Virology;* 26 (3): 265-275.

Keeling MJ and Eames KT. 2005. Networks and epidemic models. *Journal of the Royal Society Interface*; 2(4): 295–307. doi:

Klassen W. 2005. Area-wide integrated pest management and the sterile insect technique. In: Dyck VA, Hendrichs J, Robinson AS, eds. *Sterile insect technique: principles and practice in area-wide integrated pest management*. Dordrecht, Springer :39–68.

Kleinberg J. 1999. Authoritative sources in a hyperlinked environment. *Journal of the Association for Computing Machinery (JACM*); 46: 604–632.

Klovdahl AS. 1985. Social networks and the spread of infectious diseases: the AIDS example. *Social Science and Medicine;* 21(11): 1203-1216.

Knipling EF. 1955. Possibilities of insect control or eradication through the use of sexually sterile males. *Journal of Economic Entomology*; 48(4):459–466.

Koerner T, de Raadt P and Maudlin I. 1995. The 1901 Uganda sleeping sickness epidemic revisited — a case of mistaken identity? *Parasitology Today*; 11: 303–306.

Kopytoff I. 1986. The cultural biography of things :commoditization as process. In A. Appadurai (Ed.),The social life of things: Commodities in cultural perspective (pp. 64–91). Cambridge: Cambridge University Press.

Koschu¨tzki D, Lehmann KA, Peeters L, Richter S, Tenfelde-Podehl D and Zlotowski O. 2005: Centrality indices. In: Brandes, U., and T. Erleback (eds), Network Analysis. pp. 16–61. Springer, Berlin.

Krafsur ES. 2009. Tsetse flies: Genetics, evolution, and role as vectors. *Infection, Genetics and Evolution; 9*: 124–141.

Krause J, Croft DP and James R. 2007. Social network theory in the behavioural sciences: potential applications. *Behavioral Ecology and Sociobiology*; 62:15–27.

Krause J, Lusseau D and James R. 2009. Animal social networks: an introduction. . *Behavioral Ecology and Sociobiology* ; 63(7): 967-973. doi:10.1007/s00265-009-0747-0.

Kristjanson PM, Swallow BM, Rowlands GJ, Kruska RL and de Leeuw PN. 1999. Measuring the costs of African animal trypanosomiasis, the potential benefits of control and returns to research. *Agricultural Systems*; 59: 79-98.

Kuzoe FAS. 1991. Perspectives in research on and control of African trypanosomiasis. *Annals of Tropical Medicine and Parasitology;* 85(1): 33-41.

Kyeyamwa H, Speelman S, Van Huylenbroeck G, Opudo-Asibo J and Verbeke W. 2008. Raising offtake from cattle grazed on natural rangelands in sub-Saharan Africa: A transaction cost economics approach. *Agricultural Economics*; 39: 63–72.

Kyvsgaard NC, Johansen MV and Carabin H. 2007. Simulating transmission and control of Taenia solium infections using a Reed-Frost stochastic model. *International Journal for Parasitology*; 37: 547-558.

Lalonde LG and Sukigara T. 1997 Livestock Development and Planning System 2 – User's Guide. FAO, Rome. http://www.fao.org/fileadmin/templates/lead/pdf/user97.pdf.

Langlands BW. 1967. *The sleeping sickness epidemic of Uganda, 1900–1920: a study in historical geography*. Kampala, Makerere University College (Occasional Paper No. 1).

Laveissiere C and Grebaut P. 1990. Recherches sur les pieges a glossines (Diptera: Glossinidae). Mise au point d'un modele economique: le piege Vavoua [Research on *Glossina* (Diptera: Glossinidae) traps. Design of an economic model: the Vavoua trap]. *Tropical Medicine and Parasitology*; 41:185–192.

Le S, Josse J and Husson F. 2008. FactoMineR: An R Package for Multivariate Analysis. *Journal of statistical software*; 25(1): 1-18.

Leak S. 1998. Tsetse biology and ecology: their role in the epidemiology and control of trypanosomosis. Wallingford, Oxfordshire, CABI Publishing.

Leak SGA, Mulatu W, Rowlands GJ and d'Ieteren GDM. 1995. A trial of a cypermetherin 'pour-on' insecticide to control Glossina pallidipes, G. fuscipes fuscipes and G. morsitans submorsitans in south-west Ethiopia. *Bulletin of Entomological Research* 85: 241-251.

Leak SGA. 1999. Tsetse Biology and Ecology: Their Role in the Epidemiology and Control of Trypanosomosis. CABI, Oxford, UK.

Leplaideur A. 1992. Conflicts and alliances between the international marketing system and the traditional marketing system in Africa and Madagascar: The results of experience with rice and with vegetables in six countries. In L. Cammann (Ed.), Traditional marketing systems. Feldafing, Germany: DSE (Foundation for International Development).

Lightowlers MW. 2013. Control of Taenia solium taeniasis/cysticercosis: past practices and new possibilities. *Parasitology*; 140: 1566–1577. doi:10.1017/S0031182013001005.

Li L, Alderson D, Doyle JC and Willinge W. 2005. Towards a Theory of Scale-Free Graphs: Definition,Properties and Implications. *Internet Mathematics*; 2(4): 431-523.

Liljeros F, Edling CR, Amaral LAN, Stanley HE and Aberg Y. 2001. The web of human sexual contacts. *Nature*; 411: 907-908.

Lister S, Baryabanoha W, Steffensen J and Williamson T. 2006. Evaluation of General Budget Support – Uganda Country Study Coordinator. *The Organisation for Economic Co-operation and Development (OECD)*.
http://ec.europa.eu/europeaid/how/evaluation/evaluation_reports/reports/2006/705_ug_en.pdf

Longworth N, Mourits MC and Saatkamp HW. 2014. Economic analysis of HPAI control in the Netherlands II: comparison of control strategies. *Transboundary Emerging Diseases*; 61(3):217-32. doi: 10.1111/tbed.12034.

Mableson HE, Okello A, Picozzi K *et al*. 2014. Neglected zoonotic diseases—the long and winding road to advocacy. *PLoS Neglected Tropical Disease*; 8: e2800.

MacKichan IW. 1944. Rhodesian sleeping sickness in eastern Uganda. *Transactions of the Royal Society of Tropical Medicine and Hygiene*; 38:49–60.

Magona JW and Walubengo J. 2011. Mass treatment of insecticide-spraying of animal reservoirs for emergency control of rhodesiense sleeping sickness in Uganda. *Journal of Vector Borne Diseases*; 48:105–108.

Mahadevan P and Parsons DJ. 1970**.** Livestock. In: *Agriculture in Uganda*. Ed. Jameson, J. D.

Magona JW, Walubengo J, Odiit M, Okedi LA, Abila P, Katabazi BK, Gidudu AM and Olaho-Mukani W. 2005. Implications of the re-invasion of Southeast Uganda by *Glossina pallidipes* on the epidemiology of bovine trypanosomiasis. *Veterinary Parasitology;* 128:1–9.

Majok AA and Schwabe CW. 1996. Development Among Africa's Migratory Pastoralists. Greenwood, Westport.

Map of Lao PDR. 2016. http://www.mapsopensource.com

Map of Uganda. 2016. http://www.un.org/Depts/Cartographic/map/profile/uganda.pdf

Marsden PV. 1990. Network data and measurement. *Annual Review of Sociology*; 16: 435-463.

Martínez-López B, Perez AM and Sánchez-Vizcaíno JM. 2009. Social network analysis. Review of general concepts and use in preventive veterinary medicine. *Transboundary and emerging diseases*; 56(4):109-20. doi: 10.1111/j.1865-1682.2009.01073.x.

Mathers CD, Vos T, Lopez AD, Salomon J and Ezzati M. 2001. National Burden of Disease Studies: A Practical Guide. Edition 2.0. Global Program on Evidence for Health Policy. Geneva: World Health Organization.

Mathers CD, Ezzati M and Lopez AD. 2007. Measuring the Burden of Neglected Tropical Diseases: The Global Burden of Disease Framework. *PLoS Neglected Tropical Disease* 1(2): e114. doi:10.1371/journal.pntd.0000114.

Mathers CD. 2002. Health expectancies: an overview and critical appraisal. In: Murray CJL,Salomon JA, Mathers CD, Lopez AD (2002) Summary Measures of Population Health; pp 177–204.

May RM and Anderson RM. 1988. The transmission dynamics of human immunodeficiency virus (HIV). *Philosophical Transaction of the Royal Society of London B*; 321: 565-607.

May RM and Anderson RM. 1987. Transmission dynamics of HIV infection. *Nature;* 326 (6109): 137–142.

Maudlin I, Holmes PH and Miles MA. 2004. The Trypanosomiases. CAB International. ISBN: 0-85199-475-X.

Maudlin I. 2006. African trypanosomiasis. Annals of tropical medicine and parasitology; 100(8):679-701.

McInerney JP, Howe KS and Schepers JA. 1992. A framework for the economic analysis of disease in farm livestock. *Preventive Veterinary Medicine*; 13: 137-154.

McInerney JP. 1987. An economist's approach to estimating disease losses. In: KS Howe and JP McInerney (Eds.), Disease in Farm Livestock: Economics and Policy. Commission of the EEC, Luxembourg, pp. 25-60.

Mecaskey JW, Ngirwamungu E and Kilima PM. 2003. Integration of trachoma control into primary health care: the Tanzanian experience. American journal of tropical medicine and hygiene; 69(5): 29-32.

Meltzer MI. 2011. Introduction to health economics for physicians. *Lancet*; 358: 993-998.

Meyers LA, Newman MEJ, Martin M and Schrag S. 2003. Applying network theory to epidemics: control measures for Mycoplasma pneumoniae outbreaks. *Emerging Infectious Diseases*; 9: 204–210.

Meyers LA, Pourbohloul B, Newman ME, Skowronski DM, Brunham RC. 2005. Network theory and SARS: predicting outbreak diversity. *Journal of Theoretical Biology*; 232(1):71-81.

Mihok S. 2002. The development of a multipurpose trap (the Nzi) for tsetse and other biting flies. *Bulletin of Entomological Research*; 92:385–403.

Ministry of Finance, planning and economic development. Annual report; Government Outlays Analysis, 2007/08 Fiscal Year. https://www.google.co.uk/search?q=type+decentralized+governance+in+Uganda&ie=utf8&oe=utf8&gws_rd=cr&ei=M0FYVtiDKsfxaKOeuMgF#q=global+outlays+framework+for+poverty+analysis+uganda. Accessed 27/11/2015

Ministry of agriculture, animal husbandry and fisheries. Statistical abstract. http://www.agriculture.go.ug/userfiles/Statistical%20Abstract%202011.pdf. Accessed 27/11/2015

Ministry of agriculture and forestry. 2011. Lao PDR agricultural master plan, 2011to 2015. http://asialeds.org/sites/default/files/resource/file/3.-Agricultural-Master-Plan-2011-2015.pdf. Accessed 3/6/2014.

Molyneux DH, Neira M, Liese B and Heymann D. 2000. Elimination of lymphatic filariasis as a public health problem. *Transactions of the Royal Society of Tropical Medicine and Hyiene; 94*: 589-591.

Molyneux DH, Hotez PJ and Fenwick A. 2005. "Rapid-Impact Interventions": How a Policy of Integrated Control for Africa's Neglected Tropical Diseases Could Benefit the Poor. PLoS Medicine 2(11): e336. doi:10.1371/journal.pmed.0020336

Molyneux D, Ndung'u J and Maudlin I. 2010. Controlling Sleeping Sickness—"When Will They Ever Learn?". *PLoS Neglected Tropical Diseases* 4(5): e609. doi:10.1371/journal.pntd.0000609

Moloo SK, Kutuza SB, Boreham PF. 1980. Studies on Glossina pallidipes, G. fuscipes fuscipes and G. brevipalpis in terms of the epidemiology and epizootiology of trypanosomiases in south-eastern Uganda. *Annals of Tropical Medicine and Parasitology;* 74(2):219-237.

Moore S *et al*. 2011.Predicting the effect of climate change on African trypanosomiasis: integrating epidemiology with parasite and vector biology. *Journal of the Royal Society Interface*; 9:817–830.

Moreno JL. 1934. Who Shall Survive? Nervous and Mental Disease Publishing Company, Washington, DC.

Morris RS. 1999. The application of economics in animal health programmes: a practical guide. *Revue scientifique et technique (International office of Epizootics)*; 18(2):305-314.

Moslonka-Lefebvre M, Monod H, Gilligan CA, Vergu E and Filipe JAN. 2015. Epidemics in markets with trade friction and imperfect transactions. *Journal of Theoretical Biology*; 374: 165-178.

Muhanguzi D, Picozzi K, Hatendorf J, Thrusfield M, Welburn SC, Kabasa JD and Waiswa C. 2014a. Collateral benefits of restricted insecticide application for control of African trypanosomiasis on Theileria parva in cattle: a randomized controlled trial. *Parasites and Vectors*; 7:432. http://www.parasitesandvectors.com/content/7/1/432

Muhanguzi D, Picozzi K, Hatendorf J, Thrusfield M, Welburn SC, Kabasa JD and Waiswa. 2014b. Improvements on Restricted Insecticide Application Protocol for Control of Human and Animal African Trypanosomiasis in Eastern Uganda. *PLoS Neglected Tropical Diseases*; 8(10): e3284. doi:10.1371/journal.pntd.0003284

Muhanguzi D, Okello WO, Kabasa JD, Waiswa C, Welburn SC and Shaw APM. 2015.
Cost analysis of options for management of African animal trypanosomiasis using interventions targeted at cattle in Tororo District; south-easternUganda. *Parasites and Vectors*; 8:387

Mugalla, C., Swallow, B. and M. Kamuanga .1997. The effects of trypanosomiasis risk on farmers' livestock portfolios: evidence from The Gambia. Proceedings of the 24th meeting of the ISCTRC, Maputo, Mozambique, OAU/ISTRC, Nairobi, Kenya, pp. 472-473.

Murray WA. 1921. History of the introduction and spread of human trypanosomiasis (sleeping sickness) in British Nyasaland in 1908 and following years. *Transactions of the Royal Society of Tropical Medicine and Hygiene*; 15: 121–128.

Murray CJL *et al*. 2012. Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet*; 380: 2197–223.

Murray CJL, Lopez AD, eds. 1996. *The global burden of disease: a comprehensive assessment of mortality and disability from diseases, injuries and risk factors in 1990 and projected to 2020*. Cambridge, Harvard School of Public Health on behalf of the World Health Organization and the World Bank.

Murray CJL and Lopez AD. 1998. The global burden of disease, 1990–2020. *Nature medicine*; 14(11): 1241-1243.

Narrod C, Zinsstag J and Tiongco M. 2012. A One Health Framework for estimating the economic costs of zoonotic diseases on Society. EcoHealth. d.o.i: 10.1007/s10393-01.

Newman MEJ, Watts DJ and Strogatz SH. 2002. Random graph models of social networks. *Proceedings of the National Academy of Science*; 99(1): 2566–2572.

Newman MEJ and Girvan M. 2004. Finding and evaluating community structure in networks. *Physical Review E*; 69: 026113.

Newstead RA. 1911. Revision of the tsetse flies (*Glossina*) based on a study of the male genital armature. *Bulletin of Entomological Research*; 2:9–36.

Newton CR and Garcia HH. 2010. Epilepsy in poor regions of the world. *Lancet*; 380: 1193–1201

Ngategize PK and Kaneene JB. 1985. Evaluation of the economic impact of animal diseases on production: a review. *Veterinary Bulletin*; 55: 153-162.

Nicolas G, Durand B, Duboz R, Rakotondravao R and Chevalier V. 2013. Description and analysis of the cattle trade network in the Madagascar highlands: Potential role in the diffusion of Rift Valley fever virus. *Acta Tropica*; 126(1): 19-27.

Njiokou F *et al*. 2006. Wild fauna as a probable animal reservoir for *Trypanosoma brucei gambiense* in Cameroon. *Infection, Genetics and Evolution*; 6:147–153.

OandA. Historical exchange rates. Accessed 31/12/2014.
http://www.oanda.com/currency/historical-rates-classic?srccont=rightnav

Odermatt P, Ly S, Simmala C, Angerth T, Phongsamouth V, Mac TL, Gaulier JM, Strobel M, Preux PM. 2007. Availability and Costs of Antiepileptic Drugs and Quality of Phenobarbital in Vientiane Municipality, Lao PDR. *Neuroepidemiology*; 28:169–174.

O'Neal S, Winthrop K and Gonzalez A. 2011. Cysticercosis control: bringing advances to the field. *Journal of Global Infectious Diseases*; 3: 156-160.

Organisation mondiale de la santé animale (OIE)/Word animal health organization, 2011. OIE PVS evaluation, Lao PDR.

http://www.oie.int/fileadmin/Home/eng/Support_to_OIE_Members/pdf/PVS-FU_Report-Lao.pdf

Okello AL, Gibbs EPJ, Vandersmissen A and Welburn SC. 2011.One Health and the neglected zoonoses: turning rhetoric into reality. *Veterinary Record*; 169: 281-285. doi: 10.1136/vr.d5378.

Okello AL, Ash A, Keokhamphet C, Hobbs E, Khamlome B, Dorny P, Thomas L and Allen J. 2014. Investigating a hyper-endemic focus of *Taenia solium* in northern Lao PDR. *Parasites & Vectors*; 7:134 doi:10.1186/1756-3305-7-134

Okello AL, Burniston S, Conlan JV, Inthavong P, Khamlome B, Welburn SC, Gilbert J, Allen J and Blacksell SD. 2015. Prevalence of Endemic Pig-Associated Zoonoses in Southeast Asia: A Review of Findings from the Lao People's Democratic Republic. *American Journal of Tropical Medicine and Hygiene*; 92(5): 1059–1066.

Okello AL, Welburn SC and Smith J. 2014. Crossing institutional boundaries: mapping the policy process for improved control of endemic and neglected zoonoses in sub-Saharan Africa. *Health policy and planning*: 1-9.

Okello A, Thomas L, Inthavong P, Ash A, Khamlome B, Keokamphet C, Newberry K, Gauci CG, Gabriël S, Dorny P, RC Thompson ARC, Lightowlers MW and Allen J. 2016. Assessing the impact of a joint human-porcine intervention package for *Taenia solium* control: Results of a pilot study from northern Lao PDR**.** *Acta Tropica*; 159: 185-191.

Okello WO. 2012. Socio-economic contribution of animal traction to rural livelihoods in south-east Uganda. Masters thesis, University of Edinburgh.

Okello WO, Muhanguzi D, MacLeod ET, Welburn SC, Waiswa C and Shaw AP. 2015. Contribution of draft cattle to rural livelihoods in a district of southeastern Uganda endemic for bovine parasitic diseases: an economic evaluation. *Parasites and Vectors; 8:571*.

Okello-Onen J, Mukhebi AW, Tukahirwa EM, Musisi G, Bode E, Heinonen R, Perry BD and Opuda-Asibo J. 1998. Financial analysis of dipping strategies for indigenous cattle under ranch conditions in Uganda. *Preventive Veterinary Medicine*; 33(1-4): 241-250.

Okoth JO. 1986.Peridomestic breeding sites of *Glossina fuscipes fuscipes* Newst. in Busoga, Uganda, and epidemiologic implications for trypanosomiasis. *Acta Tropica*, 1986, 43:283–286.

Okoth JO and Kapaata R. 1986. Trypanosome infection rates in *Glossina fuscipes fuscipes* Newst. in the Busoga sleeping sickness focus, Uganda. *Annals of Tropical Medicine and Parasitology*; 80, 459–461.

Osburn B, Scott C and Gibbs P. 2009. One World - One Medicine – One Health: emerging veterinary challenges and opportunities. *Rev. sci. tech. Off. int. Epiz.*; 28 (2): 481-486.

Osofsky SA, Cleaveland S, Karesh WB, Kock MD, Nyhus PJ, Starr L and Yang A. (Eds.). 2005. Conservation and Development Interventions at the Wildlife/Livestock Interface: Implications for Wildlife, Livestock and Human Health. Gland, Switzerland/Cambridge, UK.

Otte MJ and Chilonda P. 2000. Animal Health Economics: An Introduction. Animal Production and Healthy Division (AGA), FAO, Rome, Italy. 12 pp.

Oxford Policy Management (OPM). 2005. The plan for the modernisation of agriculture. Evaluation report.
http://www.opml.co.uk/sites/default/files/PMA evaluation final report_0.pdf

Palla G , Imre Derényi I, Farkas I and Vicsek T. 2005. Uncovering the overlapping community structure of complex networks in nature and society. *Nature;* 435: 814-818. doi:10.1038/nature03607.

Pearson RD and Hewlett EL. 1985. Niclosamide therapy for tapeworm infections. *Annals of Internal Medicine*; 102(4):550-551.

Phengsavanh P, OgleB, Stür W, Lindberg BEF and Lindberg JE. 2011. Smallholder Pig Rearing Systems in Northern Lao PDR. *Asian-Australasian Journal of Animal Sciences*; 24(6): 867 – 874. doi: 10.5713/ajas.2011.10289.

Phengsavanh P and Stür W. 2006. Farmer-led research in village pig production in Lao PDR. http://lad.nafri.org.la/fulltext/3771-0.pdf

Phommasack B, Moen A, Vongphrachanh P, Tsuyuoka R, Cox N, Khamphaphongphanh B, Phonekeo D, Kasai T, Ketmayoon P, Lewis H, Kounnavong B, Khanthamaly V and Corwin A. 2012. Capacity Building in Response to Pandemic Influenza Threats: Lao PDR Case Study. American Journal of Tropical Medicine and Hygiene:87(6):965–971.

Pica-Ciamarra U and Otte J. 2008. Animal Health Policies in Developing Countries–A Review of Options. *Pro-Poor Livestock Policy Initiative*; 8: 1–27.

Picozzi K, Fèvre EM, Odiit M, Carrington M, Eisler MC, Maudlin I and Welburn SC. 2005. Sleeping sickness in Uganda: a thin line between two fatal diseases. *British Medical Journal*; 331(7527): 1238–1241.

Plass D, Mangen MJ and Pinheiro P. 2012. Health Adjusted Life Years (HALY) –A Promising Measure to Estimate the Burden of Zoonotic Diseases on Human Health? INTECH Open Access Publisher. ISBN 9535104799.

Potts WH and Jackson CHN. 1952. The Shinyanga game destruction experiment. *Bulletin of Entomological Research*; 1952, 53:365–374.

Praet N, Speybroeck N, Manzanedo R, Berkvens D, Nsame Nforninwe D, *et al*. 2009. The Disease Burden of Taenia solium Cysticercosis in Cameroon. *PLoS Neglected Tropical Diseases* 3(3): e406. doi:10.1371/journal.pntd.0000406.

Preux PM and Cabanac MD. 2005. Epidemiology and aetiology of epilepsy in sub-Saharan Africa. *Lancet Neurology*; 4: 21–31.

Pullan RL, Smith JL, Jasrasaria R and Brooker SJ. 2014. Global numbers of infection and disease burden of soil transmitted helminth infections in 2010. *Parasites and Vectors*; 7:37.

Putt SNH, Shaw APM, Matthewman RW, Bourn DM, Underwood M, James AD, Hallam MJ and Ellis PR. 1980. The Social and Economic Implications of Trypanosomiasis Control: A Study of its Impact on Livestock Production and Rural Development in Northern Nigeria. University of Reading.

Radicchi F, Castellano C, Cecconi F, Loreto V and Parisi D. 2004. Defining and identifying communities in networks. *Proceedings of the National Academy of Science*;101: 2658–2663.

Rajshekhar V, Joshi DD, Doanh NQ, van De N and Xiaonong Z. 2003. Taenia solium taeniosis/cysticercosis in Asia: epidemiology, impact and issues. *Acta Tropica*; 87: 53-60.

Rasamoelina-Andriamanivo H, Dubozc R, Lancelotd R, Maminiainaa OF, Jourdane M, Rakotondramaroa TMC, Rakotonjanaharya SN, Servan de Almeidad R, Rakotondravaoa, Durandf B and Chevalierc V. 2014. Description and analysis of the poultry trading network in the Lake Alaotra region, Madagascar: Implications for the surveillance and control of Newcastle disease. *Acta Tropica*; 135: 10–18.

Rayaisse JB *et al*. 2011.Towards an optimal design of target for tsetse control: Comparisons of novel targets for the control of palpalis group tsetse in West Africa. *PLoS Neglected Tropical Diseases*; 5(9):e1332.

Rayaisse JB *et al*. 2010. Prospects for odour bait development to control vectors of trypanosomiasis in West Africa, the tsetse flies *Glossina tachinoides* and *G. palpalis* s.l. *PLoS Neglected Tropical Diseases*; 4:e632.

Reid RS. 1997. Impacts of trypanosomiasis on land-use and the environment in Africa: state of our knowledge and future directions. Proceedings of the 24th Meeting of the International Scientific Council for Trypanosomiasis Research and Control (ISCTRC), Maputo, Mozambique, OAU/ISTRC, pp. 500-514.

Reid RS, Kruska RL, Deichmann U, Thornton PK and Leak SGA. 1997. Will human population growth and land-use change control tsetse during our lifetimes? Proceedings of the 24th Meeting of the International Scientific Council for Trypanosomiasis Research and Control (ISCTRC), Maputo, Mozambique, OAU/ISTRC, pp. 500-514.

Reid AH, Fanning TG, Hultin JV and Taubenberger JK . 1999. Origin and evolution of the 1918 Spanish influenza virus haemagglutinin gene. *Proceedings of the Natural Academy of Sciences;* 96: 1651-1656.

Reynolds IN. 1961. Selecting the proper depreciation method. *The Accounting Review;* 36(2): 239-248.

Robinson SE and Christley RM. 2007. Exploring the role of auction markets in cattle movements within Great Britain. *Preventive Veterinary Medicine*; 81(1-3): 21-37.

Rogers DJ, Randolph SE 1984. A review of density-dependent processes in tsetse populations. *Insect Science and its Application*; 5:397–402.

Rogers DJ and Hay S. 1996. Identifying the constraints on livestock productivity and land-use in Africa imposed by trypanosomosis. Final Technical Report to the Overseas Development Organization.

Roth F, Zinsstag J, Orkhon D, Chimed-Ochir G, Hutton G, Cosivi O, Carrin G and Otte J. 2003. Human health benefits from livestock vaccination for brucellosis: case study. *Bulletin of the World Health Organization*; 81 (12): 867-876.

Rowlands GJ, Mulatu W, Authié E, d'Ieteren GDM, Leak SGA and Nagda SM. 1994. Effects of trypanosomiasis on growth and mortality of young East African Zebu cattle exposed to drug-resistant trypanosomes. *Preventive Veterinary Medicine*; 21 (1): 87-101.

Rushby FJA and Hanison K. 2001. Calculating and presenting disability adjusted life years (DALYs) in cost-effectiveness analysis. *Health Policy and Planning*; 16(3): 326-331.

Rutto JJ and Karuga JW. 2009. Temporal and spatial epidemiology of sleeping sickness and use of geographical information system (GIS) in Kenya. *Journal of Vector Borne Diseases*; 46:18–25.

Rushton J, Thornton PK and Otte MJ. 1999. Methods of economic impact assessment. *Rev. sci. tech. Off. int. Epiz.*; 18 (2): 315-342.

Rushton J, Ahuja V, Beck V, Bonnet P, Devendra C, James A *et al*. 2009. The economics of animal health and production. Published by CABI ISBN-13: 978-1-84593-194-0.

Rushton J, Viscarra R, Guerne BE and McLeod A. 2005. Impact of avian influenza outbreaks in the poultry sectors of five South East Asian countries (Cambodia, Indonesia, Lao PDR, Thailand, Viet Nam) outbreak costs, responses and potential long term Control. *World's Poultry Science Journal*; 61: 492-514.

Rwakakamba M. 2008. Challenges Facing the Agricultural Sector in Uganda. In *Presentation at the Uganda National Farmers Dialogue*. Uganda Nataional Farmers Federation.

Sabidussi G.1966. The centrality index of a graph. *Psychometrika*; 31: 581–603.

Sailer LD. 1978. Structural Equivalence: Meaning and Definition, Computation and Application. *Social Networks;* 1: 73-90.

Salomon JA *et al*. 2012. Common values in assessing health outcomes from disease and injury: disability weights measurement study for the Global Burden of Disease Study 2010. *Lancet*; 380: 2129–2143.

Sarti E ,Schantz PM, Avila G, Ambrosio J, Medina-Santillán R and Flisser A. 2000. Mass treatment against human taeniasis for the control of cysticercosis: a population-based intervention study. *Transactions of the Royal Society of Tropical Medicine and Hygiene;* 94(1):85-89.

Savadogo K, Reardon T and Pietola K. 1994. Farm productivity in Burkina Faso: effects of animal traction and non-farm income. *American Journal of Agricultural Economics*; 76: 608-612.

Savadogo K, Reardon T and Pietola K. 1996. Mechanization and agricultural supply response in the Sahel: a farm-level profit function analysis. *Journal of African Economies*; 4(3): 336-377.

Schantz P. 2002. Taenia solium cysticercosis: an overview of global distribution and transmission. In Taenia solium Cysticercosis from Basic to Clinical Science (ed. Singh, G. and Prabhakar, S.), pp. 63–73. CABI Publishing, Wallingford.

Schantz PM, Cruz M, Sarti E and Pawlowski Z. 1993. Potential eradicability of taeniasis and cysticercosis. *Bulletin of the Pan American Health Organization*; 27, 397–403.

Schofield CJ and Maudlin I. 2001. Trypanosomiasis control. *International Journal for Parasitology;* 31*:* 614-619.

Schroder SA. 2012. Incidence, prevalence, and hybrid approaches to calculating disability-adjusted life years. *Population Health Metrics*; 10:19.
http://www.pophealthmetrics.com/content/10/1/19

Scott J. 2013. Social Network Analysis: A Handbook, Sec.ed. Sage Publications, London. ISBN 978-1-4462-0903-5.

Schwabe CW, Williams and Wilkins. 1984. Veterinary Medicine and Human Health. Baltimore.

Selby R, Bardosh K, Picozzi K, Waiswa C and Welburn SC. 2013. Cattle movements and trypanosomes: restocking efforts and the spread of *Trypanosoma brucei rhodesiense* sleeping sickness in post-conflict Uganda. *Parasites and Vectors*; 136: 281.

Seketeli A, Adeoye G, Eyamba A, Nnoruka E, Drameh P, Amazigo UV, Noma M, Agboton F, Aholou Y, Kale OO and Dadzie KY. 2002. The achievements and challenges of the African Programme for Onchocerciasis Control (APOC). *Annals of tropical medicine and parasitology*; 96 (1): 15–28.

Shaffer JD. 1980. Food system organization and performance: Towards a conceptual framework. *American Journal of Agricultural Economics*; 62(2): 310–318.

Sharrer GT. 1995. The great glanders epizootic, 1861-1866: A civil war legacy. *Agricultural History;* 69(1): 79-97.

Shaw APM. 1989. Mathematical models of trypanosomiasis control. ISCTRC 20th meeting. Mombasa, Kenya, April 1989. ISCTRC Publication No. 115, pp. 106-114.

Shaw APM. 2004. economics of African trypanosomiasis. In; Maudlin I, Holmes PH and Miles MA (eds). in: *The Trypanosomiases*, pp. 369–402. Wallingford, UK, CABI Publishing.

Shaw A, Hendrickx G, Gilbert M, Mattioli R, Codjia V, Dao B, *et al*. 2006. Mapping the benefits: a new decision tool for tsetse and trypanosomiasis interventions. Research Report, Department for International Development, Animal Health Programme, Centre for Tropical Veterinary Medicine, University of Edinburgh and PAAT. Rome: FAO; 2006.
http://www.fao.org/ag/againfo/programmes/en/paat/documents/papers/Paper_2006.pdf. Accessed April 18 2012.

Shaw APM. 2009. Assessing the economics of animal trypanosomosis in Africa-history and current perspectives. *The Onderstepoort journal of veterinary research*; 76 (1): 27–32.

Shaw A. 2009. The Economics of Zoonoses and Their Control. In: Rushton, J
The Economics of Animal Health and Production. London; CABI: 161-167.

Shaw APM, Torr SJ, Waiswa C, Ceechi G, Wint GRW, Mattioli RC and Robinson TP. 2013. Estimating the costs of tsetse control options: An example for Uganda. Preventive Veterinary Medicine; 110 (2013): 290–303.

Shaw A, Cecchi G, Wint W, Mattioli R and Robinson T. 2014. Mapping the benefits to livestock keepers from controlling animal trypanosomiasis in eastern Africa. *Preventive Veterinary Medicine*; 113(2):197–210.

Shaw APM, Tirados I, Mangwiro CTN, Esterhuizen J, Lehane MJ, Torr SJ and Kovacic V. 2015. Costs Of Using “Tiny Targets” to Control *Glossina fuscipes fuscipes*, a Vector of *Gambiense* Sleeping Sickness in Arua District of Uganda. *PLoS. Neglected Tropical Diseases*: 9, e3624.

Sikasunge CS, Johansen MV, Willingham III L, Leifsson PS and Phiri IK. 2008.Taenia solium porcine cysticercosis: Viability of cysticerci and persistency of antibodies and cysticercal antigens after treatment with oxfendazole**.** *Veterinary Parasitology*; 158: 55-66.

Simarro PP, Diarra A, Postigo JAR, Franco JR and Jannin JG. 2011. The human African trypanosomiasis control and surveillance programme of the World Health

Organization 2000–2009: the way forward. *PLoS Neglected Tropical Diseases*, 5:e1007.

Simarro PP, Cecchi G, Franco JR, Paone M, Diarra A, Ruiz-Postigo JA, Fèvre EM, Mattioli RC and Jannin JG. 2012. Estimating and mapping the population at risk of sleeping sickness. *PLoS Neglected Tropical Diseases*, 2012, 6:e1859.

Slingenbergh J. 1992. Tsetse control and agricultural development in Ethiopia. *World Animal Review;* 70/71: 30-36.

Smith DH, Pepin J, Stich AHR. 1998. Human African trypanosomiasis: an emerging public health crisis. *British Medical Bulletin*, 1998, 54:341–355.

Solano P *et al*. 2009. The population structure of *Glossina palpalis bamiensis* from island and continental locations in coastal Guinea. *PLoS Neglected Tropical Diseases*; 3:e392.

SPSS Inc. Released 2007. SPSS for Windows, Version 16.0. Chicago, SPSS Inc.

Stanghellini A and Josenando T. 2001.The situation of sleeping sickness in Angola: a calamity. *Tropical Medicine and International Health*; 6:330–344.

Steinfeld H. 1988. Livestock Development in Mixed Farming Systems: A Study of Livestock Production Systems in Zimbabwe. Kiel Wissenschaftsverlag Vauk, Kiel, Germany. https://www.researchgate.net/publication/39000646_Livestock_development_in_mixed_farming_systems_A_study_of_smallholder_livestock_production_systems_in_Zimbabwe.

Stelling J, Klamt S, Bettenbrock K, Schuster S and Gilles ED. 2002. Metabolic network structure determines key aspects of functionality and regulation. *Nature*; 420: 190–193.

Stevenson M, Nunes T, Sanchez J, Thornton R, Reiczigel J, Robison-Cox J and Sebastiani P. 2012. Package 'epiR': An R package for the analysis of epidemiological data.

https://www.massey.ac.nz/massey/fms/Colleges/College%20of%20Sciences/Epicenter/EpiR/epiR.pdf?0695F854B020601D9FEC0B96F7F19CCB

Steverding D. 2008. The history of African trypanosomiasis. *Parasites & Vectors*;1(3) :1-8. http://www.parasitesandvectors.com/content/1/1/3

Strogatz SH. 2001. Exploring complex networks. *Nature*; 410: 268-276. doi:10.1038/35065725.

Stoltzfus RJ, Dreyfuss ML, Chwaya HM, and Albonico M. 1997. Hookworm Control as a Strategy to Prevent Iron Deficiency. *Nutrition Reviews;* 55(6): 223-232.

Swallow BM, Mulatu W and Leak SGA. 1995. Potential demand for a mixed public-private animal health input: evaluation of a pour-on insecticide for controlling tsetse-transmitted trypanosomiasis in Ethiopia. *Preventive Veterinary Medicine*; 24:266-275.

Swallow BM. 1999. Impacts of trypanosomiasis on African agriculture. http://www.fao.org/ag/againfo/programmes/en/paat/documents/papers/Paper_1999.pdf

Swynnerton CFM. 1925. An experiment in the control of tsetse flies at Shinyanga, Tanganyika Territory. *Bulletin of Entomological Research*; 15,313–337.

Taubenberger JK, Reid RH, Lourens RM, Wang R, Jin G and Fanning TG. 2005. Characterisation of the 1918 influenza virus polymerase genes. *Nature;* 437: 889-893.

Taylor N and Rushton J. 2011. A value chain approach to animal diseases risk management: technical foundations and practical framework for field application. FAO Animal Production and Health Guidelines, 4. FAO, Rome, pp121. ISBN 978925106868.

Taylor LH, Latham SM and Woolhouse ME. 2001.Risk factors for human disease emergence. *Philosophical Transactions of the Royal Society,* 356: 983–989

Thornton DS and Forde RM. 1902. The discovery of the human *Trypanosoma. British Medical Journal*, ii(2187):1741.

Torr SJ, Wilson PJ , Schofield S, Mangwiro TC, Akber Sand White BN. 2001. Application of DNA markers to identify the individual-specific hosts of tsetse feeding on cattle, *Medical and Veterinary Entomology;* 15:78–86.

Torr SJ, Maudlin I and Vale GA. 2007. Less is more: restricted application of insecticide to cattle to improve the cost and efficacy of tsetse control. *Medical and Veterinary Entomology*; 21: 53–64.

Torr SJ, Wilson PJ , Schofield S. 2007. Is there safety in numbers? The effect of cattle herding on biting risk from tsetse flies. *Medical and Veterinary Entomology*; 21:301–11.

Trail JCM, Sones K, Jibbo JMC, Durkin J, Light DE and Murray M.1985. Productivity of Boran Cattle Maintained by Chemoprophylaxis under Trypanosomiasis Risk. Research Report 9. Addis Ababa: ILCA.

Trail JCM, d'Ieteren GDM, Feron A, Kakiese O, Mulungo M and Pelo, M. 1991. Effect of trypanosome infection control of parasitaemia and control of anemia development on productivity of N'Dama cattle. *Acta Tropica;* 48: 137-145.

Tran DS, Odermatt P, Singphuoangphet S, Cabanac MD, Preux PM, Strobel M and Barennes H. 2007. Epilepsy in Lao PDR: Knowledge, attitudes, and practices in the community. *Epilepsy & Behavio*r; 10: 565–570

Tran DS, Zen J, Strobel M, Odermatt P, Preux PM, Huc Pierre, Delneuville L and Barennes H. 2008. The challenges of epilepsy control in deprived settings: Low compliance and high fatality rates during a community-based Phenobarbital program in rural Lao. *Epilepsia*; 49(3).

Tran DS, Odermatt P, Le TO, Huc P, Cabanac MD, Barennes H, Strobel M and Preux PM. 2006 Prevalence of Epilepsy in a Rural District of Central Lao PDR. *Neuroepidemiology*; 26:199–206. DOI: 10.1159/000092407.

Tsourapas A and Frew E. 2011. Evaluating 'success' in programme budgeting and marginal analysis: a literature review. *Journal of Health Services Research and Policy*; 16:177–183. doi: 10.1258/jhsrp.2010.009053.

Turner MD and Williams TO. 2002. Livestock Market Dynamics and Local Vulnerabilities in the Sahel. *World Development*; 30 (4): 683–705.

Turner RL. 2005. Livestock, Liberalization, and Democracy: Constraints and Opportunities for Rural Livestock Producers in Reforming Uganda. Pro-poor Livestock Policy Initiative Working Paper No. 29 and Policy Brief. Rome: Food and Agriculture Organization of the United Nations.

Uganda Bureau of Statistics (UBOS). 2011. Uganda Demographic and Health Survey https://dhsprogram.com/pubs/pdf/FR264/FR264.pdf

United Nations. Available from: digital commons.butler.edu/facsch_papers/476/
United Nation's development programme (UNDP). 2015. Accessed 27/11/2015 http://hdr.undp.org/en/countries

United Nations Development Programme. 2013. Uganda's National Development Plan (2010/11-2014/15). Accessed 17/7/2013. http://www.undp-alm.org/resources/naps-least-developed-countries-ldcs/uganda%E2%80%99s-national-development-plan-201011-201415-%E2%80%93.

United Nations Development Programme. 1999. Decentralizatio: a sampling of definitions. http://web.undp.org/evaluation/documents/decentralization_working_report.PDF

Upton M. 1989. Livestock productivity assessment and herd growth models. *Agricultural Systems;* 29: 149-164.

Utzinger J and Keiser J. 2004. Schistosomiasis and soil-transmitted helminthiasis: common drugs for treatment and control. *Expert opinion on pharmacotherapy*; 5: 263–285.

Utzinger J and de Savigny D. 2006. Control of neglected tropical diseases: integrated chemotherapy and beyond. *PLoS Medicine;* 3: e112.

Vale G and Torr **S.** 2004. Development of bait technology to control tsetse. In: Maudlin, I., Holmes, P. & Miles, M. (eds.) *The Trypanosomiases*, pp. 509–523. Wallingford, UK, CABI Publishing.

von Kaufmann R, McIntire J, Itty P. 1990. ILCA Bio-Economic Herd Model for Microcomputer. Technical Reference Guide, ILCA, Addis Ababa, Ethiopia.

Vreysen MJB *et al*. 2000. The use of the sterile insect technique (SIT) for the eradication of the tsetse fly *Glossina austeni* (Diptera: Glossinidae) on the island of Unguja (Zanzibar). *Journal of Economic Entomology*; 93:123–135.

Vreysen MJB. 2005. Monitoring sterile and wild insects in area-wide integrated pest management programmes. In: Dyck VA, Hendrichs J, Robinson AS,eds. Sterile insect technique. *Principles and practice in area-wide integrated pest management*. Dordrecht, Springer: 325–361.

Vreysen MJB *et al*. 2012. Tsetse flies: their biology and control using area-wide integrated pest management approaches. *Journal of Invertebrate Pathology*; 112(1): 15–25.

Wacher TJ, Milligan PM, Rawlings P and Snow WF. 1994. "Spatial factors in the assessment of trypanosomiasis challenge," in B.D. Perry and J.W. Hansen (eds.), Modelling Vector-Borne and Other Parasitic Diseases: Proceedings of a Workshop Organized Jointly by the International Labouratory for Research on Animal Diseases and the Food and Agriculture Organization of the United Nations. Nairobi, Kenya: ILRAD, pp. 119-130.

Waiswa C, Olaho-Mukani W, Katunguka-Rwakishaya E. 2003. Domestic animals as reservoirs for sleeping sickness in three endemic foci in south-eastern Uganda. *Annals of the Tropical Medicine and Parasitology;* 97, 149–155.

Waiswa C, Picozzi K, Katunguka-Rwakishaya E, Olaho-Mukani W, Musoke RA and Welburn SC. 2006. Glossina fuscipes fuscipes in the trypanosomiasis endemic areas of south eastern Uganda: Apparent density, trypanosome infection rates and host feeding preferences. *Acta Tropica*; 99: 23-29.

Watts DJ and Strogatz SH. 1998. Collective dynamics of "small-world" networks, *Nature*; 393: 440–442.

Wendo C.2002. Uganda revises cattle treatment to protect humans from sleeping sickness. Lancet; 359 (9302): 239.

Welburn SC, Fèvre EM, Coleman PG, Odiit M and Maudlin I. 2001. Sleeping sickness: a tale of two diseases. *Trends in Parasitology*; 17:19–24.

Welburn SC and Maudlin I. 1992. The nature of the teneral state in *Glossina* and its role in the acquisition of trypanosome infection in tsetse. *Annals of Tropical Medicine and Parasitology*; 86:529–536.

Welburn SC, Coleman PG, Maudlin I, Fèvre EM, Odiit, M and Eisler MC. 2006. Crisis, what crisis? Control of Rhodesian sleeping sickness. *TRENDS in Parasitology*; 22(3): 123-128.

Welburn SC and Coleman PG. 2015. Human and animal African trypanosomiasis. In. Zinsstag, J., Schelling, E., Waltner-Toews, D., Whittaker, M., Tanner, M. (Eds.) One Health: The Theory and Practice of Integrated Health Approaches. CAB International. ISBN1780643411. pp 201-221.

Williamson OE. 1985. The economic institutions of capitalism: Firms, markets, relational contracting. New York: Free Press.

Williams TO, Spycher B and Okike I. 2006. Improving livestock marketing and intra-regional trade in West Africa: Determining appropriate economic incentives and policy framework. Nairobi, Kenya; ILRI (International Livestock Research Institute): 122.

Willingham AL and Engels D. 2006. Control of Taenia solium cysticercosis/taeniosis. *Advances in Parasitology*; 61: 509–566.

Wilson RT. 2007. Status and prospects for livestock production in the Lao People's Democratic Republic. *Tropical Animal Health and Production;* 39(6):443-452.

Wint, W. (1998) Web page of the Programme Against African Trypanosomiasis (www.fao.org/paat).

World Bank. 2015. Uganda country profile. Accessed 2/5/2015.
http://data.worldbank.org/.

World Health Organisation. 2010. Working to Overcome the Global Impact of Neglected Tropical Diseases, World Health Organisation.WHO/HTM/NTD/2010.1, Geneva.

World Health Organization and Ministry of Health Lao PDR. 2012. Health services delivery, Lao PDR. Accessed 4/6/2014.
http://www.wpro.who.int/health_services/service_delivery_profile_laopdr.pdf

World Health Organization. 2003. Making choices in health: WHO guide to cost-effectiveness analysis.
http://www.who.int/choice/publications/p_2003_generalised_cea.pdf

World Health Organization. 2014. Health statistics data.
http://www.who.int/gho/countries/lao/en/

World Health Organization. 2012. Accelerating work to overcome the global impact of neglected tropical diseases: a roadmap for implementation.

World Health Organization. 2012. Report of a WHO meeting on elimination of African trypanosomiasis (*Trypanosoma brucei gambiense*).

Wymann S, Sommer R and Wenger R. 2007. The Livestock Revolution : An Opportunity for Poor Farmers ? *InfoResources*; 1: 1–16.

Zepeda C, Salmana M, Ruppanner R. 2001. International trade, animal health and veterinary epidemiology: challenges and opportunities. *Preventive Veterinary Medicine*; 48: 261-271.

Zinsstag J, Schelling E, Wyss K, Bechir M. 2005. Potential of cooperation between human and animal health to strengthen health systems. *Lancet*; 366: 2142-2145.

Zinsstag J, Roth F, Orkhon D, Chimed-Ochir G, Nansalmaa M, Kolar J and Vounatsou P. 2005. A model of animal–human brucellosis transmission in Mongolia. *Preventive Veterinary Medicine*; 69: 77–95.

Zinsstag J, Schelling E, Roth F, Bonfoh B, de Savigny D and Tanner M. 2007. Human benefits of animal interventions for zoonosis control. *Emerging Infectious Diseases*; 13(4):527-531.

Zinsstag J and Tanner M. 2008. "One health": the potential of closer cooperation between human and animal health in Africa. *Ethiopian Journal of Health Development*; 22:105–109.

Zinsstag J, Dürr S, Penny MA, Mindekem R, Roth F, Menendez Gonzalez S, Naissengar S, Hattendorf J. 2009. Transmission dynamics and economics of rabies control in dogs and humans in an African city. *PNAS*; 106(35): 14996–5001.

Zinsstag J, Schelling E, Bonfoh B, Fooks AR, Kasymbekov J, Waltner-Toews D, Tanner M. 2009. Towards a "one health" research and application tool box. *Veterinaria Italiana*; 45: 121-133.

Zinsstag J, Schelling E, Waltner-Toews D, and Tanner M. 2011. From "one medicine" to "one health" and systemic approaches to health and well-being. *Preventive Veterinary Medicine*; 101(3-4): 148–156.

Zinsstag J, Schelling E and Whittaker M. 2015.One Health: The Theory and Practice of Integrated Health Approaches. CAB International. ISBN1780643411.

ANNEX 1

HOUSEHOLD SOCIO-ECONOMIC QUESTIONNAIRE: HOUSEHOLD AND LIVESTOCK PRODUCTIVITY DATA Situation now and what happened in <u>last 6-months</u>

Interviewer: *Has household screening successfully completed?* YES |__| NO |__|

If NO this MUST be completed before going further.

SECTION 1 INTERVIEW IDENTIFICATION

101.GPS reading latitude (north /south) in degree with decimal |__|__| |__|__|__|__|__|__|

102.GPS reading longitude (east / west) in degree with decimal |__|__| |__|__|__|__|__|__|

103. Time interview started (24hr clock: hh-mm) |__|__| - |__|__|

104. Name of person being interviewed ____

105. Name of head of household____

Is this the same person as interviewee? **1.** Yes |__| **0.** No |__|

If the person being interviewed is not the househ*old head, what is their position? Please specify:*

____

(For example: The household head's wife, husband, son, daughter, father or mother, other family member, household employee

Interviewer, *please write down the answers to the questions below, by observing the household. If you are not at the house, you can ask the question and explain it will help you to identify the house again.*

106. *What kind of house does this household have?*

1. Mud house |__|
2. Brick house |__|
3. Tent |__|
4. Other__________ |__|

107. What kind of roof does it have?

1. Grass thatch |__|
2. Tin (corrugated iron) |__|
3. Tiled (Cray or Zinc Alum) |__|
4. Other (specify) ________________|__|

108. Interviewer – please write down any other special thing about the house that will help us find it again.

SECTION 2 HOUSEHOLD PEOPLE

Interviewer to say:*"We would like to know a bit about who lives in your household and what type of farming and livestock keeping and other types of work your household does."*

People in the household

201. How many people live in your household? |__|__|

202. Please list all the people in your household, including interviewee, family members, lodgers and servants

Name or position in household (for example household head, father, wife, grandmother, 1st born etc, cousin, live in worker) List interviewee first and write **I** after their name	**Sex** (M or F)	**Age in years** (months if under 1 year old)	**Main occupation** (include going to school)	**Highest level of schooling completed** 1 None 2 Primary 3 O-Level 4 A-Level 5 Diploma

Write **HH** after the household head's name. (**I** and **HH** may be the same person)				6 University and above

SECTION 3 – LIVESTOCK AND CATTLE PRODUCTIVITY

301. How many animals does your household own and keep in this area? (*Put 0 if there are none)*

1. Cattle |__|__|
2. Sheep |__|__|
3. Goats |__|__|
4. Pigs |__|__|
5. Chickens |__|__|
6. Any other animals (specify) ______________________________ number|__|__|
7. Any other animals (specify) ______________________________ number|__|__|

302. Please tell us about the **male** cattle you have at the moment.

Type of MALE cattle	**Number you have now**	**Number of these that are used for draught work (put 0 if none)**
Male calves (aged less than 1 year)		
Young males (age more than 1 year but less than less than 4 years)		
Castrated adult males (4 years or more)		
Other adult males (more than 4 years or more old)		
Total males		

303. Please tell us about the **female** cattle you have at the moment.

Type of FEMALE cattle	**Number you have now**
Calves = females less than 1 year old	
Heifers = young females (females that have never yet calved but may be pregnant)	
Cows = adult females (cows that have calved at least once)	
Total females	

304. What breed(s) of cattle do you keep? Give number of each breed kept or put 0 if none

1. Ankole long horned cattle |__|__|

2. Short horn zebu (e.g. Nganda etc) |__|__|

3. Boran |__|__|

4. Exotic (Including crosses above F5) |__|__|

5. Crossbreed? (any local breed X exotic breed or less than F5 cross breed) |__|__|

6. Other (specify)____ |__|__|

305. Please tell us about the cows you have with you now (cows are adult females which have had calves).

Fill this table in for the first 10 cows.			
Cow No.	Age now (years Y)	Age when it first gave birth (years Y plus months M)	How many live calves has it had? *Put number or 0 for none*
1st	|__|__|Y	|__|__|Y |__|__|M	
2nd	|__|__|Y	|__|__|Y |__|__|M	
3rd	|__|__|Y	|__|__|Y |__|__|M	
4th	|__|__|Y	|__|__|Y |__|__|M	
5th	|__|__|Y	|__|__|Y |__|__|M	
6th	|__|__|Y	|__|__|Y |__|__|M	
7th	|__|__|Y	|__|__|Y |__|__|M	
8th	|__|__|Y	|__|__|Y |__|__|M	
9th	|__|__|Y	|__|__|Y |__|__|M	
10th	|__|__|Y	|__|__|Y |__|__|M	

If there are more than 10 cows fill this table in			
Cow No.	Age now (years Y)	Age when it first gave birth (years Y plus months M)	How many live calves has it had? *Put number or 0 for none*
11th	|__|__|Y	|__|__|Y |__|__|M	
12th	|__|__|Y	|__|__|Y |__|__|M	
13th	|__|__|Y	|__|__|Y |__|__|M	
14th	|__|__|Y	|__|__|Y |__|__|M	
15th	|__|__|Y	|__|__|Y |__|__|M	
16th	|__|__|Y	|__|__|Y |__|__|M	
17th	|__|__|Y	|__|__|Y |__|__|M	
18th	|__|__|Y	|__|__|Y |__|__|M	
19th	|__|__|Y	|__|__|Y |__|__|M	
20th	|__|__|Y	|__|__|Y |__|__|M	

306 Does the household have more than 20 cows (adult females that have calved)?

0. No |__|

1. Yes |__|

If yes please give the information for extra cows in the space at the bottom of this page or on the back.
Interviewer: make sure 6 months ago timing clear to people – relate to date, an event, a season.
Then say: We would now like to ask some questions about what has happened to your cattle between May/June 2011 and now, that is Nov/Dec 2011. We need to be clear about what is included as the

*past **SIX MONTHS**. We will only ask about cattle owned by your household and kept (by household members or others) in the parish or reasonably nearby. We will refer to these as "your cattle".*

307. Six months ago, in May/June 2011 how many **male** cattle did you have? |__|__|

308. Six months ago, in May/June 2011 how many **female** cattle did you have? |__|__|

Exits = cattle that left
*Please tell us about any of your cattle which **left your cattle herd** during the **past SIX MONTHS.** These are the cattle that you own and keep in the area, and which were there six moths ago but are no longer with you.*

309. Deaths (Due to disease or accidents like being knocked down by a vehicle or cattle fights etc)

Number died	Types of cattle died[a]	Reason for death[b]

a Females: female calf, heifer or cow   Males: male calf, young male, adult male (describe: for breeding, draft, castrate)
***b** Select from: disease (specify name of disease if known or symptoms), accident, predator, other (specify)*

310. Slaughter (*cattle that were slaughtered for home consumption or for sale of meat and had not died of disease or accidents*)

Number slaughtered	Types of cattle slaughtered	Reason for slaughter[b]

***a** Females: female calf, heifer or cow   Males: male calf, young male, adult male (describe: for breeding, draft, castrate)*
***b** Select from: old age, it was ill, for a family celebration, other (specify)*

311. Sales

Number sold	Types of cattle sold[a]	Reason for sale[b]	Price received UGX

***a** Females: female calf, heifer or cow   Males: male calf, young male, adult male (describe: for breeding, draft, castrate)*

***b** Select from: old age, to get money, it was ill, other (specify)*

312. Transfers out of the herd (*these are cattle sent to another household or place, loans, gifts and even include any cattle stolen from you)*

Number left	Types of cattle left[a]	Reason for leaving

***a** Females: female calf, heifer or cow   Males: male calf, young male, adult male (describe: for breeding, draft, castrate)*
***b** Select from: gift, sent to another place, theft, other (specify)*

313. Other: are there any other reasons cattle left your cattle herd?

Number	Types of cattle left[a]	Reason for leaving

***a** Females: female calf, heifer or cow   Males: male calf, young male, adult male (describe: for breeding, draft, castrate)*

Entries = cattle that came in

*Please tell us about cattle which came **into your cattle herd** during **past SIX MONTHS.** (as defined before).*
These are the cattle that weren't there six months ago but arrived during the last six months. Some of these cattle may have also left during those six months, for example calves that were born but died very young or cattle you bought but sold quite quickly.

314. Births

	Number born	Number of these still in your cattle herd now
Males		
Females		

315. Cattle bought

Number Bought	Types of cattle bought[a]	Price Paid (UGX)

***a** Females: female calf, heifer or cow   Males: male calf, young male, adult male (describe: for breeding, draft, castrate)*

316. Transfers in - these are cattle brought from another household or place, loans or gifts received

Number coming in	Types of cattle coming in[a]	Reason for coming in[b]

***a** Females: female calf, heifer or cow   Males: male calf, young male, adult male (describe: for breeding, draft, castrate)*
***b** Select from: loan, gift, brought in from another place, other (specify)*

317. Other - are there any other reasons cattle came into your cattle herd?

Number	Types of cattle	Reason

***a** Females: female calf, heifer or cow   Males: male calf, young male, adult male (describe: for breeding, draft, castrate)*

SECTION 4 DRAFT POWER

401. How many acres* does your household plant crops in? |__|__| Acres/hectares/square feet (delete as case may be)

402. Does anyone in your household own the following? Write **number** owned or write 0 for none.

1. A working ox plow |__|__|
2. A working cart |__|__|
3. A working tractor |__|__|

403. Does your household use its own or other people's cattle for any draft work (ploughing, pulling carts, pulling logs etc.). Both 1 and 2 may be true.

1. We use our own cattle |__| - go to question 404
2. We use other people's cattle |__| - go to question 421
3. We don't use cattle at all for draft work |__| - go to section 5

404. What work do your draft cattle do during each season?

Season	Activity (ploughing, weeding, pulling cart, rest, etc.)
1. Long wet	
2. Long dry	
3. Short wet	
4. Short dry	

The timing of the seasons changes obviously a bit every year but usually in Uganda these would be: 1:March-June; 2: July-September; 3: October-November, 4: December-February

405. List all the cattle your household uses for draft and how much work they did during the last 6 months: *May/June 2011 up to now (Nov/Dec 2011).* If there are more than 6 please tick here |__| and write about the others on back of paper.

	Sex: Male: M Castrated male: CM Female: F	Age (years)	Number of days worked for your household during last 6 months		Number of days worked for other people's households during last 6 months	
			Ploughing	Other draft work	Ploughing	Other draft work
1						
2						
3						
4						
5						
6						

406. Do you ever use female cattle for draft work?

0. No, never |__|
1. Yes, |__| If yes, please specify when or why you would use them.

____

407. How do your draft cattle work together?

1. For ploughing we usually use 1 animal (cow, oxen, bullock, etc) |__|
2. For ploughing we usually use 2 animals (cow, oxen, bullock, etc) |__|
3. For ploughing we usually use 4 animals (cow, oxen, bullock, etc) |__|
4. For ploughing we usually use more than 4 animals (cow, oxen, bullock, etc)

Describe the typical working life of draft animals

408. At what age do they usually start to work? |__| Years |__| months
409. At what age do they usually stop working? |__|years
410. What is the price for young draft animals if bought? |__|__|__|__|__|__|__|__|__| UGX
411. What is the price for old draft cattle if sold? |__|__|__|__|__|__|__|__|__| UGX
412. How many hours do your cattle work in one day on ploughing?

1. Number of hours worked in the morning |__|__| hours
2. Number of hours worked in the afternoon |__|__| hours

413. How many days does it take to plow one acre? |__| days *(could include ½ days)*

Describe how it works when you let other people use your draft cattle

414. When your cattle work for other households, do you go with the cattle and do the work?

1. 1. Yes – always |__|
2. No – never |__|
3. Sometimes |__|

415. When your cattle plow for other households do they use your plow?

1. Yes – always |__|
2. No – never |__|
3. Sometimes |__|

416. When your cattle work for other households, how do they repay you for this?

1. They come and work for me |__|
2. They pay me some money |__|
3. They give me some gifts |__|
4. They don't repay me in any way |__|
5. Other (specify) ____

417. If they repay you in money, how much do they pay per day /acre (delete as necessary) of ploughing?

|__|__|__|__|__|__|__| UGX

418. If they repay you in money, how much do they pay for transport work with a cart?

|__|__|__|__|__|__|__| UGX

Please explain exactly what type of transport work this payment was for (e.g carrying one sack of maize, pulling logs and grass for 3 hours or whatever).

____

____

419. Were there any times during the last 6 months when you could not use your draft cattle because they were sick? **1** Yes |__| **2** No |__|

420. If YES, please describe

1. Number of cattle affected |__|__|
2. Type of illness ____________________________________
3. How long they were ill? |__|__| days
4. How long couldn't they work? |__|__| days
5. How did you treat them ____
6. How much did the treatment cost? |__|__|__|__|__|__ |__|__| UGX

<u>The next questions are for people who hired or borrowed cattle from other people.</u>

421. How many days did you use someone else's cattle for ploughing during the last 6 months? |__|__|

422. How many days did you use some else's cattle for other draft work during the last 6 months? |__|__|

423. What kind of other draft work did you use them for?

____

424. When you borrowed or hired someone's cattle, did they come with their cattle and do the work?

1. Yes – always |__|
2. No – never |__|
3. Sometimes |__|

425. When you borrowed or hired someone's cattle for ploughing did you use that person's plow?

1. Yes – always |__|
2. No – never |__|
3. Sometimes |__|

426. When you borrowed or hired someone's cattle how did you t repay them for this?

1. I came and did some work for them |__|
2. I paid them some money |__|
3. I gave them some gifts |__|
4. I did not repay them in any way |__|
5. Other (specify) ____

427. If you paid in money, how much did you pay per day of ploughing?
|__|__|__|__|__|__|__|__| UGX
428. If you paid in money, how much did you pay for transport work with a cart?
|__|__|__|__|__|__|__|__| UGX
Please explain exactly what type of transport work this payment was for (e.g carrying one sack of maize, pulling logs and grass for 3 hours or whatever).

____

SECTION 5: MASTITIS

Interviewer: *Most farmers will have seen mastitis, but may use another name. You must make sure they understand the symptoms described below.*

Mastitis is a condition affecting the udder (teats/quarters) of the cows especially when they are milking. Often the first sign of mastitis will be the cow trying to kick or resist milking, due to pain. Other symptoms include a hot, swollen udder, hard teats (can be more than one quarter affected), and watery or clotted milk. This section aims to understand whether mastitis is a problem in your cows and what you believe are the most effective treatments (if any).

501. Have any of your cows ever had mastitis? / (insert local name)_________________________________?
1. Yes |__|
0. No |__| If no go on to next section (6)

502. How important a problem do you feel mastitis is in your cows?
1. Not a problem at all |__|
2. A bit of a problem |__|
3. A regular problem that causes some worry |__|
4. An important problem that worries me a lot |__|
5. A very big problem |__|

503. What do you believe is the main cause of mastitis?
1. Not washing the udder before and after milking |__|
2. Dirty kraals that keep the udder dirty |__|
3. Dirty milk men |__|
4. Flies |__|
5. Other causes (specify) ____

504. When you get mastitis in a cow how many quarters (teats) are usually affected?
1 One |__|
2 Two |__|
3. Three |__|
4. Four |__|

505. During the **past 6 months**, how many of your cows had mastitis? |__|__|

506. For the cows which had mastitis, how many times did they have it
1. Only 1 time |__|
2. Two times |__|
3. More than 2 times |__|

507. When a cow gets mastitis how do you try to make it get better (there may be more than 1 answer)
1. Take all the milk from the infected teat (milk out the infected quarter) |__|
2. Get an injection for the cow |__|
3. Get a medicine to put into the teat (insert drug into the teat) |__|
4. Other treatment (specify)____

508. During the **past six months** did you spend any money on treating your cows for mastitis?
1. Yes |__| Go to question 509
0. No |__| If no go on to next section (6)

509. Tell us about what you spent on treating cows with mastitis during the **past six months**

Name of drug used	How was it used? (inject cow, put into teat, other)	How many teats were infected?	Who gave the drug to the cow?[b]	What did you pay in total for the treatment for one cow UGX	Cost breakdown for **each** cow treated *(if not known write "**DN** = don't know", if none write **0**)*	
					Payment to person giving treatment UGX	Cost of drug UGX

b *Owner, other livestock keeper, animal health worker, other = please specify*

SECTION 6 ANIMAL HEALTH AND OTHER COSTS OF KEEPING CATTLE

We would also like to talk about how much it costs to keep cattle, and especially to keep them healthy. We are particularly interested in ticks and flies, especially tsetse flies, and the disease known as nagana.

601. What have you spent on trypanocides (Veridium, Berenil, Veriben) on your cattle in the last **6 MONTHS**?

Name of drug used ?and month???	Number and types of cattle treated	Number of treat-ments given to each one	Who gave the drugs to the cattle[b]?	Total cost in cash for **each** cattle treated **each time** it was treated UGX	Cost breakdown for **each** cattle treated *(if not known write "DN = don't know", if none write 0)*		How much time (write minutes or hours did you have to spend dealing with this each time?
					Pay-ment to person giving treat-ment UGX	Cost of drug UGX	

a *Female calf, heifer, cow; male calf, young male, adult male for breeding, adult draft male, adult castrate)*
b *Owner, other livestock keeper, animal health worker, other = please specify*

602. What else have you spent on cattle health between in the last 6 months . This includes both when they were sick and the things you do to keep your cattle healthy, like vaccinating them or giving them any other medicines or treatments to keep them well.

Type of treatment and name of product or drug used	Type of cattle treated	How many cattle	How many times were they treated?	Total cost in cash UGX	Who did the treatment?

a *Female calf, heifer, cow; male calf, young male, adult male for breeding, adult draft male, adult castrate)*

b *Owner, other livestock keeper, animal health worker, other = please specify*

603. Have there been any other cash (money) expenses for your cattle between in the last 6 months? For example feed, grazing costs, fines for crop damage, crush repairs, ropes, labour, etc

What was the expense for?	Cost in Cash (UGX)

SECTION 7 INTERVIEW CONCLUSIONS AND ADDITIONAL NOTES

We would like to thank you very much for your time and for this useful information. We hope it will help to plan good disease control work both for people and for their livestock.

ANNEX 2

QUESTIONNAIRE FOR CATTLE KEEPERS ON RELATIVE COSTS OF RESTRICTED APPLICATION AND OTHER METHODS TO CONTROL TRYPANOSOMIASIS, TSETSE AND TICKS

A.GENERAL

1. HOUSEHOLD SCREENING

Time interview started:

1.1	Are cattle kept by your household? NO – thank and terminate YES – Proceed with questionnaire	
1.2	How many cattle do you own and keep in this area now?	
1.3	How many cattle did you own and keep in this area one year ago? (Nov 2011 to Nov 2012)	

2. HOUSEHOLD IDENTIFICATION AND CHARACTERISTICS

2.1	GPS reading	
2.2	Name of house head	
2.3	Name of respondent	
2.4	Relationship to household head	
2.5	How many household members are there in total?	

2.6	Of these, how many household members are adults (over 18 years old)	
2.7	Of these, how many house hold members are aged below 18 years old?	
2.9	Other observations	

B. TRYPANOCIDES

3. What have you spent on trypanocides (Veridium, Berenil, Veriben,…) on your cattle during the past six months ?

Name of drug used	Number of cattle treated	Number of treatments given to each one	Cost in Cash for the medicine (Ugandan shillings)	Payments (if any) to animal health people	Treated by who	How much time did you have to spend dealing with this?

C. TICK CONTROL

4. What measures do you use to control ticks in your cattle (mark all that apply)

A. Removing ticks by hand	**B.** Pour-on applications	**C.** Spraying with Makerere University and Vectocid restricted application	**D.** Buying and using vectocid yourself	**E.** Getting someone else to help you apply vectocid	**F.** Spraying cattle using Amitraz	**G.** Other methods of spraying cattle	**H.** Other (specify)

Instructions for interviewer

You will now need to complete details in one or both of the two following sections.

- *If they have said yes to C go to section D1 on this page questions 5–13*
- *If they have said yes to D go to section E1 on page 6 questions 14-25*
- *If they have said yes to E go to section E1 on page 6 questions 14-25*
- *Then please for all respondents go to section F on page 10 question 26*

D1. RESTRICTED APPLICATION USING VECTOCID APPLIED BY MU

5. When you take your animals for spraying with Vectocid by Makerere University, who goes with them?

Head of household	
Other member(s) of household (specify who)	
A herder or farm worker working for you (*explain how much of time that person spends looking after household's cattle e.g full time, 3 months a year, etc.*)	
Other person (specify)	

6. If anyone goes with you, do you have to pay that person with money or gifts?

NO	YES	What do you pay them just for doing this work? (*cash plus gifts plus anything else. Please put gift name and local value of the gift in of in Ushs)*	Do they usually work for you for looking after your cattle	
			What do you pay them for all their work? (*for example, cash plus gifts plus milk or calves, if is milk or an animal, please estimate value of that milk or animal*)	How much work do they have to do to earn these payments (*For example herding cattle all year for one hour a day, or helping all dry season*)

7. How many times have your cattle been sprayed with Vectocid by Makerere University? About how many cattle were sprayed each time?

When sprayed by Makerere University (month and year)	**Number of cattle sprayed**
June 2012	
July 2012	
August 2012	
September 2012	
October 2012	
November 2012	
December 2012	
January 2013	
February 2013	

When sprayed by Makerere University (month and year)	**Number of cattle sprayed**
March 2013	
April 2013	
May 2013	
June 2013	
July 2013	
August 2013	
September 2013	
October 2013	
November 2013	

.8. How much time does it take each time your cattle are sprayed? Please add up the time it takes to get the cattle together, to take them to where they will be sprayed, to have them sprayed, and take them back.

Less than 1 hour			2 – 5 hours	

1 -2 hours	

More than 5 hours	

9. How much do you have to pay per animal for the treatment / spray?

Type of animal	Cash (Ugandan shillings)	Other (specify type of gift and approximate value in UGshs)
Calf (less than one year old)		
Young male or female		
Adult animal		

10. Does the spraying have any other costs to you? If yes please describe and say what the cost is in time and money e.g ropes, crush, crop-damage, restraint etc

Rope.....................
Crush maintenance....................
Crop-damage.................................
Restraint.......................................
Injuries to other animals....................
Water for mixing drugs........................
Other...

11. How does the spraying affect the cattle? Please tick any of the things below which apply.
Prompt: have you had any accidents or injuries to the cattle while they are all together being treated/sprayed. When they get home have all the ticks dropped off? Are some of them a bit sick, or give less milk or have trouble ploughing? Or do they seem healthier?)

Short term effects while the spraying is being done:

No effects	
Accidents or injuries while spraying or rounding them up for spraying	
Other (specify)	

Long term effects after the spraying:

No effect	

Positive effects	
Ticks drop off	
Cows give more milk	
Draft animals work better	
Cattle seem	

Negative effects	
Ticks do not drop off	
Cows give less milk	

;'

Any effect on you?.................................

....

12. Do you feel that it is necessary to spray the whole animal? YES or NO

If NO, Please indicate which parts of the cattle you think should be sprayed?

Select from: (may be more than one)	
A. Back	
B. Belly	
C. Legs	
D. Ears	
E. Tail	
F. Other (describe)	

13. Which category of cattle do you think benefit most from the spraying?

Select from: (may be more than one)	
A	All cattle
B	Calves
C	Young males
D	Heifers
E	Cows
F	Ploughing animals
G	Bulls
H	Other (describe)

If they also do spraying on their own or with help from friends go to section E1 below.
If not, go to section F on page 26.

E1. BUYING AND USING VECTOCID BY THE FARMER AND OR GETTING SOMEONE ELSE TO HELP SPRAY THE CATTLE

14. Where do you buy the Vectocid?

Name of village/town	
Seller (specify if shop, individual, the person who helps you spray them, etc.)	
Distance from your house	
How many times have you bought it during the last six months	

15. What quantity do you buy and how much does it cost?

Size of unit	20 ml single serve	100 ml
Price per unit		
Number bought in last six months		
Total cost		

16. How much time does it take each time your cattle are sprayed? Please add up the time it takes to get the cattle together, to take them to where they will be sprayed, to have them sprayed, and take them back.

Less than 1 hour	
1 -2 hours	

2 – 5 hours	
More than 5 hours	

17. Does anyone help you when you spray the cattle? NO [ ] YES [ ]

If YES, please specify:

Age and sex of helper	
Are they a member of the household	
Are they a herder or farm worker working for you? (*explain how much of time that person spends looking after household's cattle e.g full time, 3 months a year, etc.*)	
Are they trained in animal health or work for the veterinary or extension services? If YES, please describe.	
Other person (specify)	

18. If anyone helps, do you have to pay that person with money or gifts?

NO		YES	If YES what do you pay them just for doing this work? (*cash plus gifts plus anything else, please estimate value of gifts*)	If YES, and they usually work for you looking after your cattle	
				What do you pay them for all their work? (*for example, cash plus gifts plus milk or calves, if is milk or an animal, please estimate value of that milk or animal*)	How much work do they have to do to earn these payments (*For example herding cattle all year for one hour a day, or helping all dry season*)

19. How many times have your cattle been sprayed by yourself or by other people (not including the times it was done by Makerere University)? About how many cattle were sprayed each time?

When sprayed by Makerere University (month and year)	**Number of cattle sprayed**
June 2012	
July 2012	
August 2012	
September 2012	
October 2012	
November 2012	
December 2012	
January 2013	
February 2013	

When sprayed by Makerere University (month and year)	**Number of cattle sprayed**
March 2013	
April 2013	
May 2013	
June 2013	
July 2013	
August 2013	
September 2013	
October 2013	
November 2013	

20. What was used to apply the Vectocid to the cattle's body?

Select from:	
A. Own sprayer	
B. Someone else's sprayer	
C. Group pump	
D. Pour-on	
E. Other (describe)	

21. If you used your own spray pump:

How many spray pumps do you own?	
How much does a new pump cost now?	
How many years can you use a pump before you need to buy a new one?	

22**.** Does the spraying have any other costs to you? If yes please describe and say what the cost was in time and money.

23. Does the spray have any effect on the cattle? Please tick any of the things below which apply.

Prompt: have you had any accidents or injuries to the cattle while they are all together being treated/sprayed. When they get home have all the ticks dropped off? Are some of them a bit sick, or give less milk or have trouble ploughing? Or do they seem healthier?) ***If you already answered question 12 above and the same answers apply you do not need to answer this question.***

Short term effects during the spraying: while the spraying is being done:

No effects	
Accidents or injuries while spraying or rounding them up for spraying	
Other (specify)	

Longer term effects after the spraying has been done:

No effects	

Positive effects	
Ticks drop off	
Cows give more milk	
Draft animals work better	
Cattle seem healthier	
Other (specify)	

Negative Effects	
Cows give less milk	
Draft animals don't work so well	
Animals a bit sick	
Other (specify)	

24. Do you feel that it is necessary to spray the whole animal? YES [ ] NO [ ]

If NO, Please indicate which parts of the cattle you think should be sprayed?

If you already answered question 13 above and the same answers apply you do not need to answer this question.

Select from: (may be more than one)	
A	Back
B	Belly
C	Legs

D	Ears
E	Tail
F	Other (describe)

25. Which category of cattle do you think benefit most from the spraying? ***If you already answered question 13 above and the same answers apply you do not need to answer this question.***

Select from: (may be more than one)	
A	All cattle
B	Calves
C	Young males
D	Heifers
E	Cows
F	Ploughing animals
G	Bulls
H	Other (describe)

F. OTHER MEASURES TO CONTROL TICKS (*to be answered by <u>all respondents</u>*)

26. What other measures do you use to control ticks in your cattle?

Name of product/method used	Number of cattle usually treated during the last six months	Number of times cattle usually treated during the last six months	Who carried out the activity? a-owner b-vet/AHT c-other	Amount of money you spent on the product in the last six months (Ugandan shillings)	Total payments during the last six months (if any) to other people for applying this product	How much time did you have to spend dealing with this each time the cattle were treated?

G.GENERAL INTERVIEW

27. How many acres do you own and cultivate?.............hire and cultivate...........amount.............
Acres lended.....................

28. What method do you use for cultivation?

A. Hand hoe	
B. Own and use draft oxen/bull	
C. Other people's draft oxen/bull	
D. tractor	
E. Other	

For those who own ox-plow, how much does it cost you to maintain the plow per year...................................

29. Do you use fertilizer? YES...........NO........

If yes, what type of fertilizer do you use?

Animal manure	
Inorganic fertilizer	
Other e;g. crop residue	

30. How many acres of the crops below do you plough in one season? How many bags did you harvest?

Prompt: within the last six months

Produce	**Acres ploughed**	**kg harvested**	**Kg consumed**	**kg sold**	**Price/kg**
A. maize					
B. millet					
C. sorghum					
D. rice					
E. cotton					
F.tobacco					
G.cassava					
H.beans					
F. other					

31. How do you acquire your animals?

A. Through inheritance	
B. Buying from market	
C. Buying from neighbours	
D. gifts	
E. other	

31.Family labour? Yes.................No...............

32.Hired labour? Yes...................No.............If yes,

Labour	**land preparation**	**weeding**	**harvesting**	**transport**
Amount/season				
Season (first, second and other)				

Other type of payment.........................

33. Do you use pesticide? Yes..........No.............

If yes, amount per season...Number of season.................

G.CLOSING COMMENTS

31. Do you have any questions for us?

APPENDIX 3

HOUSEHOLD QUESTIONNAIRRE FOR TAENIASIS/CYSTICERCOSIS INTERVENTION

LAO PDR

SECTION 1 INTERVIEW IDENTIFICATION

109. Name of person being interviewed

____

110. Name of head of household____________________________________

Is this the same person as interviewee? Yes |__| No |__|

If the person being interviewed is not the househ*old head, what is their position? Please specify:*

---

111. What is the sex of the person being interviewed?

1. **1.** Male |__|
2. **2.** Female |__|

112. What is the age of the person being interviewed?__________________

113. What is the ethnicity of the person being interviewed?

1. Thai Dam |__|

2. Lao Loum |__|

3. Khmu |__|

4. Other(specify)____________

114. What type of house does this household have?

1. Double storey with both storey made of wood |__|

2. Double storey with upper storey made of wood and lower made of bamboo |__|

3. Double storey with upper storey made of bamboo and lower made of wood |__|

4. Single storey made of wood |__|

5. Single storey made of bamboo |__|

6. Other(specify) __________

115. Do you have a toilet? Yes |__| No |__|

SECTION 2 HOUSEHOLD COMPOSITION

203. How many people live in your household? |__|__|

204. How many adults live in your household? |__|__|

205. How many children live in your household? |__|__|

206. What is the highest education level of the head of household?

1.primary |__|
2.secondary |__|
3.college |__|
4.none __|

207. What is the main source of house hold cash?

1.sell of excess rice |__|
2.sell of livestock |__|
3.rubber |__|
4.timber |__|
5.hunting |__|
6.remittance from outside the district |__|
7.other__________

SECTION 3 LIVESTOCK AND PIG PRODUCTIVITY

301. How many animals does your household own and keep in this area?

8. Cattle |__|__|

9. Buffalo |__|__|

10. Pigs |__|__|

11. Goats |__|__|

12. Sheep |__|__|

13. Chickens |__|__|

14. Any other animals (specify) ______________________ number|__|__|

302.If you keep pigs, what is there breed?

1.local |__|

2.exotic |__|

3.cross-breed |__|

303.Please tell us about the pigs you have at the moment

1.How many boars do you have now? |__|__|

2.How many sows do you have now? |__|__|

3.How many growers do you have now? |__|__|

4.How many weaned piglets do you have now? |__|__|

5.How many piglets do you have now? |__|__|

304.What feed do you give your feed?

1.Free range |__|

2.Commercial |__|

3.household leftovers |__|

4.forage |__|

5.Other____________________________

305.What is the weight of your pigs now? (please put DN if the farmer does not know)

1.Boars |__|__||__|

2.sows |__|__||__|

3. growers |__|__||__|

4. weaned piglets |__|__||__|

5. piglets |__|__||__|

306.How do you acquire your pigs?

1.breeding |__|

2.buying from market |__|

3. neighbor |__|

4. gifts |__|

5. Inheritance |__|

6.Other (specify)____________

SECTION 4 EXITS AND ENTRIES

401.One year ago, how many **male** pigs did you have? |__|__|

402.One year ago, how many **female** pigs did you have? |__|__|

403. Please tell us about any of your pigs which **left** during the **past ONE YEAR**

Deaths (Due to disease or accidents etc)

Number died	Type of pig died	Reason for death
	boar	disease
	sow	accident
	grower	predator
	Weaned piglets	Other (specify)
	piglets	

Slaughter (*pigs that were slaughtered for home consumption or for sale of meat and had not died of disease or accidents*)

Number slaughtered	Types of pigs slaughtered	Reason for slaughter
	boar	Family celebration
	sow	Ritual offering
	grower	old
	Weaned piglets	sick
	piglets	Other (specify)

Sales

Number sold	Types of pigs sold	Reason for sale	Price received UGX
	boar	To get money	
	sow	old	
	grower	sick	
	Weaned piglets	Other (specify)	
	piglets		

Transfers out of the herd (*these are cattle sent to another household or place, loans, gifts and even include any pig stolen from you)*

Number left	Types of pigs left	Reason for leaving
	boar	Sent to another place
	sow	gift
	grower	stolen
	Weaned piglets	Other(specify)
	piglets	

Other: are there any other reasons pigs left your herd?

Number	Types of cattle left	Reason for leaving
	boar	
	sow	
	grower	
	Weaned piglets	
	piglets	

404.*Please tell us about pigs which came* ***into your herd*** *during the* ***past ONE YEAR?***

Births

	Number born	Number of these still in your pig herd now
Males		
Females		

Pigs bought

Number Bought	Types of cattle bought[a]	Price Paid (UGX)
	boar	
	sow	
	grower	
	Weaned piglets	
	piglets	

Transfers in - these are pigs brought from another household or place, loans or gifts received

Number coming in	Types of cattle coming in[a]	Reason for coming in[b]
	boar	Brought from another place
	sow	Gift
	grower	Loan
	Weaned piglets	Other(specify)
	piglets	

Other: are there any other reasons pigs came into your pig herd?

Number	Types of cattle	Reason
	boar	
	sow	
	grower	
	Weaned piglets	
	piglets	

SECTION 5 ANIMAL HEALTH AND COSTS

501.How important a problem do you feel Classical Swine Fever is to your pigs and household?

6. Not a problem at all |__|

7. A bit of a problem |__|

8. A regular problem that causes some worry |__|

9. An important problem that worries me a lot |__|

10. A very big problem |__|

502.What is the major effect of Classical Swine Fever to your pigs?

1. death |__|
2. abortion |__|
3. diarrhoea |__|
4. causes my pigs to be condemned by the trader/butcher |__|

5. Other (specify) ____

503.How important a problem do you feel tapeworm cyst is to your pigs and household?

1. Not a problem at all |__|

2. A bit of a problem |__|

3. A regular problem that causes some worry |__|

4. An important problem that worries me a lot |__|

5. A very big problem |__|

*503***.** What do you believe is the main cause of tapeworm cysts in your pigs?

1. pigs eating human faeces |__|
2. pigs eating other pig faeces |__|
3. pigs getting in contact with infected people |__|
4. poor hygiene in the pig pen |__|

5. Other causes (specify) ____

503.What is the major effect of tapeworm cysts in your pigs and household?

1. pigs lose weight |__|
2. pigs diarrhoea |__|
3. pigs grow slowly |__|
4. causes my pigs to be condemned by the trader/butcher |__|
5. causes sickness to me and my family |__|

5. Other causes (specify) ____

504.Do you sell your pigs to the trader? Yes |__| No |__|

505. Has any of your pigs been condemned by the trader or butcher for having tapeworm cysts?

Yes |__| No |__| DN (Don't know) |__|

If yes, what was the value of the condemned pigs? __________________________KIP

506. What do you do if you find tapeworm cysts in your pig during slaughter?

1. cook the meat properly |__|
2. cut off the bits with tapeworm cysts |__|
3. condemn the whole carcass |__|
4. nothing |__|
5. Other (specify) ____

If you condemned the pig carcass, what was the value of the condemned pig?
__________________________KIP

507.In the past one year, have you dewormed your pigs against tapeworms?
Yes |__| No |__| DN (Don't know) |__|
If yes,

How many pigs were dewormed?	What types of pigs were dewormed? (boars, sows, growers, weaners or piglets)	How many times were they dewormed?	What was the total cost of deworming in KIP?	How much time in minutes did you spend deworming them?	Who dewormed them? (vet, myself or other

508.In the past one year, have you vaccinated your pigs against CSF?

Yes |__| No |__| DN (Don't know) |__|

If yes,

How many pigs were vaccinated?	What types of pigs were vaccinated? (boars, sows, growers, weaners or piglets)	How many times were they vaccinated?	What was the total cost of vaccination in KIP?	How much time in minutes did the vaccination take?	Who vaccinated them? (vet, myself or other

SECTION 6 INTERVENTION COST

601.Did you pay for the vaccination and deworming of your pigs by our team? Yes |__| No |__|

If yes, how much? ___________________________KIP.

602. How much time did you spend on vaccination and deworming exercise?

1. less than 1 hour |__|
2. 1-2 hours |__|
3. 2-5 hours |__|
4. more than 5 hours |__|

603. Did you spend any cash or gifts on the following during the intervention exercise?

1. building of a new pig pen to restrain the pigs |__|
2. repair of the pig pen after the exercise |__|
3. bought new ropes and buckets for restraint |__|

If so, how much did you spend?___________________________KIP

4. payment to another person for restraint |__|

If so, how much did you spend?___________________________KIP

5. Other (specify) ____

606. What positive effects of the intervention have you observed in your pigs and household?

1. pigs grow quicker |__|
2. pigs gain more weight |__|
3. less pigs are condemned by the trader/butcher |__|
4. pigs look healthier |__|
5. pigs produce more piglets |__|
6. less pigs die |__|
7. pigs eat more |__|
8. my family look healthier |__|
9. no effect |__|
10. Other (specify) ____

607. What negative effects of the intervention have you observed in your pigs and household?

1. pigs grow slowly |__|
2. pigs lose weight |__|
3. more pigs are condemned by the trader/butcher |__|
4. pigs look ill |__|
5. pigs produce less piglets |__|
6. more pigs die |__|
7. pigs eat less |__|
8. my family look ill |__|
9. no effect |__|
10. Other (specify) ____

608.Would like your pigs to continue joining the program? Yes |__| No|__|

SECTION 7 HUMAN HEALTH AND COSTS

701. How important a problem do you feel tapeworm is to you and your family?

1.Not a problem at all |__|

2.A bit of a problem |__|

3.A regular problem that causes some worry |__|

4.An important problem that worries me a lot |__|

5.A very big problem |__|

702. What do you believe is the main cause of tapeworm to people?

1. contact with infected pigs |__|
2. eating raw pork |__|
3. eating unwashed vegetables |__|
4. poor hygiene |__|

5. Other causes (specify) ____

703. How do you like to eat your pork?

1. well cooked |__|
2. medium cooked |__|
3. raw |__|
4. together with fresh vegetables |__|

5. Other (specify) ____

704.What do you think is the major effect of tapeworms to people?

1. epilepsy |__|

2.headache|__|

3.loss of vision |__|

4. diarrhoea |__|

3. slow growth especially children |__|

4. causes tiredness |__|

5. loss of weight |__|

6. none |__|

7. DN (don't know) |__|

8. Other (specify) ____

705. Have you or any family member ever suffered from epilepsy? Yes |__| No |__|

If yes, was the person treated? Yes |__| No|__|

If the person was treated, how much was the treatment?__________________________KIP

SECTION 8 INTERVENTION COST ON HUMAN HEALTH

801. Did you pay for the deworming by our team? Yes |__| No |__|

If yes, how much? ___________________________KIP.

802. How much time did you spend on the deworming exercise?

1. less than 1 hour |__|
2. 1-2 hours |__|
3. 2-5 hours |__|
4. more than 5 hours |__|

803.What positive effects of the intervention have you observed in yourself and household?

1. children seem to grow quicker |__|
2. less people have diarrhoea |__|
3. we have put on more weight |__|
4. we look healthier |__|
5. we work better |__|
6. less people have epilepsy|__|
7. less people have headache|__|
8. less people have vision problems |__|
9. no effect |__|
10. Other (specify) ____

804.What negative effects of the intervention have you observed in yourself and household?

1. children seem to grow slowly |__|
2. diarrhoea |__|
3. we have lost weight |__|
4. we look ill |__|
5. we work less |__|
6. more people have epilepsy
7. more people have headache
8. more people have vision problems |__|
9. no effect |__|
10. Other (specify) ____

Would like to continue joining the program? Yes |__| No |__|

ANY COMMENTS