ECONOMIC ANALYSIS OF RIFT VALLEY FEVER CONTROL OPTIONS FROM A ONE HEALTH PERSPECTIVE IN KENYA

KIMANI, TABITHA MUGETHI

A Thesis Submitted to the Graduate School in partial Fulfilment for the Requirements of the PhD. Degree in Agricultural Economics of Egerton University

EGERTON UNIVERSITY

October, 2017

DECLARATION AND RECOMMENDATION

DECLARATION

I declare that this Thesis is my original work and to the best of my knowledge has not been presented for any degree at this or any other university.

SIGNED: ____________________________ Date______________________

TABITHA MUGETHI KIMANI (MSc)

KD15/0291/11

RECOMMENDATION

I declare that this work has been done under our supervision and is being submitted with our approval.

SIGNED: ______________________ Date______________________

DR. MARGARET W. NGIGI (PhD)

Department of Agricultural Economics and Agribusiness Management

Egerton University

SIGNED: _______________________ Date______________________

DR. THOMAS F. RANDOLPH (PhD)

Market Opportunities Theme

International Livestock Research Institute, Nairobi

SIGNED: _______________________ Date______________________

DR. ESTHER SHELLING (PhD)

Human and Animal Health Unit

Swiss Tropical and Public Health Institute, Switzerland

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DEDICATION

This Thesis is dedicated to my loving parents, Mary Njeri and late Isaac Nderitu Kimani Muta. And to my sons, Kenneth and Kevin. They all have been my pillars.

ACKNOWLEDGEMENT

To God be the glory, for all this He has made possible. Many instituions and individuals have directly or indirectly contributed to this study by offering financial, technical, logistic and moral support; they deserve my gratitude Egerton University has for a second time offered me a place at the faculty of Agriculture. I am especially grateful to the chairman and staff of the department of Agricultural Economics and Agribusiness Management and his team for smooth facilitation of the course work and Thesis preparation. The Faculty of Agriculture and the Graduate School are also acknowledged for their immense support. I am especially indebted to my supervisors Drs Esther Schelling, Margaret W. Ngigi and Thomas Randolph for invaluable support, guidance, encouragement, constructive criticisms and directing. Despite their heavy schedules, they got time to read and offer direction to my work.

My gratitude also goes to my funding and collaborating institutes. This work was funded by the IDRC through the International Food Policy Research Institute (IFPRI's) Agricultural and Health Research Platform (AHRP). The three collaborating institutions were Swiss Tropical and Public Health Institute (Swiss TPH), International Livestock Research Institute Kenya Medical Research Institute (KEMRI) and Centres for Disease Control (CDC), Kenya. I also acknowledge the Director of Veterinary Services (DVS) for allowing me to undertake the study. The assistance by Samuel Fuhrimann of Swiss TPH, Bernad Bett, Delia Grace and Susan Kariuki, RoseKellen Njiru and Diana, all of ILRI cannot go unmentioned and unacknowledged. Samuel Fuhrimann developed the the herd dynamics model used in this study. Austine Bitek and Kariuki Njenga of KEMRI/CDC as well as Alexandra Shaw are also acknowledged for the different roles they played.Austine Bitek provided the data on household expenditure on human RVF cases. Finally, I cannot forget the Garissa County livestock keepers and respondents from various organizations whose cooperation during the data collection was good.

ABSTRACT

Since 1931, Rift Valley fever (RVF) epidemics have recurred in Kenya at an average inter-epidemic period of up to 10 years. The most recent epidemic occurred in 2006/2007. It resulted in losses. Estimated as KES 2.1 Billion. A post epidemic assessment recommended adoption of One Health (OH) approach to RVF management as well as implementation of livestock control strategies that offer highest benefits to both the livestock and public health sectors. Evidence to guide such decisions was inadequate. Costs and benefits analysis (CBA) of RVF control had not been conducted. This study provides the evidence in four sequential steps of data collection and analysis, focusing on RVF high risk areas in Kenya. The steps included, (i) a social network analysis at national and sub-national (Garissa County) levels that identified RVF stakeholders and the extent to which they had institutionalised One Health (OH) approach, (ii) delineation of eleven (1 baseline and 10 alternatives) livestock RVF control strategies (that combined different levels of surveillance, vaccination, and mosquito control) and estimation of the associated control costs for the period 2007-2014. The impacts of the control measures on a hypothetical epidemic 2014/2015 were simulated in a (iii) herd dynamics and RVF modelling to estimate number of animal mortality and morbidity, (iv) animal-human RVF epidemiological modelling to generate human morbidity and mortality that would arise from the animal cases. Human case data was used to estimate disability adjusted life years (DALYs). Quantitative livestock and economic CBA in Excel combined animal simulation outputs, production indices and product prices to estimate value of livestock sector losses under each control strategy. Benefits of alternative strategies represented saved losses, compared to the baseline strategy. The evaluation criteria for the alternate control strategies were net present value of incremental benefits over costs. Social network analysis showed that, at national level, stakeholders had mobilised for and institutionalized OH through formal structures. The reverse was true at sub-national level. Alternate strategies that assumed improved vaccination coverage (3-5 fold) implemented 2-3 years before the hypothetical epidemic, showed the highest benefits ~livestock sector benefit cost ratio of 1.1 to 5.0 and public health sector cost effectiveness of KES 2,847 to KES 3,485 per DALY averted. Considering that RVF outbreaks occur at sub-national level, where both OH has not been institutionalized and the baseline vaccination strategy continues to be adopted, in case of an incursion, the next epidemic would have a similar magnitude as the 2006/2007.

TABLE OF CONTENTS

DECLARATION AND RECOMMENDATION ..... **ii**
COPYRIGHT ..... **iii**
DEDICATION ..... **iv**
ABSTRACT ..... **vi**
TABLE OF CONTENTS ..... **vii**
LIST OF TABLES ..... **xi**
LIST OF FIGURES ..... **xiv**
LIST OF APPENDICES ..... **xvi**
LIST OF ACRONYMS ..... **xviii**
CHAPTER ONE **1**
GENERAL INTRODUCTION **1**
1.1 Rift Valley fever 1
1.2 Statement of the problem 4
1.3 Overall goal and objectives of the study 4
1.4 Research questions 5
1.5 Justification 5
1.6 Scope and Limitations 6
CHAPTER TWO **7**
GENERAL LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK **7**
2.1 Literature review 7
2.1.1 Approaches to multisectoral economic assessments of Rift Valley fever and other zoonoses 7
2.1.2 Approaches to One Health institutional analysis 12
2.2 Theoretical and Conceptual framework for multisectoral assessment of RVF control and OH approach 14
2.2.1 Societal costs of RVF control 16
2.2.2 Total benefits of control 20
CHAPTER THREE **21**
GENERAL METHODOLOGY **21**

3.1 Sequence of data collection and analysis 21
3.2 Study area 23
3.2.3 Rift Valley fever risk areas and farming systems 23
3.2.4 Target livestock population 25
3.2.5 Target human population 26
3.2.6 Data collection sites 26
3.3 Analysis and data collection period 29
CHAPTER FOUR 30
STAKEHOLDER AND INSTITUTIONAL ANALYSIS FOR ONE HEALTH 30
4.1 Introduction 30
4.2 Literature review and conceptual framework for OH institutional analysis 31
4.3 Methodology 35
4.3.1 *Data types, sampling techniques and sample size* 35
4.3.2 The analytical framework 36
4.4 Results 38
4.4.1 Sub-national analysis 38
4.4.2 National level analysis, ... 48
4.4.3 Historical progression of mobilisation for OH at national level 51
4.5 Chapter discussions and conclusions 56
4.6 References 61
CHAPTER FIVE 64
BASELINE AND ALTERNATE RIFT VALLEY FEVER LIVESTOCK CONTROL STRATEGIES AND ASSOCIATED COSTS 64
5.1 Introduction 64
5.2 Literature review 64
5.2.1 The Epidemiology of Rift Valley Fever 64
5.2.2 Animal RVF prevention and control options 65
5.3 Methodology 68
5.3.1 Delineation of animal RVF control options and integrated strategies 68
5.3.2 Identification and estimation of control costs 70
5.4 Results and Discussions 72
5.4.1 Measures implemented prior to and during the 2006/2007 epidemic (1998-2012 72
5.4.2 Post –epidemic baseline practice (2007-2011) and alternate strategies (2012-2014).. 74

5.4.3 Estimated number of animals targeted and reached with each option and associated costs …..78
5.5 Summary and conclusions 89
5.6 References..91
CHAPTER SIX 96
COST-BENEFIT ANALYSIS OF ELEVEN (11) RVF PREVENTION AND CONTROL STRATEGIES...96
6.1 Introduction...96
6.2 Literature review 96
6.2.1 Economic costs of Animal 2006/2007 RVF epidemic in Eastern Africa. 96
6.2.2 Economic impacts of Animal RVF epidemic on international trade 98
6.3 Methodology 98
6.3.1 Quantifying costs/losses and benefits of interventions 99
6.3.2 The SAM model: Estimation of economy wide impacts 107
6.4 Results and Discussions 109
6.4.1 Herd Dynamics and Production (outputs) – 2006 - 2015. 109
6.4.2 Epidemiological parameters during 2006/2007 and 2014/2015 RVF epidemics and impacts on herd dynamics...117
6.4.3 Estimated Milk Output and Impacts of Drought, RVF and Abortions on Production ……...132
6.4.4 Market chain value added losses associated with the two RVF epidemics. 138
6.4.5 Economy wide impacts of the RVF outbreaks 143
6.4.6 Livestock sector cost benefit analysis of the RVF control strategies. 147
6.5 Discussions and conclusions...148
6.6 References...151
CHAPTER SEVEN...153
BURDEN OF HUMAN RVF AND COST-EFFECTIVENESS OF LIVESTOCK INTERVENTION FROM A PUBLIC HEALTH PERSPECTIVE....................153
7.1 Introduction...153
7.2 Literature review 154
7.2.1 A review of human RVF epidemiological parameters 154
7.3 Methodology 159
7.3.1 The problem, conceptual model and analytical perspective 159
7.3.2 Identification and estimation of costs 160

7.3.3 Identification and determination of outcomes 160
7.3.4 Cost-effectiveness analysis and sensitivity analysis 163
7.4 Results...163
7.4.1 Estimated DALYs associated with the RVF epidemics 163
7.4.2 Estimated public health costs and monetary benefits associated with alternative animal RVF control measures..175
7.4.3 Discussions 179
CHAPTER EIGHT 189
GENERAL CONCLUSIONS AND RECOMMENDATIONS 189
7.5 Main conclusions. 189
7.5.1 One Health stakeholder and institutional analysis findings and implications for RVF control. 189
7.5.2 Annual costs associated with current (base practice) and alternative livestock level RVF prevention and control measures..190
7.5.3 Cost and benefits of RVF prevention and control from a livestock sector perspective…. 190
7.5.4 Cost-effectiveness livestock RVF prevention and control to the public health sector ……...191
7.6 Main Recommendations 191
7.6.1 To improve future prevention and control the study recommends 191
7.6.2 Contribution to livestock economics and areas of further research 191
General References 193

LIST OF TABLES

Table 3-1: Proportion of national ruminant population found in the different categories of RVF risk areas, disaggregated by species and three livelihood (farming) systems. 25
Table 3-2: Number of ruminants found in the RVF high risk area disaggregated by species and three livelihood (farming) systems. 26
Table 3-3: Human population in RVF high areas disaggregated by gender and whether they lived in rural or urban 26
Table 3-4: Sample size, data collection sites and data types for each analytical step. 28
Table 4-1: Centrality statistics measures for Garissa County stakeholders (public health actors)..46
Table 4-2: Centrality statistics measures for Garissa County stakeholders (community leaders and livestock sector) 47
Table 4-3: National OH actor network centrality measures. 55
Table 5-1: RVF control measures implemented during 2006/2007 outbreak by animal and public health sectors...73
Table 5-2: Summary of eleven prevention and control strategies 77
Table 5-3: Proportion of total population for each species and livestock system vaccinated during the period 2007 to 2014- Baseline option and in vaccinations options 1 and 2 79
Table 5-4: Estimated number of animals (thousands) that was or would be vaccinated annually under each option in each system...80
Table 5-5: Estimated annual costs (KES, hundred thousands) of baseline vaccination strategy 82
Table 5-6: Estimated annual costs (KES hundred thousands) of vaccination option 1 and 2. 83
Table 5-7: Proportions and estimated number of animals treated with pour-on insecticides during the assumed 2014/2015 epidemic in each farming systems..84
Table 5-8: Estimated costs (KES) of animal RVF surveillance options during epidemics 86
Table 5-9: Estimated total costs (KES Million) of the 11 prevention and control strategies ..89
Table 6-1: Variables (outputs) generated from simulations- based on start population of 2000 animals 102
Table 6-2: Proportional livestock growth rate by year, farming systems and species...........110
Table 6-3: Proportion (%) by which population changed during RVF epidemics (2014/2015 under baseline control scenario) 112
Table 6-4: Estimated total mortality rate during drought and normal years. 115

Table 6-5: Estimated off takes rates –Slaughter and Sold 116
Table 6-6: Proportion by which alternate strategies (S2-S11) reduced RVF infections compared to baseline (S1)...119
Table 6-7: Summary of animals infected with RVF during the 2006/2007 and next assumed 2014/2015 outbreak under 11 alternate strategies 121
Table 6-8: Estimated changes (%) in livestock population over the 2006/2007 RVF epidemic and next assumed (2014/2015) by farming systems under 11 prevention and control strategies 122
Table 6-9: Fertility and production rates (%) -2006/2007 epidemics –all systems 124
Table 6-10: Number of births and abortions for the 2006/2007 RVF epidemic period 125
Table 6-11: Estimated RVF mortality by species, farming system and strategy during the RVF epidemics...128
Table 6-12: Total annual milk production output and losses (million litres) by species and livestock systems -all systems combined...132
Table 6-13: Milk losses (Million litres) by cause during the years with RVF 133
Table 6-14: Proportionate of total milk losses from each species and cause disaggregated by production system for the period 2006-2007 133
Table 6-15: Estimated Milk losses (million litres) during the 2006/2007 RVF epidemic.....134
Table 6-16: Estimated value (Billion KES) of production and losses during the period 2006-2015 (all species combined)...137
Table 6-17: Estimated milk value addition losses for the RVF epidemic of 2006/2006 and the 2014/2015 under different prevention and control scenarios. 139
Table 6-18: Estimated reduction (%) in number sold and slaughtered during a with RVF outbreak compared to without RVF..140
Table 6-19: Estimated value addition and losses (KES Billion) during the RVF epidemics 141
Table 6-20: Percentage reduction in annual milk off takes- sales only compared to years without RVF...143
Table 6-21: SAM derived impacts/losses (KES millions) of the 200/6007 RVF outbreak and the next assumed 2014/2015 under base prevention and control strategy compared to without RVF..145
Table 6-22: 2006/2007 RVF SAM analysis income effects compared to without RVF 146
Table 6-23: SAM output derived saved losses (KES millions) and incremental benefits during the 2014/2015 outbreak..146

Table 6-24: The Present value (PV) of the costs (KES) of control for the 8 year period compared to RVF losses associated with the 2014/2015 RVF outbreak. 147
Table 6-25: Incremental benefits and costs and benefit cost analysis (in KES) 148
Table 7-1: Number of 2006/2007 probable and confirmed human RVF cases, deaths and CFR, by age group and sex 165
Table 7-2: Estimated YLL for the RVF high risk areas in PAP areas and for the 2006/2007 epidemic 166
Table 7-3: Estimated YLD for acute cases for the 2006/2007 RVF high risk areas in PAP .167
Table 7-4: Total DALYS for the 2006/2007 RVF high risk areas in PAP 168
Table 7-5: Estimated number of animal risk factors for all species combined and by epidemic and control options...169
Table 7-6: Sero-prevalence derived animal cases during specific epidemics in selected countries 172
Table 7-7 Sero-prevalence derived human cases during specific epidemics in selected countries 173
Table 7-8: Estimated number of human RVF mortality during the 2014/2015 and disaggregated other case categories by prevention and control options 174
Table 7-9; Estimated DALYs (and averted) for the hypothetical 2014/2015 by prevention and control options 175
Table 7-10: Estimates for out of pocket expenditures for Human RVF cases......................177
Table 7-11; Estimated avoided monetary costs for the 2014/2015 by prevention and control strategy...178
Table 7-12: Summary of benefits and cost-effectiveness by strategy (KES 00,000) 179

LIST OF FIGURES

Figure 1-1: Global RVF Distribution map 1

Figure 1-2: Map of Kenya showing the 2006/2007 RVF Status of Outbreaks 3

Figure 2-1: Conceptual framework for the costs of RVF prevention and control 18

Figure 3-1: Schematic representation of the 4 sequential steps for data collection and analysis 22

Figure 3-2: Revised Kenya's RVF Risk Map 23

Figure 3-3: Livelihood Map of Kenya. 24

Figure 3-4: Map of Kenya showing the study areas and sites. 27

Figure 4-1: Conceptual framework for OH institutional analysis 34

Figure 4-2: Schematic diagram of RVF and OH stakeholders and coordination/cooperation structures. 39

Figure 4-3: Thematic network for barriers to effective role playing by the communities and the health sectors (animal and public health). 41

Figure 4-4: Sociogram of the Garissa County OH network. 48

Figure 4-5: Schematic diagram of national level OH institutionalisation process and in Kenya 52

Figure 4-6: Sociogram of the national level actors. 56

Figure 5-1: Transmission of Rift Valley Fever Virus 65

Figure 5-2: An RVF map of East Africa. 66

Figure 5-3: Categories of RVF prevention and control costs 71

Figure 5-4: Estimated annual costs (million KES) of various RVF prevention and control options (base practice) for the period 2006 to 2011 87

Figure 5-5: Estimated total costs for the period 2012 to 2015 for the 11 alternate strategies . 89

Figure 6-1: Flow chart (simplified outline) of the individual-based demographic livestock and RVF transmission model 100

Figure 6-2: Flow chart diagram of a national economy. 107

Figure 6-3: Average proportion of adult females that gave birth during years with no shock and with specified shocks 113

Figure 6-4: Proportion of adult females that abort by livestock system. 114

Figure 6-5: Proportion of animals infected by RVF in high risk areas-PAP 117

Figure 6-6: Proportion of animals infected by RVF in high risk areas-MFM 118

Figure 6-7: Proportion of animals infected by RVF in high risk areas-MFHP 118

Figure 6-8: Total number of abortions in all farming systems combined during 2014/2015 RVF epidemic 125
Figure 6-9: A comparison of cattle baseline (other) and RVF mortalities during the RVF epidemics 129
Figure 6-10: A comparison of sheep baseline (other) and RVF mortalities during the RVF epidemics 129
Figure 6-11 A comparison of goats baseline (other) and RVF mortalities during the RVF epidemics 130
Figure 6-12: A comparison of camels' baseline (other) and RVF mortalities during the RVF epidemics 130
Figure 6-13: Number of RVF infected animals sold or slaughtered in all systems combined. 131
Figure 6-14: Summary of RVF and non RVF associated losses during the years with epidemics 142
Figure 6-15: Distribution of RVF production and marketing losses associated with the 2006/2007 epidemic 142
Figure 7-1: Pathological Form of RVF in humans. 156
Figure 7-2: Steps involved in CEA. 159
Figure 7-3: Disaggregated incidence of the RVF cases in RVF hot spots 164
Figure 7-4: Estimated number of human cases associated with 2014/2015 hypothetical epidemic under eleven prevention and control strategies (S1-S11). 174

LIST OF APPENDICES

Appendix 1: Checklists and Questionnaire 202
Appendix 2: Number of Health facilities per persons, area and province. 211
Appendix 3: Health personnel capacity in NEP and at national level 212
Appendix 4: RVF specific stakeholder roles played during the RVF epidemics and inter-epidemic period. 213
Appendix 5:2010 drought mitigation animal health interventions with RVF alert. 215
Appendix 6: List of data sourced from literature and expert opinions 216
Appendix 7: National Average Live Animal Market prices 219
Appendix 8: Red meat and raw milk value chain sample 221
Appendix 9: Number of births by species in the PAP. 221
Appendix 10: Number of births by species in the MFM. 222
Appendix 11: Number of births by species in the MFHP. 222
Appendix 12: Number of abortions by species in PAP 222
Appendix 13: Number of abortions by species in MFM 223
Appendix 14: Number of abortions by species in MFHP 223
Appendix 15: Number of dead by species in PAP 223
Appendix 16: Number of dead by species in MFM 224
Appendix 17: Number of dead by species in MFHP 224
Appendix 18: Number of sold and home slaughtered animals by species and year in PAP . 224
Appendix 19: Number of sold and home slaughtered animals by species and year in MFM 225
Appendix 20: Number of sold and home slaughtered animals by species and year in MFHP 225
Appendix 21: Number of animals that die from baseline mortality in each farming system by strategy. 226
Appendix 22: Number of births, base and RVF abortions by species and control options during the RVF epidemics in PAP. 227
Appendix 23: Number of births, base and RVF abortions by species and control options during the RVF epidemics in MFM. 228
Appendix 24: Number of births, base and RVF abortions by species and control options during the RVF epidemics in MFHP. 229
Appendix 25 : Number of animals sold and slaughtered –PAP during the RVF epidemics . 230

Appendix 26: Number of animals sold and slaughtered MFM...231
Appendix 27: Number of animals sold and slaughtered MFHP 232
Appendix 28: Total Annual milk production output and losses (million litres) by species and livestock systems 233
Appendix 29: Milk production and losses (million litres) during 2014-2015 under different control strategies 234
Appendix 30: Estimate value (Billion KES) of milk production and losses during the period 2014 -2015 by systems..235
Appendix 31: Human Population in rural and urban high risk areas by farming systems. ...236
Appendix 32: Clinical symptoms associated with RVFV sero-positivity. 237
Appendix 33: Risk factors for RVF sero-postivity, acute, severe and dead cases in three districts (Garissa, 1997-98, 2006-2007; Baringo and Kilifi (2006-2007) in Kenya 239
Appendix 34: Estimated risk factors for human RVF. 241
Appendix 35: Summary of calculated DALYs by age and sex categories for each respective control strategy for the 22014/2015 RVF epidemic 244
Appendix 36: Publication 1- One Health Satekholder and Institutional analysis in Kenya. .246
Appendix 37: Publication 2- Public Health Benefits from Livestock Rift Valley Fever Control: A Simulation of Two Epidemics in Kenya...247

LIST OF ACRONYMS

AH	Animal health
AHNGO	Animal health non-governmental organization
AHRP	Agriculture and health research platform
ALPHIA II	Aids population health integrated assistance
ALRMP	Arid lands resource management project
ANT	Actor Network theory
AU-IBAR	African Union, Inter-African Bureau on Animal resources
BSE	Bovine spongiform encephalopathy
CARE	Cooperative for Assistance and Relief Everywhere
CBA	Benefit cost analysis
CBAHWS	Community based animal health workers
CDC	Centers for disease control
CEA	Cost-effectiveness analysis
CHWs	Community health workers
CP	Climate prediction
CVL	Central veterinary laboratory
DALY	Disability –adjusted life years
DAO	District Agriculture Officer
DLP	District Livestock Production Officer
DLPO	District Livestock Production Officer
DMLC	District Livestock Marketing Council
DMOH	District Medical Officer of Health
DMOH-MS	District Medical Officer of Health Medical Services
DMOH-PHS	District Medical Officer of Health Public Health Services
DMS	Directors of Medical Services
DSG	District steering group
DVO	District Veterinary Officer
DVS	Director of Veterinary Services
DVS	Department of Veterinary of Services
EAC	East African Community
EIDs	Emerging infectious diseases

EMPRESS	Emergency Prevention System for Transboundary Animal and Plant
FAO	Food and Agricultural Organization of the United Nations
GF-TADs	Global Framework for Transboundary Animal diseases
GIES	Global Emerging Infections Surveillance and Response System
GLEWS	Global Livestock Early Warning System
HH	Human health
HHNGO	Human health non-governmental organization
HPAI	Highly pathogenic avian influenza
IAWG	Interagency working group
ICIPE	International Centre for Insect Physiology and Ecology
ICPAC	IGAD Climate Predictions and Applications Centre
ICPALD	IGAD Centre for Pastoral and Livestock Development
IEP	Inter epidemic period
IGAD	Inter-Governmental Authority on Development
IgG	Immunoglobulin G
IgM	Immunoglobulin M
ILRI	International Livestock Research Institute
I-O	Input Output
IPAC	Climate Predictions and Applications Centre
IPR	Institute of Primate Research
KALRO	Kenya Agriculture Livestock Research Organisation
KARI	Kenya Agricultural Research Institute
KDLDP	Kenya dry lands Livestock development programme
KEMRI	Kenya Medical Research Institute
KEVEVAPI	Kenya veterinary vaccines production institute
KLMC	Kenya livestock marketing council
KMD	Kenya Meteorological Department
KVB:	Kenya Veterinary Board
KWS	Kenya Wildlife Service
LH	Livestock health
Local-GOV	Local Government
MFHP	Mixed farming high potential systems

MFM	Mixed farming marginal systems
MOA	Ministry of Agriculture
MOH	Ministries in charge of health
NASA	National Aeronautics and Space Administration
NGO	Non-governmental organization
NMK	National Museums of Kenya
OH	One Health
OHCEA	The Central and East Africa network
OIE	World Organization for Animal Health
PAP	Pastoral and agro-pastoral systems
PDLP	Provincial Director of Livestock Production
PDMS	Provincial Directors of Medical Services
PDPHS	Provincial Directors of Public Health Services
PDVS	Provincial Director of Veterinary Services
PH	Public health
PMOH	Provincial medical Officer of Health
PSAHS	Private sector animal health service
ROK	Republic of Kenya
RVF	Rift Valley fever
RVFV	Rift Valley fever virus
SAM	Social Accounting Matrix
SARS	Severe Acute Respiratory Syndrome
SEARG	Southern and Eastern African rabies group
SEIR	Susceptible-Exposed-Infectious-Recovered
SNA	social network analysis
STS	socio-technical systems’
TADs	Transboundary animal diseases
UNHCR	United Nations High Commission for Refugees
UNICEF	United Nations Children Education Fund
UNPHM	University of Nairobi Public Health Medicine
UONVS	University of Nairobi Veterinary Science
WCS	Wildlife Conservation Society

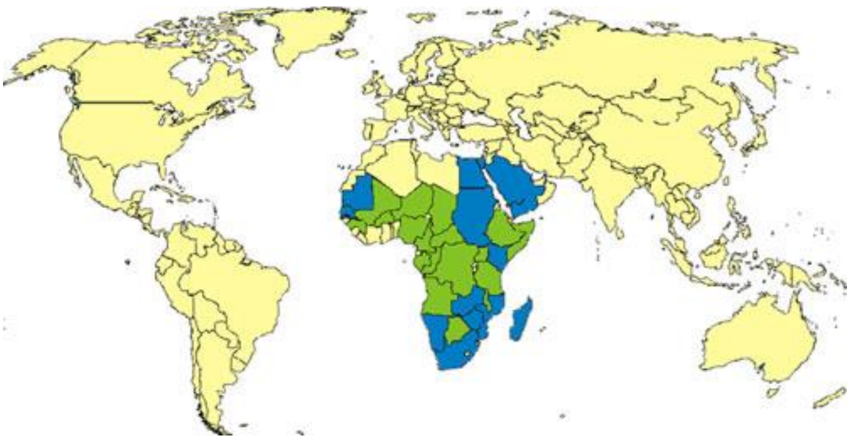
WH	Wildlife Health
WHO	World Health Organization
YLD	Years lived with disability
YLL	years of healthy life lost
ZDU	Zoonotic Disease Unit
ZTWG	Zoonotic technical working group

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Rift Valley fever

Rift Valley fever (RVF) is a Phlebovirus arthropod-borne zoonosis. The zoonosis primarily affects livestock (cattle, sheep, goats, and camels), wildlife (buffalos, dromedaries, antelopes and wildebeest) and human beings, (WHO, 2007a; OIE[1], 2002). It was first identified in 1931 in the Rift Valley of Kenya (Kitchen, 1934). Since then, RVF has been reported throughout much of sub-Saharan Africa and, in the Arabian peninsula (Gerdes, 2004; (Shoemaker *et al*., 2002; Figure 0-1).



■ (blue)	**Countries with endemic disease and substantial outbreaks of RVF:**	Gambia, Senegal, Mauritania, Namibia, South Africa, Mozambique, Zimbabwe, Zambia, Kenya, Sudan, Egypt, Madagascar, Saudi Arabia, Yemen
■ (green)	**Countries known to have some cases, periodic isolation of virus, or serologic evidence of RVF:**	Botswana, Angola, Democratic Republic of the Congo, Congo, Gabon, Cameroon, Nigeria, Central African Republic, Chad, Niger, Burkina Faso, Mali, Guinea, Tanzania, Malawi, Uganda, Ethiopia, Somalia

Figure 0-1: Global RVF Distribution map

Source: http://www.cdc.gov/ncidod/dvrd/spb/mnpages/dispages/rvfmap.htm accessed on 08/01/2013

[1] World organisation for animal health

The disease is among transboundary animal diseases (TADs) prioritized at global level (Domenech *et al*., 2006), Eastern Africa (EAC, 2011), and in Kenya (ROK, 2010).

Animal outbreaks result from bites of infected mosquitoes. Mosquito eggs can already be infected through transovarian transmission. Majority of human infections result from contact with blood or organs of infected animals (WHO, 2007a). A few result from bites of infected mosquitoes.

Rift Valley fever epidemics or outbreaks recorded over the past 40 years have mainly been in Eastern Africa (Meegan, 1981; Zeller *et al.*, 1997; Saluzzo *et al.*, 1987; El Akkad, 1997; Madani, *et al.*, 2003; Abdo-Salem, 2006; Gerdes, 2004; Woods *et al.*, 2002; Munyua *et al.*, 2010). They have occurred every 3 to 10 years (Linthicum *et al*., 1999). The epidemics are associated with above normal rain from warming incidents in the Western Equatorial Indian Ocean and El Niño effects (Linthicum *et al*., 1991). The conditions favour hatching of *Aedes* mosquitoes that transmit the disease (Diallo *et al*., 2005). However, in West Africa, outbreaks are associated with water masses (Swanepoel and Coetzer, 1994).

The last two Rift Valley Fever outbreaks in Eastern Africa are among six major outbreaks of highly fatal zoonoses that were recorded globally between 1997 and 2009 (World Bank, 2012). The others include Nipah virus (Malaysia), West Nile fever (North America), severe acute respiratory syndrome (SARs in Asia, Canada), highly pathogenic avian influenza (HPAI in Asia, Europe), and bovine spongiform encephalitis (BSE) in Britain and North America. The six had a combined economic loss estimated at US$ 80 billion. Rift Valley fever is associated with heavy public health losses (Clements *et al*., 2007), livestock sector, and economy wide impacts (Rich and Wanyoike, 2010).

In Kenya, an average inter-epidemic period of 3.6 years has been documented (Murithi *et al*, 2010). The two most recent epidemics occurred in 1997/98 and 2006/2007. The epicentres of the epidemics were in Northeast Kenya (WHO, 2007b; OIE, 2007). The latter outbreak affected 37/74 administrative districts (Munyua *et al.*, 2010; Figure 0-2). The losses associated with the 2006/2007 outbreak went beyond immediate effects on producers and extended to other livestock value chain actors and connected sectors of the economy. Rich and Wanyoike, (2010) estimated Kenyan economy wide impacts of US$ 30 million and deaths of 321,068 animals (cattle, sheep and goats) in Garissa County. Total mortality could have been much higher, at least considering the geographical scale of the outbreak. The impacts attributed to RVF morbidity, mortality, marketing bans (supply shocks), consumer shocks, and price effects affected households (production and incomes losses); other actors (forgone revenue and income losses), and the national economy (from decreased demand for other goods and services). For example, households spent about US$ 40 on RVF prevention and control while the public sectors spent more than KES 200 million (.

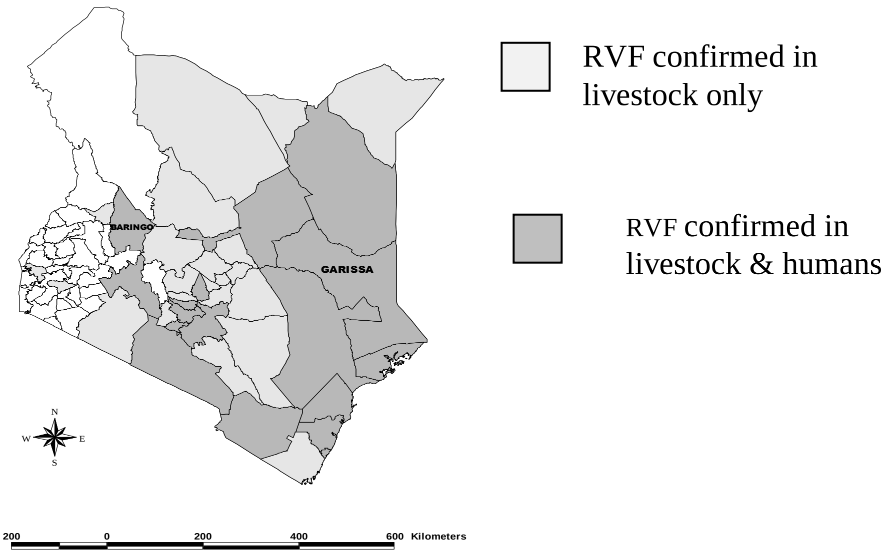


Figure 0-2: Map of Kenya showing the 2006/2007 RVF Status of Outbreaks

A post outbreak assessment attributed the large geographical spread and the consequent huge losses to two factors (i) delayed detection and response by animal and public health sectors, and (ii) implementation of inadequate control measures (Nzietchueng *et al*., 2007; Schelling and Kimani, 2007; Wanyoike and Rich, 2007). Both health sectors had weak collaborations, were unprepared, and had no contingency plans or emergency funds. Inadequate risk communication among stakeholders was also identified. Two key recommendations on how to improve response to future outbreaks included (i) adoption of One Health (OH) approach (to improve cross-sectoral collaborations) and, (ii) implementation of livestock control measures during the next inter-epidemic period which is cost-effective to both sectors (CDC-Kenya, 2008).

The OH approach places health issues in the broader developmental and ecological context. The approach can be defined as the collaborative efforts of multiple disciplines and multiple sectors to attain optimal health for people, animals and the environment (WCS 2004; Schwabe, 1984; FAO *et al.,* 2008a). Calls for OH approach in management of zoonotic diseases is driven by the fact that about 60% human infectious diseases have their source in animals (domestic/wild), 70% of the emerging infectious diseases are zoonoses and so are 80% of the pathogens that could be used for bioterrorism (OIE, 2009) (Taylor *et al*., 2001; Woolhouse and Goutage, 2005). The OH approach is expected to put into best use, the limited resources available to health sectors. One Health can be understood as any added value in terms of better health and wellbeing for humans and animals, financial savings and environmental services from closer cooperation's (Zinsstag *et al.*, 2015).

1.2 Statement of the problem

Since, 1931, RVF epidemics have reoccurred in Kenya with significant impacts on the livestock and public health sectors and, connectors activities of the economy. As mentioned in the foregoing section, a 2006/2007 post outbreak assessment recommended implementation of livestock control strategies that offer both highest returns to the livestock sector as well as cost-effectiveness to the public health sector. The assessment also recommended adoption of OH approach to RVF management. At the time of executing this study, information on the costs and benefits of animal RVF control measures to the livestock sector and their benefits to public health was scarce. Also, the extent to which OH had been institutionalised in management on RVF and other zoonoses was not documented.

In designing disease control policies, decision makers face extremely complex biological and socio-economic considerations surround animal health decision making as difficult choices have to be made on which diseases deserve priority and strategies to use (Putt *et al.,* 1987). The decision makers face multiple diseases affecting multiple livestock species and reared in diverse farming systems. For each disease, a range of different control options of varying costs and technical efficiencies may be available. Providing evidence to guide RVF policies in Kenya was important.

1.3 Overall goal and objectives of the study

The overall goal was to improve OH decisions on the prevention and control of Rift Valley fever and other zoonoses in Kenya.

The specific objectives of the study were to:

1. Undertake a national and sub-national stakeholder and institutional analysis using RVF (as a model disease) to establish levels of institutionalisation of One Health approach in Kenya
2. Assess baseline and realistic alternative livestock level RVF prevention and control strategies and the associated costs

3. Estimate RVF outbreaks associated livestock and economy wide costs and benefits of the control strategies to the livestock sector.
4. Estimate the burden of RVF epidemics to the public health sector and cost-effectiveness of livestock interventions to the sector.

1.4 Research questions

The specific objectives led to formulation of four research questions that were addressed by the study.

1. Who are the stakeholders of RVF prevention and control at national and sub-national level, and to what extent have they instutionalised OH approach to RVF control?
2. What are the annual costs associated with baseline and alternate livestock level prevention and control measures implemented during the 2007-2014 inter-epidemic period. ?
3. What are the impacts of RVF outbreaks on the livestock sector and national economy and what are the benefits associated with the alternate livestock level prevention and control measures compared to the baseline?
4. What are the impacts of RVF outbreaks on the public health sector and what is the cost-effectiveness of the alternate livestock level prevention and control measures to the sector?

1.5 Justification

This study has generated sufficient information to guide evidence-based RVF contingency planning and resource allocation decisions in Kenya. The information can be used by other at risk countries in the region with similar farming systems and RVF dynamics. Specifically, vaccination , vector control, and surveillance options that offer highest returns to the livestock sector, and are also cost-effective to the public health sector have been identified. The gaps in OH institutionalisation have been identified. Addressing the gaps will significantly improve multisectoral cooperation's (especially at community levels where outbreaks occur.) in order to ensure cost-effective control approaches yield expected benefits. The stakeholders and organisations identified as critical for RVF also apply for other priority endemic and epidemic zoonotic diseases. This study has generated new knowledge on the costs and benefits associated with RVF control from multisector perspective. Further areas of research have been identified. A long term perspective used in the analysis show that if the inter-epidemic period is long (10 years), non RVF losses are more significant. Finally, the study's approach for OH assessments can be extrapolated to other zoonotic diseases with similar epidemiological patterns both at regional and global levels.

1.6 Scope and Limitations

The study compared costs, benefits, and cost-effectiveness of several (baseline and alternate) Rift Valley fever control measures from both livestock and public health perspectives. The level of institutionalisation of OH (a multisectoral approach to management of diseases) was investigated at national (Nairobi County) and sub-national (Garissa County) levels. The study focused on RVF high risk areas only and collected data from livestock value chain actors ranging from livestock producers to disease control decision makers. Data was collected in 2011-2013. The period considered in the analysis was 10 years, covering two RVF epidemics, the 2006/2007 and a hypothetical one in 2014/2015. Bio-economic modelling was applied. Two simulation models (individual based herd dynamics RVF simulation model and animal to human RVF model) linked through data produced the biological parameters associated with two RVF epidemics. A Microsoft Excel framework and a SAM model were used to generate monetary and non-monetary losses under each control strategy.

The main limitations of this study were (i) in the OH institutionalisation analysis, the strength of relationships as perceived by respondents was subjective and could have introduced respondent bias. Secondly, inherent to SNA methods, creating a binary variable from the relationship strength data led to some information loss. (ii) Insufficient RVF animal and human biological data particularly which has been captured through joint investigations during epidemics. (iii) Lack of comprehensive animal-human RVF transmission model to simulate epidemics under different control options. The study therefore developed and used multiple models linked through data. (iv) There was inadequate data on the relative contribution of different animal and public health measures such as surveillance, sanitary bans and communication on the outcome of the epidemic; contact rates and transmission probabilities. In absence of data, expert opinions on impacts of control measures were subjective.

CHAPTER TWO

GENERAL LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

2.1 Literature review

This review highlights current status of economic assessments of RVF control as well as the gaps being addressed by the study. It also reviews major conceptual models and approaches relevant to economic analysis of zoonotic diseases from a multisectoral perspective as a basis of understanding their strengths and weaknesses and justifying our choice of analytical approach through identification of which ones were closer or appropriate for RVF cost benefit analysis. The One Health (OH) concept as a research and policy tool to improve zoonoses control is also reviewed.

2.1.1 Approaches to multisectoral economic assessments of Rift Valley fever and other zoonoses

In Kenya, few studies have examined the impacts of the 2006/2007 RVF outbreak focusing on either household, livestock producers, post –producer's actors, or the national economy. They include, Wanyoike and Rich, (2008); Rich and Wanyoike, (2010); ROK (2009); ILRI, (2008); Schelling and Kimani (2008). Only one study, Schelling and Kimani, (2008), had explored the public health costs of the same epidemic. This review did not identify any literature (grey or published) on economic assessment of outbreaks that happened prior to 2006 in Kenya. Within the Eastern Africa region, FAO, 2008b and Sindato *et al*., (2011) have documented the impacts of RVF outbreaks in Tanzania. Regardless of the different analytical approaches used, none of the studies have attempted to generate multi-sectoral impacts of RVF outbreaks or benefits associated with control measures.

These review findings are similar to a systematic review output by Peyre *et al.,* (2015). The latter study notes that globally, few studies have examined the socio-economic impact of the disease. From the few, 13 types of RVF socio-economic impacts are identifiable depending on the sector impacted, the level and temporal scale of the impact. Peyre *et al.,* (2015) notes that many of the studies reviewed, undertook partial cost analysis and had limited reference to mid- and long-term impact, public health or risk mitigation measures. The review recommended, comprehensive RVF impact studies to provide decision-makers with science-based information on the best intervention measures. This study sought to provide a comprehensive analysis of the impacts of RVF control and therefore addressed the gaps identified above. This required identification of analytical approaches suitable for multisectoral assessments of zoonotic diseases.

A review of literature shows that much more often economic analysis of zoonoses control was and is done from a single sector perspective (either animal or public health); few examine the multisectoral impacts of zoonoses. In the case of RVF, Rich and Wanyoike (2010) examined livestock sector and economy wide impacts, and did not consider any impacts on public health. On the other hand, LaBeaud *et al.*, (2011) examined RVF burden in public health only. Only Randi, (2011) was identified as a study that has modelled potential dual impacts of RVF on the economy and public health in case of an incursion in Texas. The few that have examined multisectoral impacts of other zoonoses (rabies, brucellosis) include: Aubert, (1999); Fisbein *et al.*, (1991); Budke *et al.*, (2005); Carabin *et al.*, (2005); and Roth *et al.*, (2003). The studies applied different approaches, but largely combined elements of animal and human disease economic frameworks namely, cost-effectiveness analysis (CEA), and cost-benefit analysis (CBA).

Rushton *et al.*, (1999); Morris (1999); Ramsay *et al.*, (1999); Marsh, (1999); Rich *et al.*, (2005a and 2005b); Dijkhuizen, (1992) and Bennett, (1992) present various analytical and conceptual frameworks used for analysis of livestock disease impacts and control policies. They include partial budgeting; gross margins/enterprise analysis; decision analysis, optimisation methods (linear and dynamic programming); breakeven analysis and household simulation or modelling; cost-benefit analysis (CBA); linear and dynamic models; simulation modelling; decision tree analysis; cost-effectiveness analysis (CEA)**;** policy analysis matrix (PAM); partial and computable general equilibrium analysis; input output (I-O) models; and social accounting matrices (SAMs). Despite the many frameworks, combining scale of analysis and economic questions narrows the analytical model options, but rarely isolates a single dominant method. The framework adopted for a given study depends on issues, highlighted below

(i) Target users of the evidence generated as they determine boundaries of analysis. As the impact evaluation moves from livestock keepers to societal level perspectives the analysis changes from financial to economic. In the case of RVF, a multisectoral assessment of its control implies that the key target users are the livestock and public health sector policy makers who would be interested in total societal costs and benefits of control, particularly measures that offer the highest returns to both sectors.

(ii) Disease in question, as epidemiology of endemic, sporadic and epidemic diseases differs including whether it's a zoonosis or not. Rift Valley fever affects multiple livestock species and human beings and occurs as irregular epidemics. This implies a multispecies analytical framework that incorporates probability of occurrence is suitable for its analysis.

(iii) Level of analysis. The levels can be at herd, household, community, livestock sub sector, agricultural sector, public health sector, national economy, and global economies. To generate evidence for multisectoral RVF control policies, two levels of analysis were critical, public health sector and livestock sub sector (including the spill over to other sectors of the national economy). These levels of analysis defined the boundaries on the depth and dimensions of the information required,

(iv) The livestock systems within which a disease occurs. Rift Valley fever occurs in diverse farming systems or value chains and therefore they were an important consideration in the impact assessment.

(v) Availability of data (epidemiological, production, economics); and resources available to collect and analyse the data. In absence of good epidemiological data, epidemiological modelling is applied. A review of literature showed that, in Kenya, Munyua *et al.,* 2010; Nguku *et al.,* 2010; Anyangu *et al.,* 2010; and Woods *et al.,* 2002, provide insights on morbidity and mortality rates of Rift Valley fever.

Based on Roth *et al*., (2003) and the foregoing, this study narrowed the suitable frameworks to include CBA and CEA. A CBA framework attempts to incorporate costs and benefits (economic, environmental, biological and medical) that arise from particular choices (Rushton *et al.,* 1999). The utility of CBA is that sector-specific and distributional impacts embodied in the social accounting matrix can be better understood. The major weakness of CBA in animal disease analysis is its failure to capture price effects; spill over to other sectors; long term dynamic effects; and impacts at a broader scale (Rich *et al.,* 2005a and 2005b; Otte *et al.,* 2004) such as international trade and tourism. Rich and Wanyoike, (2010) demonstrates that RVF as significant spill over effects and therefore CBA would fail to capture them. However, Rich *et al.,* (2005a and 2005b) suggest that these short comings could be overcome by supplementing CBA with Input – output (I-O) models and partial and computable general equilibrium models. Partial equilibrium models capture producer and consumer surplus, aggregate impacts and distributional aspects of a disease shock such as price changes, linkages or welfare changes.

I-O models and Social Accounting Matrix (SAM) offer the ability to capture linkages between economic sectors but do not allow for price and other dynamic changes unlike partial equilibrium models. Such price changes, however, are important in the agriculture sector making I-O and SAM less attractive than partial equilibrium when medium and long term effects are considered. Also, an I-O framework assumes that changes in the economy are due to demand curve shifts rather than supply constraints and, therefore, may miss important supply effects of a disease. Further, partial and I-O models lack the capacity of CBA to incorporate detailed farm level or specific government programme costs.

Computable general equilibrium (CGE) models such as SAM have distinct advantages of over I-O and partial equilibrium models in the ability to capture a wide array of economic linkages across sectors. Garner and Lack, (1995) and Perry e*t al.*, (2003) have applied CBA and the economy wide frameworks mentioned above to evaluate foot and mouth disease (FMD) impacts. The CBA frameworks generated direct impacts (deaths, production losses, and control costs) while I-O, partial equilibrium or CGE models using income and employment multipliers determined the extent and nature of indirect effects (denied access to markets, income or employment loss) on other industries. Finally, this study adopted a CBA linked to the Kenyan SAM to estimate the livestock sector losses and spill over to the connected sectors of the economy. Rich and Wanyoike (2010) used the 2003 SAM (described in Kiringai *et al.,* 2006) in their analysis of RVF impacts. A latest Kenyan SAM, 2009 (Omolo, 2014**)** is available. However compared to the 2003 SAM, the latter is highly aggregated and therefore the former was used for this study.

In animal health, conventional CBA frameworks are often linked to an epidemiological data or model. In the case of sporadic epidemics such as the case of RVF, the probability of occurrence should be considered. In addition, considering that the inter-epidemic period is 3-10 years, control programmes will often be long term. Epidemiological models, are the most appropriate to simulate impacts of different disease mitigation strategies or long-term disease control programmes at regional and national levels (Dijkhuizen *et al.,* 1995). When biological complexity of risk factors is anticipated, epidemiological and economic modelling improves plausibility of conclusions reached. Combining epidemiologic and economic models has proved successful in providing guidelines and decision-making criteria for animal health programs, (McInerney *et al*., 1992). The approach has been applied to evaluate net societal costs and benefits associated with disease management strategies and can be viewed as a complement to cost-benefit analysis (Whitten and Bennet, 2004) and by extension cost-effectiveness analysis.

However, literature review showed that RVF models were few. Gaff *et al.,* (2007) presents in detail a mathematical model for a RVF outbreak in animals. In addition, literature on livestock demographic models which are commonly the basis of a RVF epidemiological transmission model was missing (Fuhrimann *et al., (*2011). To fill the gaps, this study developed a herd dynamics RVF transmission model to generate RVF rates for the livestock sector.

Cost-effectiveness analysis (CEA) is a frequently used analytical framework to assess costs and benefits of public health sector interventions (Meltzer, 2001). It is presented as a cost-effectiveness ratio; making it an ideal tool to compare different control strategies of different diseases (Weisten *et al.,* (1996). Since this study, also, sought to evaluate the benefits of different control strategies to the public health sector, cost-effectiveness analysis for the public health analysis was attractive. Noting difficulties in combining monetary and non-monetary costs of human mortality and morbidity in economic assessments, the World Health Organization (WHO, 2005) recommends the use of disability–adjusted life years (Daly's) to represent the outcome of a health event.

Effectiveness is measured in Daly's averted while the CEA ratio is expressed as cost per DALY averted (Meltzer, 2001; Bobadilla *et al.*, 1994). Daly's were first constructed by Murray and Lopez, (1996). One DALY is equal to one lost year of "healthy life". Similar weighting values of disability and common expected years to live have been used globally, making the Daly's comparable. However, there are ongoing discussions on culture-dependent different valuing of disease outcomes. It cannot be denied that the inclusion of morbidity and the valuing of death the same way over the globe was a big step towards emphasis on reduction of burden (vs. optimising good health).

Control interventions can be compared as costs per one averted DALY in cost-effectiveness analysis. To estimate cost-effectiveness of livestock RVF interventions to the public health sector, data on Daly's associated with epidemics were required. While the study, Bitek (2013) had estimated RVF associated Daly's for four Counties- Kilifi, Garissa, Baringo and Ijara, RVF occurs in other areas too and therefore total DALY's estimation for all high risk area was necessary. Estimation of Daly's requiring data on RVF rates for human epidemics which was scarce at the time of the analysis. Several studies such as Anyangu *et* *al.,* (2010); Nguku *et al., (2010) and* LaBeaud *et al., (*2011*)* had derived number of human cases by extrapolating sero-prevalence rates.

Similar to the animal health sector, public health epidemiologists overcome data gaps by using mathematical epidemiological models such as decision trees, Markov and Monte Carlo models to simulate human disease outcomes under different control programs (Meltzer, 2001). However, in the case of this study, no epidemiological models for animal to human RVF transmission were identified. To overcome the shortcoming, this study developed a simple animal-human RVF transmission model.

In summary, the preceding review showed that data on multisectoral economic assessments of RVF impacts and benefits of control was not available. The review identified Roth *et al.,* (2003) as suitable study to guide our multisectoral analysis through CBA and CEA. This review also, identifies weaknesses of CBA which was addressed by adoption of the SAM modelling to capture RVF spill over to other connected sectors of the economy. Epidemiological modelling of animal and human RVF cases was adopted to overcome the data gaps.

2.1.2 Approaches to One Health institutional analysis

One Health emerged from the One Medicine concept by Schwabe, (1984) and Majok and Schwabe, (1996). It strongly advocates for intersectoral collaboration between public health, veterinary and other sectors. In 2004, the Wildlife Conservation Society (WCS, 2004) patented the concept as One World One Health (OWOH). This was in the wave of control measures against the further spread of highly pathogenic avian influenza which raised fear that animal conservation could be sacrificed for the sake of unknown public health gains from control of the disease in wildlife. International technical agencies thereafter branded it as OH (FAO, *et al.,* 2008a). Lessons learnt during control of EIDs at all levels (global to local) over the last one and half decade have further advocated for a paradigm shift to OH and with broader considerations of the environment (including wildlife) now commonly considered as the Animal-human-ecosystem (AHE) health interface (Zinsstag *et al.,* 2005a; King, 2004). Most EIDs and other zoonoses have links to wildlife, livestock and all to people's health (OIE, 2009).

The goal of OH is to reduce impacts of zoonoses on livestock, people and economies through increased efficiency and effectiveness of detection and control. Several studies (World Bank, 2012; Zinsstag *et al.*,2007, 2009; Schelling *et al.*, (2005) and Ward *et al*,

(1993) have shown some of the benefits of adopting OH. in control of zoonoses but also in seeking synergies in service delivery between sectors.

However, beyond financial and health benefits, OH adoption requires institutionalisation of cross-sectoral collaborations at the international, regional, national and local levels. Consequently, the process is expected to drive institutional changes at the various levels and across sectors. For example, organizations such as the American Medical and Veterinary Associations have established the "One Health initiative" (Enserink, 2007) while FAO, WHO and OIE have entered into a tripartite agreement. As OH gains momentum, it is therefore important to understand how institutional changes are evolving at national levels to address specific zoonoses such as RVF. This study provides such needed evidence to guide institutional frameworks at the national and grass root through an institutional and organizational analysis for OH in Kenya using RVF as the specific OH issue.

In economics it is important to distinguish between institutions and organisations (North, 1990). Organisations refer to groups of persons bound together by a common purpose and mutually maintain social relationships and jointly manage resources. On the other hand, institutions refer to the wider set of rules, including norms, beliefs, values, habits, behaviour, and agreements that structure human interactions (Esman and Uphoff, 1994; Menard, 2000). Institutional arrangements include public-private cooperation; contracting schemes; organizational networking and policy arrangements (Geels, 2004). The agreements are simultaneously shaped by economic exchange, socio-cultural norms and political regimes, and may provide welfare, identity, solidarity and sense of belonging at local, national, regional and international levels.

An institutional analysis of OH with a specific focus on RVF would therefore focus on pre-existing inter- and intra-relationships or linkages among animal and public health stakeholders with a goal of improving prevention and control of the disease (and other zoonoses) and to what extent the concept has been institutionalized. Several approaches such as Actor Network theory (ANT) and social network analysis (SNA) are used to trace such associations or relationships between network components (or actors). Actor-Network Theory (ANT) draws on the socio-technical systems' (STS) perspective and considers the world as networks (Law 1992). The STS can be described as a system (e.g. organizations such as the national animal or public health services) and where technical dimensions and social dimensions (e.g. attitudes and relationships of stakeholders) are interrelated (Law 1992). These networks can include humans, things, ideas, concepts - all of which are referred to as "actors" in the network. The ANT investigates how networks are established, traces what associations exist, how they move, how actors are enrolled into a network, how parts of a network form a whole network and how networks achieve temporary stability or, conversely, why some new connections may form networks that are unstable (Doolin and Lowe, 2002; Callon, 1986). Several studies have applied ANT to understand the relationships between health systems, stakeholders and information technology (Kwait *et al.,* 2001; Doolin and McLeod, 2005; Creswell *et al*., 2010).

The characteristic of OH -a new non-material technology or policy innovation involving different groups of people and their organizations and networks - lends its institutional and organization analysis to the Actor Network theory (ANT). However, the ANT approach has been described as too descriptive and failing to come up with any detailed suggestions of how actors should be seen, and their actions analysed and interpreted (Creswell *et al.*, 2010). Social network analysis involves mapping relationships or ties among people or organizations. In social network analysis, people and their actions are viewed as interdependent and lasting patterns of relations over time, among people to constitute the social structure (Wasserman and Faust, 1984). Social network analysis has not been used widely in health promotion research (Hawe and Ghali, 2008). Yet it does have the advantage of providing statistical measures of relational strengths and linkages. This study sought to contribute to the One Health institutional analysis using ANT and SNT approaches.

2.2 Theoretical and Conceptual framework for multisectoral assessment of RVF control and OH approach

McInerney (1996) highlights conceptual models underlying analysis of economic processes that include three major components: people, products, and resources. Within livestock value chains livestock keepers, as economic agents, undertake economic processes (raise animals as productive assets) that transform resources into a wide range of products (goods and services). Part of the products are consumed or utilised at household level, while the rest flows to other economic agents in the marketing and processing related enterprises of the value chain and is turned into an array of value added products. The range of goods and services include: raw, processed milk and milk products; meat and meat products; draught power; dung (for manure, fuel, and building); hides and skins; wool and fibre; and live animals. One could add transportation means and increased social status of owners among the benefits of livestock keeping as well as benefits to grasslands. Income from livestock-related activities is used to purchase goods and services from other economic sectors resulting in important linkages to the rest of the economy. Consumed products generate human health and nutritional benefits.

Animal diseases and pests impacts on the production of products, act as shocks to national economies, and negatively affect public health (when zoonotic pathogens are transmitted from livestock to people and lost nutritional value). Disease control measures attempts to avoid or control the damage caused. Where epidemiological information is sufficient and adequate resources are available, technical decisions on whether and how a zoonosis should be controlled seem to be a straight forward decision. However in practice, numerous difficulties, primarily because of uncertainties revolving around biological and economic effects of diseases and their control and delivery strategies face decision makers. In addition, no threshold values have been defined (in terms of prevalence rates, or magnitude of losses) to guide decisions on whether to intervent or not. An assessment of the value of different control programs helps to guide resource allocation to alternatives with highest expected payoffs and also on the nature, intensity, and end point of the program(s). Disease control as a micro-level production decision by individual livestock producers can be modelled through a damage control or risk management lens. Livestock keepers incur costs associated with extra inputs applied to reduce negative effects of the damage agent (disease). From a societal perspective, and particularly for public-funded national animal and public health zoonoses programs, economists and decision makers would be interested in evaluating total societal costs and benefits from a multisectoral perspective.

Analysis of benefits and costs has a theoretical basis in welfare economics (Garber *et al.*, 1996; Garber and Phelps, 1997). Welfare economics is based on two assumptions:

a) Individuals maximize a well-defined preference function. In other words, their utility or sense of well-being depends on, among others, material consumption, and their utility or preference function follows certain conditions of rationality and logical consistency, and
b) The overall welfare of society is a function of these individual preferences.

However, based on uncertainty of both animal and human health status and the effects of health interventions, the principal approach used in modelling control is expected utility (Garber *et al.*, 1996). According to the expected utility theory, alternative actions are characterized by a set of possible outcomes and a set of probabilities corresponding to each outcome. Quantitative representation of the preferences or utilities is assigned to each possible outcome (e.g. health intervention) that may occur. To choose the best action, the probabilities of each outcome are multiplied by the utility of that outcome. The products are then summed across all possible outcomes to derive the expected value of utility.

Benefit costs analysis approaches such as CBA, CEA, cost-utility analysis, and cost minimization analysis provide a means by which one can assess desirability of alternative resource allocations from a societal point of view. Cost-effectiveness analysis is based on the premise that for any given level of resources available, society wishes to maximize the total aggregate benefits conferred (Weinstein and Stason, 1977). In the case of RVF, the expected utility theory supplies theoretical foundations for quantification of the effects in a CEA conducted at the individual level. Specifically, DALY as a measure of health benefit to an individual reflects the gain in expected utility. On the other hand in the agricultural sector, utility from RVF control at the livestock keeper level can be represented by a general utility function where utility is gained from increased production as a result of minimized disease.

On the other hand, Actor Network Theory (ANT) provides a theoretical framework for understanding and guiding successful policy or innovation in complex systems that require network building (Young *et al.*, 2010). One Health was assumed to be a policy innovation that requires network building and therefore Actor Network Theory which focuses on science–based innovation processes and provided insights on OH stakeholders, cooperation institutions and regulations required to drive adoption of the approach.

2.2.1 Societal costs of RVF control

Figure 0-1 presents a conceptual framework for assessing the sector-specific and societal costs of RVF. Based on McInerney, (1996) RVF in livestock represents an economic problem that lowers productivity of animals and the inputs used and hence decreases outputs and benefits or societal gains. Total societal monetary costs associated with RVF outbreaks is a sum of livestock sector losses (direct and indirect losses), economy wide impacts and animal health and public control costs. Total societal non-monetary costs include Daly's.

2.2.1.1 Animal and human RVF cases

Animal RVF outbreaks result from interactions of various factors, namely excess rain and flooding; RVF virus; Aedes and other mosquitoes populations; and, susceptible animal population. Human epidemics are associated with animal epidemics as people get infected through contact with infected animals. The biological impacts of animal RVF outbreaks are reflected through the number of animals that get infected and proportions that die, abort and recover. On the other hand, the biological impacts of human RVF outbreaks include number of people infected and proportion that die or recover with complications.

The number of infected animals depends on the number of susceptible livestock, proportion mosquito population that is infected (infectious) and contact rate between animals and mosquitoes. Implementation of RVF control measures affect the number of infected animals and people; the extent depending on type of measures and levels of application. Ordinarily, choice of different inputs is primarily a technical decision, but other factors such as available resources are considered.

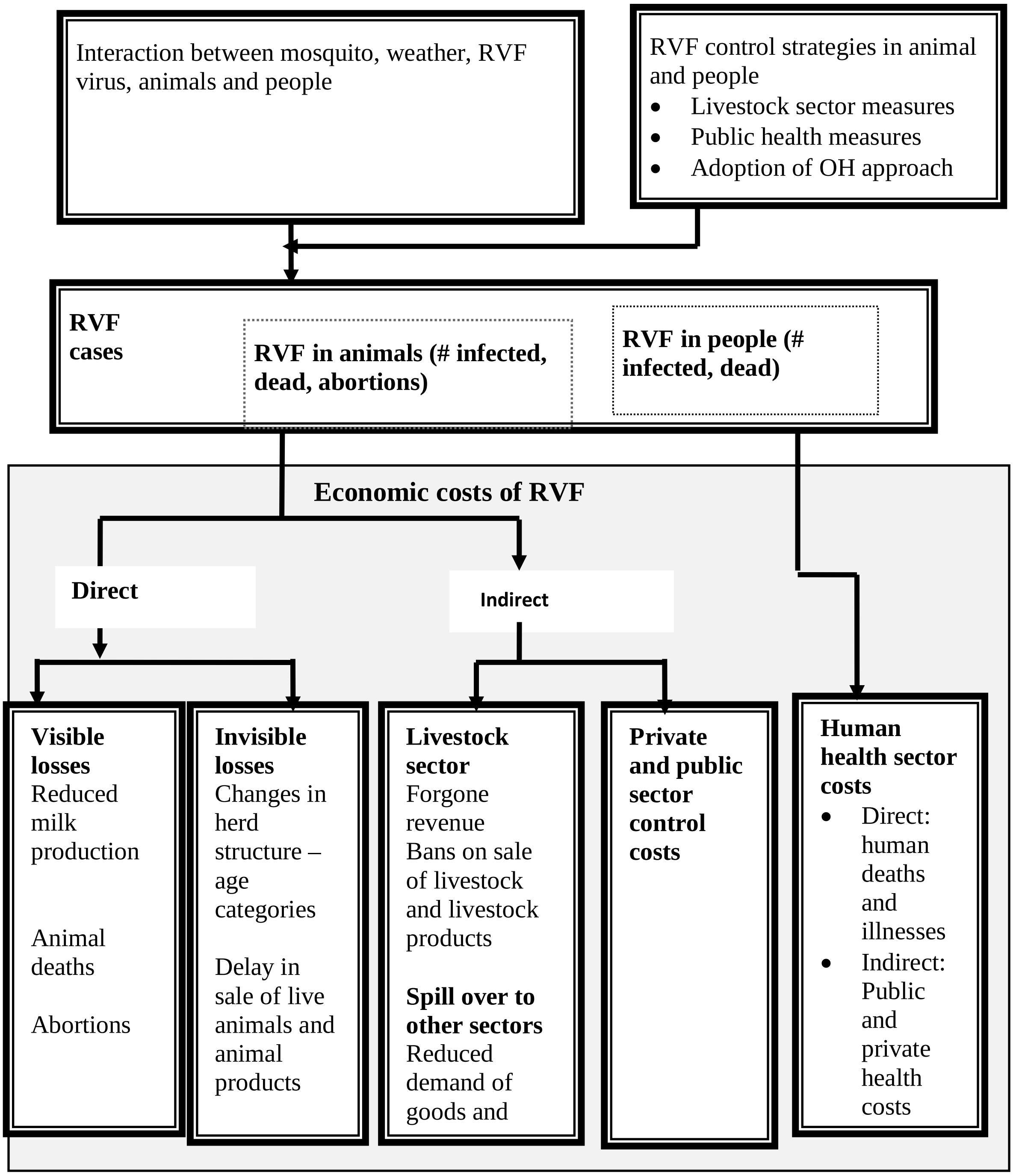


Figure 0-1: Conceptual framework for the costs of RVF prevention and control

Source: adapted from McInerney (1996).

Mathematical modelling allows computation of disease parameters for each control strategy including a no-control option. Whichever strategy is used the objective is to minimize number of human and animal cases and subsequent economic losses. The strategies can either be designed as single sector approaches or be OH based.

2.2.1.2 Economic costs of RVF

Based on Rushton *et al.*, (1999), Rich and Wanyoike (2010) and Meltzer, (2001), the economic impacts of RVF in the livestock sector and the economy include direct (visible and invisible) and indirect losses and public health costs.

2.2.1.2.1 **Direct visible and invisible production losses**

The visible direct costs include reduced production of outputs as a result of biological impacts of disease and mortality. In the presence of RVF virus infections, death of breeding and production stock, and abortions in pregnant animals reduce basic resources of production. Death and disease of productive animals result in reduced quantity of outputs such as milk, meat, manure, hides and skins. Economic models are designed to determine the quantity of products and their value without disease, with uncontrolled disease and with disease controlled under different scenarios. Production losses are influenced by numbers, species and breed of animals affected and disease biological effects on individual animal production. The worst case scenario is death when 100% of the production is lost. A national livestock herd free of RVF or free of any other shock is assumed to operate at a given efficiency utilizing inputs X_O and producing outputs $Q_{O.}$ Assuming that farmers or national veterinary authorities implement no preventive measures for RVF outbreaks, and that producers have no time to adjust input level to mitigate the disease, RVF presence is expected to reduce the total national output to $Q_{1.}$ Production losses as the forgone or lost output are represented as q which is equivalent to Q_O - $Q_{1.}$ Production losses or costs in cattle (C_c) are simply represented by equation 1 as:

$C_c = (q_{mic}p_{mic}) + (q_{mec}p_{mec}) + (q_{mac}p_{mac}) +$ -- (1)

Where q is quantity of national total product lost and p is the national average unit price of the product which is subject to changes associated with demand and supply. $_{mi}$, $_{me}$ and $_{ma}$ represent milk, meat and manure respectively and $_{c}$ represent cattle. The invisible direct losses include changes in herd structure as a result of abortions and mortality and delays in sales of live animals and products as a result to disease.

2.2.1.2.2 Indirect losses

Indirect losses can be categorized into three categories: i) other forgone revenue in the livestock subsector; ii) economy wide impacts represented by spill over to the crop subsector and other sectors of the economy; and iii) private and public sector control costs.

Forgone revenue from marketing and processing: Marketing and processing level impacts results from demand and supply shifts (reduction) as well as the resultant price effects. Supply reduction results from reduced production and quarantine measures (marketing bans). Demand effects result from consumers' behaviours to food safety issues associated with zoonoses. Livestock-based agribusinesses lose income as a result of demand and supply shocks. The simplest view of RVF outbreak associated market level impacts would be to focus on marketing margins of traders for volumes expected but not handled during an outbreak. The economic value of local and export red meat ban (a loss to livestock sector), is represented by the value of the red meat sales revenue forgone and can be represented by equation 1 except that q represents quantities not sold or transacted while p represents the unit profit margin.

Economy wide impacts: The livestock sector income loss associated with the lost or forgone income results in reduced demand for inputs and factors of production from other sectors of the economy. Computable general equilibrium models provide a comprehensive picture of the structure of a national real economy, and are best suited to capture multiplier effects calculated as the additional monetary unit reduced for each Kenyan shilling of trade revenue lost (Perry *et al.*, 2003).

Animal health prevention and control costs: Rift Valley fever's irregular outbreaks do not represent an everyday problem to address. However, ignoring the risk of outbreaks in the future is not an option. Also, the disease cannot be eradicated and only the extent mitigated. Various measures implemented during the epidemics and inter-epidemics are expected to reduce disease impacts. The measures are additional inputs and therefore increase production costs. The benefits of control depend on the mix and intensities of the measures (specific strategies). Measures represent additional inputs costs and are incurred by both public and private sectors (households) and in both health sectors. The costs of control are determined by the control strategy used.

2.2.1.3 Monetary and non-monetary public health costs

Based on Meltzer, (2001), economic analysis of RVF public health costs focuses on direct losses of human deaths and illnesses and in direct monetary costs of control and case management. The monetary public health costs are a sum of household inpatient and outpatient costs, cost of control by the government and the income loss as a result of human illnesses. The non-monetary value of mortality and morbidity is represented by DALY, which is a sum of total years lived with disability and total years lost due to premature death as a result of human RVF (Murray, 1994).

2.2.2 Total benefits of control

The societal costs of un-controlled disease represent potential costs that could be saved (benefits) by control strategies. Maximum benefits occur when the occurrence of the disease is reduced to zero - which does not apply to RVF. Each control scenario generates a stream of costs and benefits that are a function of the interaction between the disease control option and biophysical factors (disease agent and vectors, susceptible animals and humans). Total monetary benefits associated with a particular strategy will be the additive benefits accrued to the livestock and health sectors. Non-monetary benefits are the total Daly's averted. However, evaluation of RVF prevention and control strategies must consider both the size and distribution of economic costs and benefits, as well as non-economic, political and cultural factors that affect public and private decision making.

CHAPTER THREE

GENERAL METHODOLOGY

Methodology used by this study was guided by the four study objectives, overall conceptual framework and two theoretical frameworks (utility theory and actor network theory).

3.1 Sequence of data collection and analysis

Four sequential data collection/gathering and analysis steps generated three major outputs namely (i) a stakeholder and institutional analysis for OH in Kenya; (ii) a cost benefit analysis (CBA) of RVF control from a livestock sector perspective and (iii) a cost-effectiveness analysis (CEA) livestock RVF control from a public health perspective. The process is summarized in Figure 0-1.

The first step involved mapping of RVF and OH stakeholders, their cooperation/collaboration platforms and strengths of three relations namely funding, information sharing and joint planning of activities. Social network analysis using UCINET software generated national and sub-national OH network sociograms. Also generated were centrality statistics measures of stakeholder power and influence within the networks.

In a second step, realistic livestock RVF prevention and control strategies were delineated/defined. The strategies comprised of the baseline practice and hypothetical alternatives. Their associated financial costs were estimated. The third step involved epidemiological and herd dynamics modelling to simulate normal herd dynamics and biological impacts of RVF outbreaks on the dynamics. The impacts of delineated strategies on magnitude of RVF were also simulated. Outputs from the simulation model were applied to production and economic data in CBA framework to generate livestock sector production, marketing and processing losses. The proportionate reduction in supply of live animals, and livestock products livestock (estimated from the production and marketing losses) were in turn applied to a SAM model to estimate economy wide impacts.

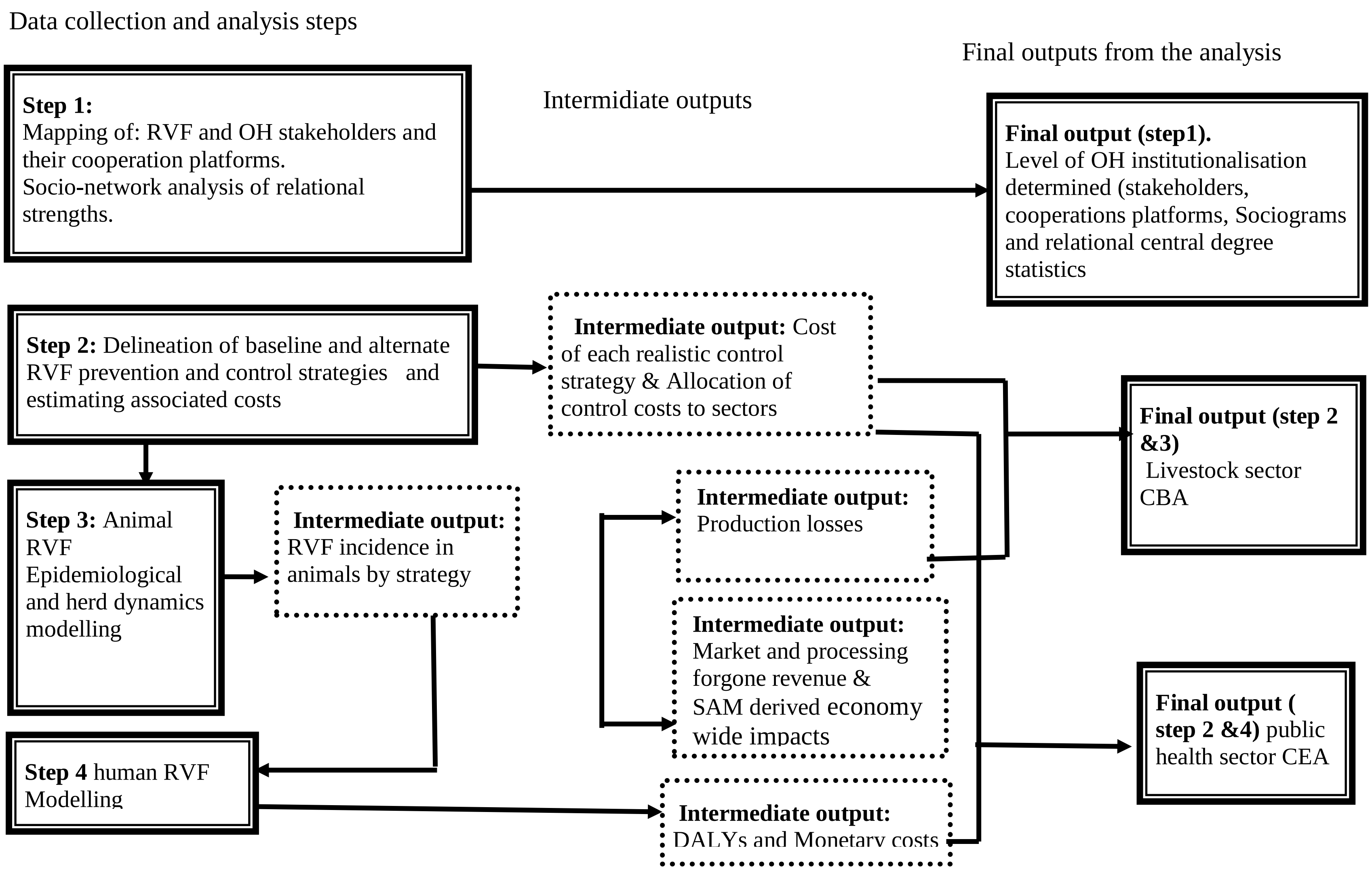


Figure 0-1: Schematic representation of the 4 sequential steps for data collection and analysis

Cost benefit analysis compared avoided losses and additional control costs of the alternatives compared to baseline practice. In the fourth and final stage, numbers of human cases transmitted from the animal cases under the different control strategies were estimated. The non-monetary measure of RVF burden in the public health sector the Daly's, were computed from human cases. Monetary case management costs were also computed. The cost-effectiveness of each alternative strategy to public health was estimated as cost per DALY averted.

3.2 Study area

3.2.3 Rift Valley fever risk areas and farming systems

This study focused on RVF high risk areas only. The RVF risk map (Figure 0-2) classifies 18, 23 and 28 Kenya Districts (as established by1990), as high, medium and low risk zones respectively. Probability of having RVF outbreaks during the period 1951 to 2007 and magnitude of RVF outbreaks in livestock and people were key considerations in risk mapping.

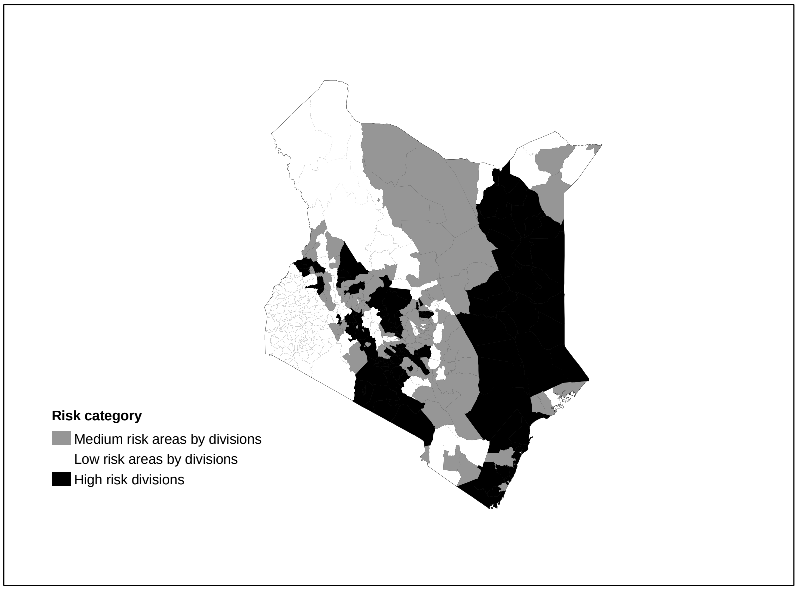


Figure 0-2: Revised Kenya's RVF Risk Map

Source: CDC, Kenya, courtesy of Peninah Munyua

Data collection sites were identified from the high risk areas. The farming/livestock systems map shown in Figure 0-4 to ensure that the sites represented the diverse farming systems within the high risk areas. Livestock in Kenya are reared in four livelihoods types, pastoral, agro-pastoral, mixed farming marginal and mixed farming high potential livelihood zones.

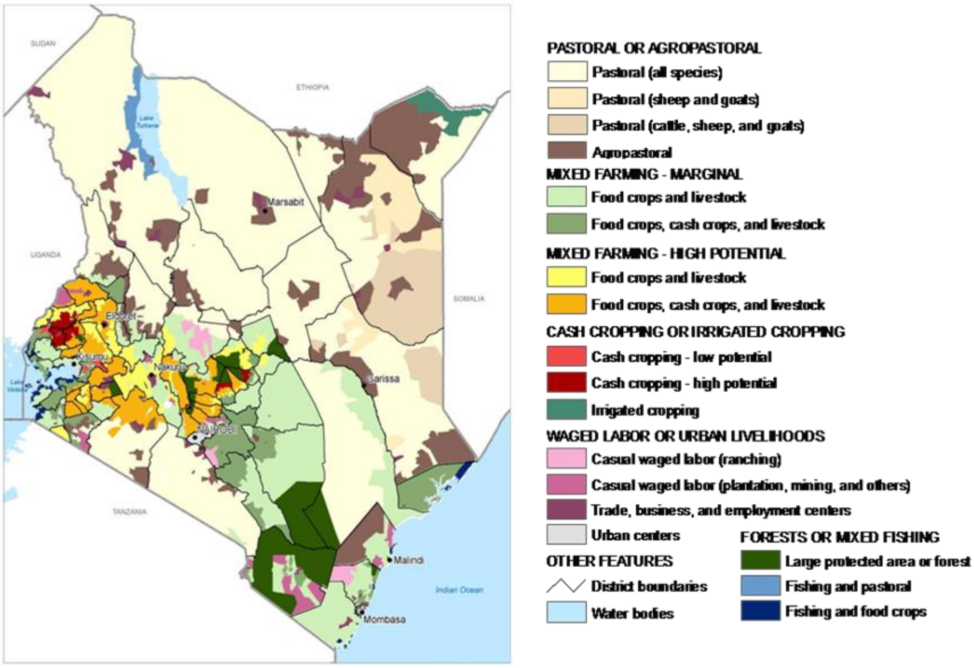


Figure 0-3: Livelihood Map of Kenya.

Source: World Resources Institute (2007)[2], **http://www.wri.org/publication/content/9506**

Livestock reared under pastoral livelihoods (P) move periodically to follow seasonal supply of water and pastures. It's practiced in the following districts: Turkana, Marsabit, Isiolo, Samburu, West Pokot, Baringo (northern part), Moyale, Tana River, Garissa, Narok and Kajiado, Wajir and Mandera (East). The agro pastoral (AP) livelihoods are similar to pastoral except that cropping activities are combined with livestock keeping. The AP are mainly found in western side of Mandera, north west of Wajir, southern parts of Ijara District, northern parts of Malindi and Kilifi Districts as well as other isolated pockets within the pastoral areas. In marginal mixed farming livelihoods (MFM) livestock and crops (food crops mostly and less cash crops) are practiced in marginal areas where rainfall is erratic or soils

[2] World resources Institute (2007) Department of Resource Surveys and Remote Sensing , Ministry of Environment and Natural Resources, Kenya; Central Bereau of Statistics , Ministry of Planning and National Development , Kenya; and International Livestock Research Institute. 2007. *Natures Benefits in Kenya, An Atlas of Ecosystems and Human Well-Being*. Washington , DC and Nairobi: World Resource Institute

are less fertile. The major districts practicing mixed farming in marginal areas include, Machakos, Kitui, Mwingi, Makueni, Malindi, Kilifi, Kwale, Mbeere, Tharaka, Meru North, Laikipia, south eastern parts of Nakuru and Koibatek. In mixed farming high potential (MFHP) livelihoods, dairy cattle and other exotic breeds are reared alongside food and cash crop production. To simplify the analysis, pastoral and agro pastoral systems (PAP) were considered jointly. Therefore only three systems were considered, PAP, MFM and MFHP.

3.2.4 Target livestock population

In 2009, Kenya had 65,306,442 ruminant population comprised of 17,465,774 cattle, 17,129,606 sheep, 27,740,153 goats and 2,970,909 camels. The PAP held the highest proportion of cattle (45.4%) sheep and goats (70%) and camels (99.6%). The system would be expected to bear higher producer losses in case of shocks to the livestock sub-sector. The MFHP had more cattle (35%) and sheep (21%) compared to MFM. The latter had more goats. About 20.2 million animals (cattle, 5,472,229, sheep 5,298,690 goats 8,565,279 and 889,894 camels) are found in RVF high risk areas (Table 0-1 and Table 0-2). They represented 31% of the ruminant population in the country and were considered as population of interest to this study. The PAP held 52 %, 66%, 73% and 100% of the cattle, sheep, goats and camels in the high risk areas.

Table 0-1: Proportion of national ruminant population found in the different categories of RVF risk areas, disaggregated by species and three livelihood (farming) systems.

Livelihood system	*Cattle*	*Sheep*	*Goats*	*Camels*
MFHP	8.7	6.9	2.7	0.0
MFM	6.2	3.6	5.7	0.1
PAP	16.4	20.4	22.5	29.9

Source: Computed from the 2009 population census data

In PAP, local livestock breeds are reared under traditional small holder systems for subsistence purposes (Njanja, 2007). In MFM and MFHP, exotic and crosses dairy cattle are reared (Staal *et al.*, 2001) in typical herds of 1-2 cows. A few larger holdings of more than 20 cows are found. The mixed crop-livestock systems (MFM and MFHP) account for 70% of marketed milk production (Omore *et al.,* 1999). Milk production from goats (indigenous dairy) contribute an insignificant proportion (<1 %) of milk sold.

Table 0-2: Number of ruminants found in the RVF high risk area disaggregated by species and three livelihood (farming) systems.

Livelihood system	Cattle	Sheep	Goats	Camels	Total
MFHP	1,517,684	1,181,854	738,990	416	3,438,944
MFM	1,082,652	624,618	1,573,933	1,875	3,283,078
PAP	2,871,893	3,492,218	6,252,356	887,603	13,504,070
Total	5,472,229	5,298,690	8,565,279	889,894	20,226,092

Source: Computed from the 2009 population census data

3.2.5 Target human population

Table 0-3 shows the human population in RVF high risk areas. Majority (64%) of the 16 million people, lived in MFHP compared to 16%, in the PAP. Due to human RVF data gaps, the public health cost-effectiveness analysis was limited to the population in the PAP.

Table 0-3: Human population in RVF high areas disaggregated by gender and whether they lived in rural or urban

System	Sex	Urban	Rural	sub-total
MFHP	Male	3,175,286	204,4921	
	Female	3,094,808	207,9837	
	sub-total	6,270,094	4,124,758	10,394,852
MFMP	Male	689,512	825,337	
	Female	662,470	892,259	
	sub-total	1,351,982	1,717,596	3,069,578
PAP	Male	158,889	1,267,052	
	Female	148,768	1,083,220	
	sub-total	307,657	2,350,272	2,657,929
Grand total				**16,122,359**

Source: Computed from the 2009 population census data

3.2.6 Data collection sites

Figure 0-4 shows the specific areas within high risk areas where primary data was collected. Justification for each site will be presented in respective subsequent chapters.

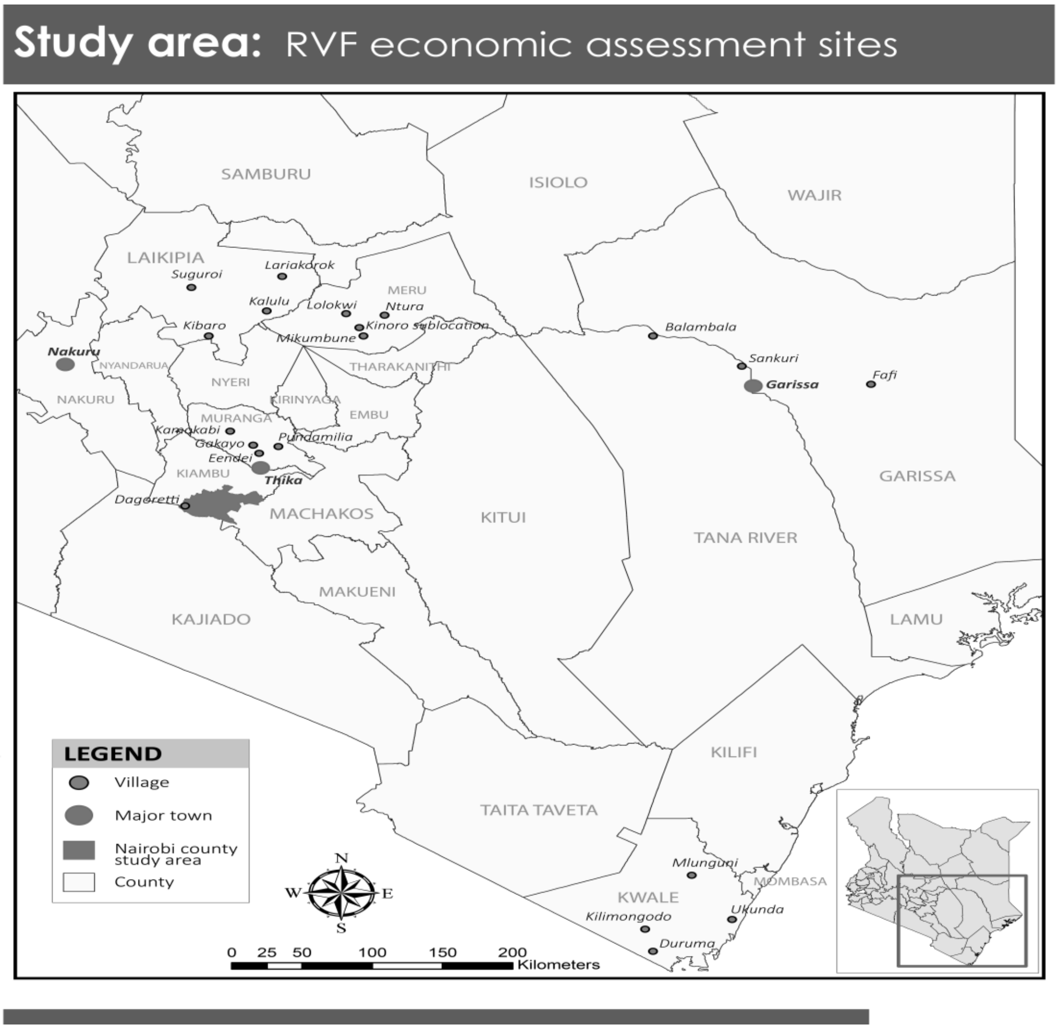


Figure 0-4: Map of Kenya showing the study areas and sites.

Table 0-4 summarises the data collection sites and types of data collected. The sites were purposively selected to represent areas adversely affected by the 2006/2007 RVF outbreak. Garissa County represented the PAP. The County was a hot spot for the 1997/98 and 2006/07 RVF outbreaks. Garissa, town hosts a live animal market described as the largest in East and Central Africa. The market has links to Thika, Kiambu and Nairobi livestock markets. Fafi District located within the County was one of the most adversely affected areas. Data was collected in Garissa town, Sankuri Division of Garissa District, Jarajira Division of Fafi District and Balambala.

Muranga, Meru Central, Kiambu, Nakuru represented the MFHP. Nakuru town was considered as an important terminal market for animals from RVF hot spots in central Rift

Valley. Laikipia and Kwale represented the MFM. Nairobi County represented the national level seat for national government technical and policy decision makers. Nairobi is also the main terminal market for livestock products.

Table 0-4: Sample size, data collection sites and data types for each analytical step.

Data collection and Analysis steps	Sample size	Data collection sites	Data types
Stakeholder mapping and OH institutionalization	• 63 key informants, • 72 livestock keepers in 4 focus group discussions	Nairobi and Garissa Counties Garissa County	• Stakeholders, • relational strength • coordination platforms
Delineation of control strategies and estimation of associated costs	• 15 key informants, • 46 subject matter experts • 72 livestock keepers in 4 focus group discussions	Nairobi and Garissa Counties Nairobi County Garissa County	Baseline and improved options of Vaccination, surveillance, vector control and feasible application levels and their impacts on disease dynamics
Animal RVF Epidemiological and herd dynamics and economics modelling	16 Focus group discussions in 16 villages Secondary data: 8 villages – Furhimann 2011 252 red meat value chain actors	Muranga (Maragwa). Meru Central, Laikipia and Kwale Garissa, Fafi Garissa town, Nairobi, Kiambu (Dagoretti market and Thika) and Nakuru (Municipality)	Herd dynamics, RVF rates, production indices, Price, volumes traded, impacts of diseases
Modelling human RVF and CEA	Secondary data Bitek (2013) and others		RVF rates in animals and people Disability weight, life expectancy

Source: Study output

The 16 villages in Kwale, Laikipia, Maragwa, and Meru-Central were randomly selected from a list of those affected by the 2006/2007 epidemic. The study also relied on the following secondary data (i) herd dynamics data collected in eight villages by Fuhriman,

(2011) (ii) the 2006/2007 RVF impacts collected in Garissa, Thika, Kilifi, Kwale, Nairobi, Maragua, Nakuru, Baringo and Elgeyo Marakwet district (ILRI, 2008; ROK, 2009b). (iii) RVF epidemics in Mauritania, Egypt and Tanzania.

3.3 Analysis and data collection period

Depending on the specific objective, data was collected between 2011 and 2013. Herd dynamics and RVF simulation modelling considered a ten year period 2006-2015. The period included the 2006/2007 RVF outbreak (which actually happened) and a next assumed 2014/2015 epidemic. The timimg of the hypothetical epidemic was informed by time frame of the last two epidemics 1997/98 and 2006/07, the inter-epidemic period was 10 years. The period was re/constructed into years with shocks (RVF and drought) and without shock (normal). Based on secondary data (Jost *et al.,* 2010), the 2006/2007 outbreak in animals started in week 45 of 2006 and lasted for about 160 days (5 months, approximately 23 weeks). The 1997/1998 outbreak started in late 1997 and spilled over to 1998 (Woods *et al.,* 2002). This study assumed the 2014/2015 outbreak, would occur over similar timelines. Weeks 1 to 37 of 2006, year 2009, 2010 and 2011 were drought periods. Year 2014 was assumed to be a drought year. The rest of years- second half of 2007, 2008, 2012 and 2013 were considered as normal years.

Inclusion of drought and normal periods in the simulation of the RVF epidemics provided insight into differences in changes in population growth, herd structure, gains and losses. This allowed analysis of the impacts of drought. Indeed, without alternating between drought and normal years it would not have been possible to have a demographic model that reflects steady growth of livestock populations in normal years and sharp decreases in drought years that are typical for Sahel countries.

CHAPTER FOUR

STAKEHOLDER AND INSTITUTIONAL ANALYSIS FOR ONE HEALTH

4.1 Introduction

Major zoonotic emerging infectious diseases (EIDs) that have occurred over the last twenty years include: bovine spongiform encephalopathy, highly pathogenic avian influenza (HPAI); severe acute respiratory syndrome; Hendra virus disease, Nipah virus encephalitis, West Nile fever, Pandemic H1N1 Influenza, Middle East respiratory syndrome and Ebola. Indications suggest that infectious diseases will continue to emerge and re-emerge, well into the foreseeable future, with profound negative impacts on animal and human health (King, 2004). Apart from the EIDs, endemic zoonoses such as Rift Valley fever (RVF) are also of great concern.

To mitigate both the worrying trend of EID's, and the endemic zooneses, the One Health (OH) strategy is expected to gain momentum as a tool to address both associated multi-sectoral impacts and environmental, animal and human health drivers for their emergence and spread. Major drivers for (re-) emergence of pathogens include: increased movements and contacts of people, wildlife and livestock; intensification of livestock production; and low biosecurity in farms and live animal or wet markets (Fournié, *et al.*,2013; Wallace and Kock 2012; Kock, 2014). Higher animal densities create fertile ground for infectious disease outbreaks while land use change increases contact with previously unexploited habitats. A main driver of RVF is climate change where El Nino events influence the frequency of outbreaks.

The OH strategy places health issues in a broader developmental and ecological context through collaborative efforts among multiple disciplines and sectors to attain optimal health for people, animals and the environment (Schwabe, 1984; WCS, 2004; FAO *et al.*, 2008a). Promotion of OH seeks to put into best use limited resources available to health sectors which may not be achieved through single sector approaches and should add value in financial savings, improved health and well-being of people and animals, and fostered environmental services (Zinsstag *et al.*,2015).

Protocols to implement OH strategy include: establishment of cross-sectoral (partnerships across sectors) and multidisciplinary committees; joint planning and implementation of multidisciplinary and cross-sectoral approaches; development of communities' capacities to report and timely response; creation and strengthening of multidisciplinary networks; developing appropriate university curricula and continuous training; and proactive disease risk management practices that address disease drivers (FAO, OIE and WHO, 2010; WCS, 2004; FAO *et al.*,2008a; WHO, 2005; WHO/FAO/OIE, 2004; World Bank, 2010). In summary, OH can be considered a complex innovation to identify and manage health problems at human, animal and environmental interfaces. It is expected to drive changes in institutional (formal and informal) and organisational arrangements. To better understand and guide national institutionalisation processes, this chapter presents a comprehensive stakeholder and institutional analysis within a broader study on RVF in an early OH adopting country – Kenya. The disease has been identified as a problem that requires OH approach (CDC, 2008).

4.2 Literature review and conceptual framework for OH institutional analysis

Whether at global, regional, national and sub-national levels, OH approaches require promotion of wide ranging institutional and organization collaborations across sectors and disciplines. Noting that the OH concept is evolving as a driver of institutions and organizational change to achieve effectiveness in zoonoses control, this study conceptualized OH as a policy or institutional innovation whose institutionalisation process analysis requires a socio-ecological approach. Policy Innovation for Health argues for shift to new mind-sets for health and health policy (Kickbusch, 2007). The study assumed the process starts with the identification of a need for all stakeholders to coordinate and cooperate on cross-sectoral health issues.

There are three non-mutually exclusive modes of economic coordination – hierarchies, markets and networks (Thompson *et al.,* 1991). Hierarchies are characterised by structures with authority; works well for frequent and substantial transaction specific investments. Markets work well for non-transaction specific investments and for those not prone to bounded rationality and opportunistic behaviour. Networks are less guided by structured authority and depend more on relationships and mutual interests through collaborative ventures between firms or organizations. Networks were taken as most appropriate for bringing together OH stakeholders. Development of OH stakeholder or actor-networks to facilitate cross-sectoral collaboration may require significant system change across sectors with already existing hierarchies.

Actor Network Theory (ANT) and Social Network Analysis (SNA) provide a theoretical and analytical framework for understanding and guiding successful policy or innovation in complex systems that require network building (Young *et al.,* 2010). Actor Network Theory focuses on science–based innovation processes and provides insights on people, research evidence, technologies, financial resources, institutions and regulations required to drive innovations. On the other hand, SNA provide insights on social diffusion and adoption of innovations and coalition formation (Waaserman and Faust, 1994). We consider all actors within OH as stakeholders and thus use the terms interchangeably. Based on Bourne and Walker (2006), and Walker and Rowlinson, (2009), stakeholders were taken to be organizations, specific groups such as communities, local leaders, projects or programmes, and thematic groups that have an interest or some rights or ownership on the issues at hand. They can contribute knowledge; support, or impact or be impacted by decisions taken and need to cooperate in the issue at hand.

Figure 4.1 shows this study's schematized five component conceptual framework for OH institutionalisation adapted from Latour (1999[3]) and Young *et al.,* (2010). The latter describes the framework in detail and system change context within which it is applied in public health policy innovation (in the case of smoke free places). The key and central component focuses on stakeholders and, their existing (and missing) relationships which would be required to initiate and institutionalise OH. The SNA has been widely used to study social networks of stakeholders and was therefore the key analytical method of the central component. In OH adoption, stakeholders would not only initiate multi-sectoral cooperation on cross-sectoral health issues but also organise and hold in place activities of the other four components (mobilisation, social acceptance, alliance-building and institutionalisation). In doing so they are guided by policy and legal frameworks. In absence of appropriate policies, the stakeholders can also influence policy and legal frameworks. Mobilisation, a dynamic interplay between evidence and arguments (young *et al.,* (2010), would shape and define how OH actions and solutions are framed. The actions and solutions are defined by stakeholders' current perceptions, provided evidence and their response capacity.

One Health policy works if key stakeholders gather cross-sectoral allies (and their resources) to join a network based on empirical evidence and benefits associated with change. However, the evidence is a social construct. Although there are scientific principles across nations, there might be strong cultural influence on what is acceptable as evidence. Often, stakeholders may focus on a common problem that requires OH approach. Social acceptance

[3] Model extracted from Young et al (2010).

process requires buy-in by governments and other actors. Further, sectors or even actors have specific epistemology. The OH approach facilitates negotiations of a common epistemology which in turn promotes acceptance and buy-in. Institutionalisation refers to the process by which authoritative acceptance and institutional support emerges with appropriate governance structures (e.g. Professional associations, issue specific government units or committees), financing, and development of appropriate policy frameworks.

To implement the framework; the study characterises RVF epidemics, as a common problem in Kenya that requires OH, and therefore mapped the RVF and OH stakeholder landscape, existing and missing links (relationships), institutions or platforms for cross-sectoral and multi-disciplinary collaborations; past and current related mobilisation to institutionalisation activities; and supporting policies and legal frameworks.

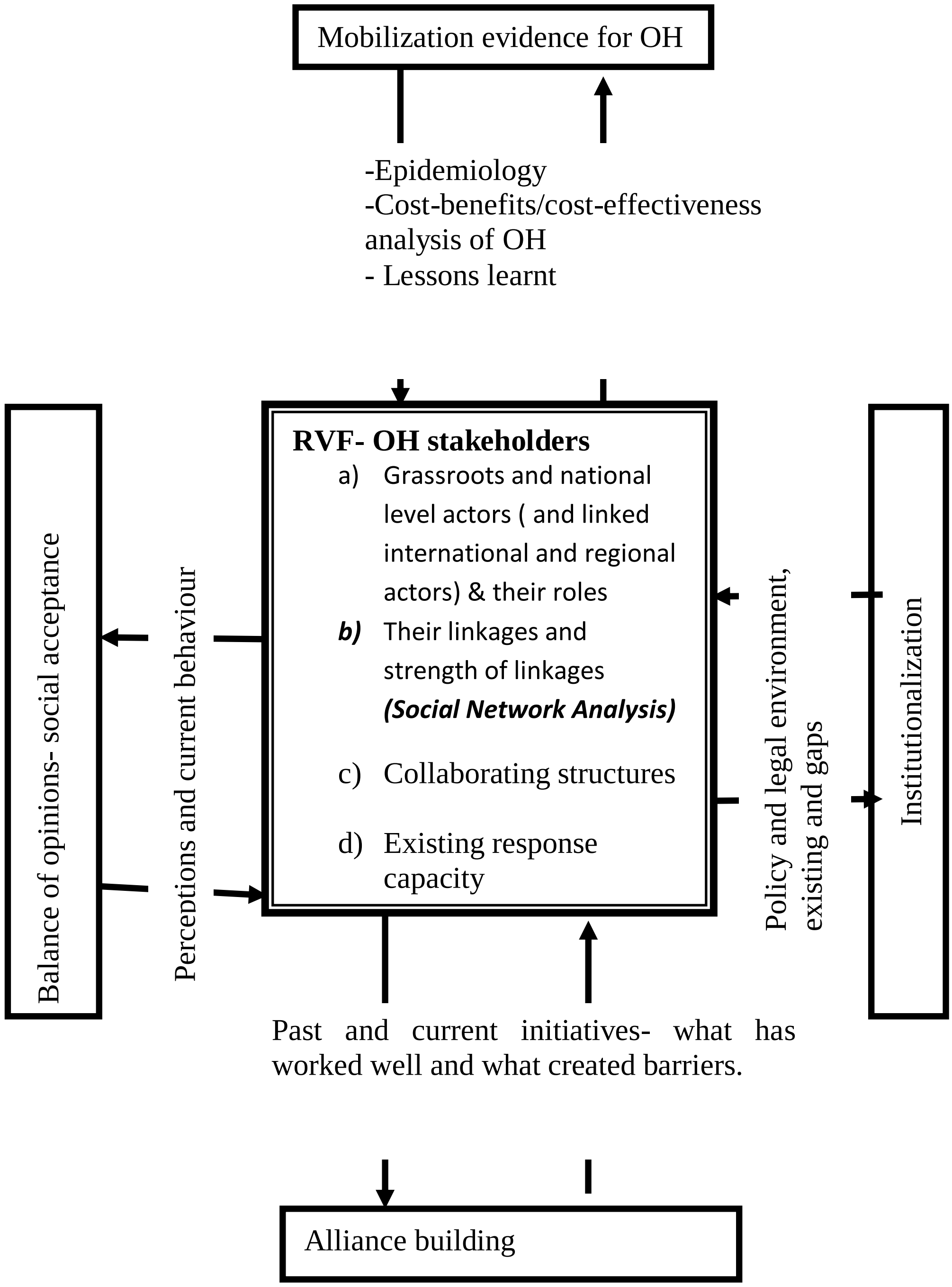


Figure 0-1: Conceptual framework for OH institutional analysis

4.3 Methodology

The conceptual framework guided the data to be collected while social network analysis described by Wasserman and Faust (1994) guided characterization of relationships between core RVF-OH stakeholders and the rest.

4.3.1 *Data types, sampling techniques and sample size*

Primary and secondary data was collected at two levels (i) Nairobi County based national or head offices of stakeholder organisations and (ii) sub-national Province and District based organisations in Garissa County in North-eastern Kenya. The two levels represented decision-making (policy and technical) and policy implementation respectively. Sub-national analysis also considered the community level where livestock keepers interfaced with the animal and public health services. Sub-national data was collected in February 2011. National data was collected between February 2011 and January 2012. However, updating of the national institutional set up continued up to 2014. Garissa County was selected since it was a hotspot for the 1997/98 and 2006/07 human and animal RVF outbreaks.

Appendix 1, (section one) included: (i) stakeholder roles in RVF and OH; collaborating partners; types of collaboration relationships; strength of relationships; (also asking for explicitly perceived missing relationships); (ii) mobilization, social acceptance, alliance building and institutionalization efforts/activities that included: past and current cross-sectoral cooperation and coordination initiatives; structures and projects used; and, relevant policies and legal frameworks supporting OH. Three relationships were considered and characterized – financial resources flows, cooperation (joint planning and implementation), and information sharing.

Full networks methods; ego-centric networks (with alter connections); ego-centric networks (ego only) and snowball methods are the different approaches to map stakeholders and their roles and relations (Hanneman and Riddle, 2005). The methods rarely draw sample sizes. Whichever method is adopted, understanding the networks and relational strength between actors or stakeholders can be measured by assigning scores or scales to the observations. Different types of scales (nominal- binary or multi category; ordinal -full rank or grouped ordinal; and intervals) have different mathematical properties and algorithms in describing patterns and testing inferences (Hanneman and Riddle, 2005). Wasserman and Faust, 1994 describes the Social Network Analysis that can be used to analyse the relationship scores.

The snowball method was adopted. Based on prior knowledge, the Department of Veterinary Services (DVS), Ministries in charge of Health (MOH) and livestock keepers were identified as key stakeholders (egos) for RVF and OH, and were chosen as the starting points to identify other stakeholders and core groups. Key informants from DVS and MOH were identified and interviewed using a semi-structured questionnaire. Seventy two (72) livestock keepers were interviewed in four group discussions held in four villages (Fafi, Garissa, Bura and Balambala), randomly selected from the ten that key informants identified as most affected during the RVF epidemic in 2007.

Starting from these three stakeholders determined the sample reached of 63 key informants, 35 from national stakeholder organisations and 28 drawn from: community animal and public health workers; public sector livestock and public health service providers; nongovernmental organizations; programmes; and livestock traders. The community animal and public health workers are semi-skilled personnel, who undertake basic health care chores with superivision of skilled technical staff. Snowballing process stopped when new interviews did not generate additional information. The process took about three weeks. While prior listing of all possible OH relevant organizations based on prior knowledge and literature review was undertaken, it mainly assisted to identify stakeholders who had no relationships to the those interviewed.

Strengths of three relationships (information sharing, financial flows and joint planning or implementation of activities) were measured by asking respondents to assign individual qualitative scores using grouped ordinal and interval approaches. They were asked to describe frequency (as high, medium, low or not applicable) and intensity (as high, medium, low or not applicable) of the relationships and based on both they scored each as either non-existent, weak, medium, strong or very strong. Often, as noted in Hanneman and Riddle [28], respondents experienced difficulties scoring each relation independently and were allowed to collapse the three and use one score instead.

4.3.2 The analytical framework

Describing stakeholders, their roles and perceptions render itself to qualitative research approaches and the associated challenges of analysing contextual data. Visual diagrams and narratives were used to organise information on stakeholder's roles and collaborations activities and platforms. The contextual data on sub-national stakeholder (egos only) capacity to effectively play their roles in OH was analysed using thematic content analysis. Thematic content analysis is a method commonly used to analyse local perceptions presented as textual data, elicited through semi-structured questionnaires and focus group discussions, by organising it into basic, organising and global themes (Attride-Stirling, 2001) The choice of thematic analysis was based on its ability to identify key themes in local perceptions data. The respondents' statements on capacity to effectively play their roles were assigned codes (basic themes). The assigned codes that described closely related capacity issues were clustered together and assigned a descriptive title consistent with the cluster (organising themes). A global theme was identified as one that fitted well in representing the clusters (organising themes).

To construct some true interval level measure of the ordinal scale data, the study assigned a quantitative score ranging 1 to 8: none or no linkage was assigned a zero (0), weak was assigned 1 or 2; medium was assigned 3 or 4; strong was assigned 5 or 6; very strong was assigned 7 or 8. The decision to assign a lower or higher quantitative score was based on the frequency or magnitude of the interactions. This helped to balance the predispositions of the researcher and the respondents' descriptions while at the same time, continuous measure of the strengths allowed estimation of statistical measures as mentioned above.

These quantitative scores were plotted in a matrix. Using UCINET software described by Everett *et al.*, (2002), the scores were used to generate sociograms and compute network centrality statistical measures of relationship strengths. To generate network sociograms the matrix score data was binarised where scores 0 and 1–8 were coded as absent (0) and present (1) respectively. Binary measures make the distinction between present or absent relations and are by far the most commonly used as most of SNA analytical methods are developed for binary data.

The statistical measures (density, clustering coefficients, actor degree of closeness (or farness), and between-ness) reflect power and influence within the network. Density of a network gives an index of degree of actor connections. Degree measures describe the way an actor is embedded in a network. The way (position) an actor is embedded in the network can create constraints, more opportunities and alternatives (for the actor). The more ties an actor has, the more power and greater opportunities they (may) have as they have more choices and are less dependent on any specific other actor, and hence more powerful. Closeness refers to how an actor is close to the others. High in-degree values for a stakeholder reflect a position where others want to influence it, for example, through information sharing. A high out-degree measure for a stakeholder reflects a position of where it wants to influence those linked to them. Between-ness refers to a position of an actor in a network as in between several pairs of actors, or no other actors lie between them and other actors. The clustering coefficient reflects the average of densities of neighbourhoods of all actors. The degree of clustering of stakeholders in a network is estimated as an average of all the neighbourhoods.

4.4 Results

4.4.1 Sub-national analysis

4.4.1.1 Stakeholders and roles

In Garissa County, 20 stakeholder organisations or groups relevant to OH included public and private service providers, livestock keeping community who were pastoralists with linked institutions, non-governmental organisations (NGOs), United Nations technical agencies, traders, and three programmes/projects (Figure 0-2; sub-national component). In this study, we classified a stakeholder as a non-governmental organization (NGO) if it was non-profit, funded by donors to support animal or public health except research and were not linked to government or United Nations.

Pastoralist community perceived their roles as that of reporting animal disease outbreaks, treatment of sick animals, seeking public health care, and compliance with control or risk reduction measures. The District Veterinary Officers (DVOs) and their teams described their role as that of implementing animal disease prevention and control measures. District Medical Officers (DMOs) described their role as that of coordinating delivery of public health services through a network of health facilities. Several stakeholders namely FAO, NGOs, projects, PDVS[4] supported DVOs while WHO, UNICEF, Health Provincial Directors, donor funded projects and NGOs supported DMOs. The roles of these included complementing and building capacities of the public agencies through provision of information, resources and direct implementation of activities. They also supported communities through direct implementation of activities in line with their mandate. The CBAHWs and local leaders acted as intermediaries between communities and DVOs

[4]The province as an administrative unit has since been scrapped and therefore provincial officers no longer exist.

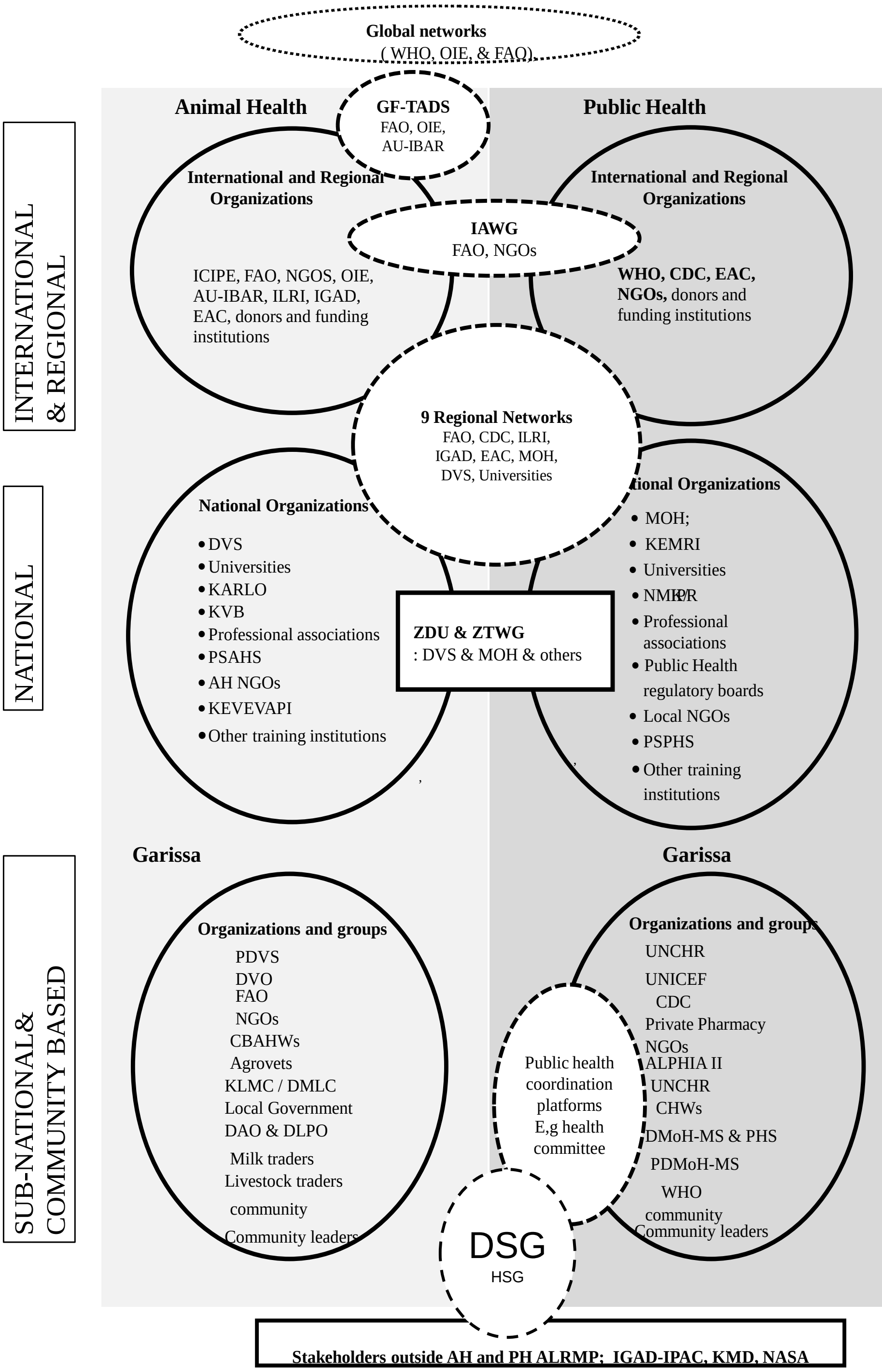


Figure 0-2: Schematic diagram of RVF and OH stakeholders and coordination/cooperation structures.

Solid circular lines enclose groups of stakeholders at each level; solid rectangular lines represent formal cross-sectoral platform; broken lines represent other coordination platform or structures (not considered as stakeholders); shades of grey differentiates sectors.

The CHWs and local leaders acted as intermediaries between communities and DMOs and other public health officials. There was more public health actors (including NGOs) compared to livestock or animal health actors. Respondents consistently pointed to inadequate capacities of the DVOs, DMOs and pastoralists to effectively play their respective roles. They described public health services as generally inadequate but more accessible compared to animal health services. Livestock keepers experienced difficulties in disease reporting and accessing veterinary services. Main barriers to effective roles are summarised in the following section

4.4.1.2 Constraints (barriers) to effective roles by key stakeholders (community, public and animal health service providers)

Exploration of focus group discussions and key informant information on perceptions of effective roles of the key stakeholders identified 22 codes (basic themes) all revolving around constraints to effective roles (**Error! Reference source not found.**). The basic themes, representing statements made in describing the challenges and the situation of the perceived effectiveness (or not) of the roles were grouped into seven organising themes that were summed up to a global theme – they faced constraints or barriers to effective role playing.

Personal and logistical capacity: statements on weak public and animal health infrastructure were made by all respondents and reflect weakened ability of livestock keepers and service providers to access and deliver services respectively. Between the two study Districts, Fafi District was considered worse. Between the two health sectors, public health personnel and logistical capacity was higher than that of the animal health services. This was triangulated through data obtained from key informants. In 2010, animal health infrastructure in Northeastern province (Counties of Wajir, Garissa, Mandera) comprised of 17 public veterinary offices, (15 districts offices (out of 20), one provincial headquarters and a Regional Veterinary Laboratory), all manned by 16 veterinarians, 34 paraprofessionals, 5 laboratory staff, 1 zoologist and 24 support staff. Only 47% (8/17) of veterinary units had a physical office to operate from while 35% lacked a vehicle for logistics. The two study districts (in Garissa County) were each manned by a veterinarian. Fafi had a total 12 CAHWs. Private sector veterinary services were poorly developed ~ only one private veterinarian and a few agro vets were based in the region. Garissa District had a vehicle and 5 motorcycles while Fafi had an old vehicle which had broken down.

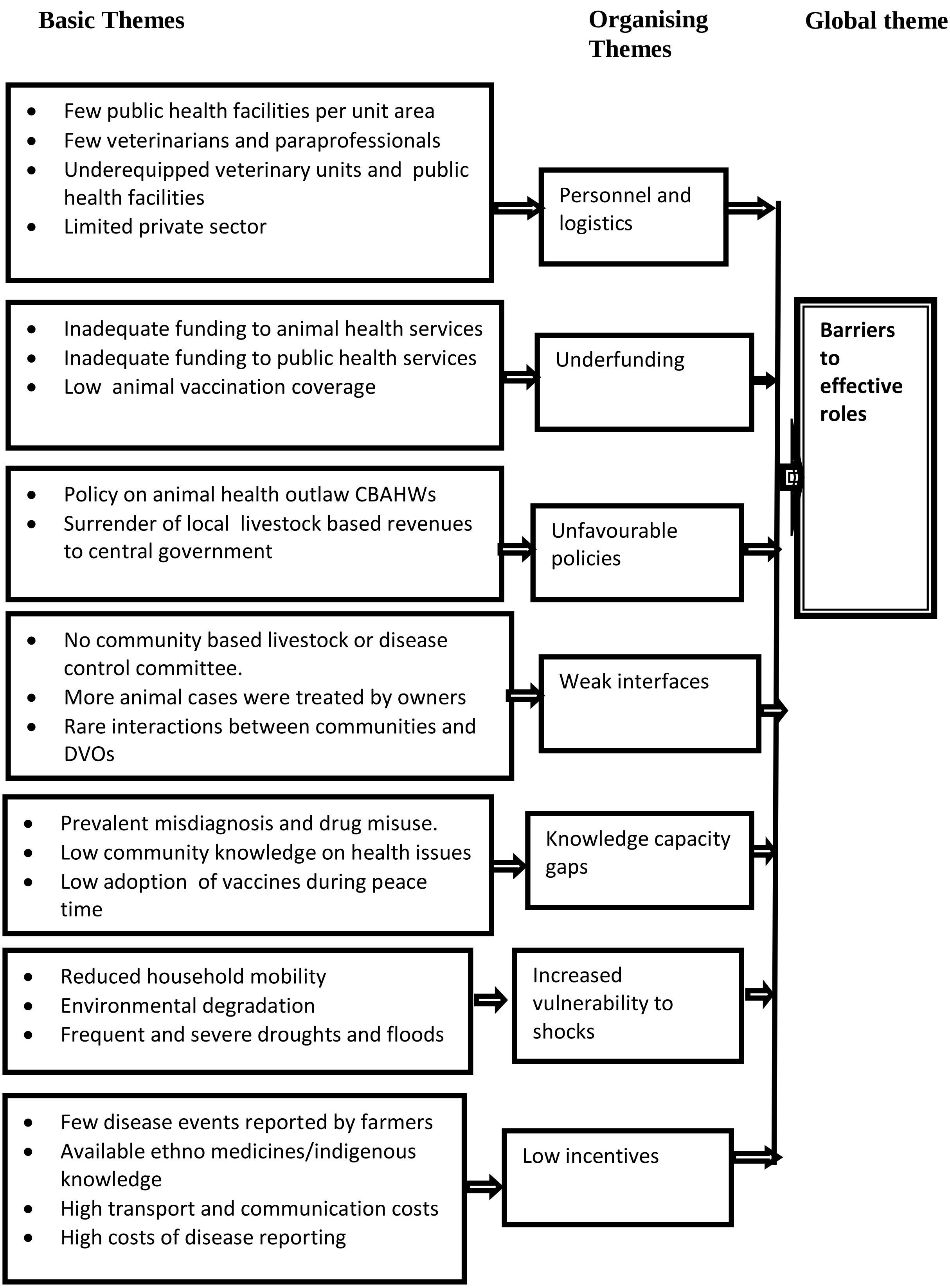


Figure 0-3: Thematic network for barriers to effective role playing by the communities and the health sectors (animal and public health).

Data aggregated for three Counties (Wajir, Garissa, Mandera) showed that veterinarians were responsible for up to four times the 100,000 Tropical Livestock Units recommended in FAO, (1993) and on average covered an average 7,931 square kilometres. In Garissa County, Fafi DVO covered 16,325 square kilometres, two times the regional average. On the other hand, public health facilities (L2-L4) capacity in the three counties expressed per 100,000 persons and per 1,000 sq. km was 14 and 1 respectively compared to national averages of 16 and 11 (**Appendix 2**).

In February 2011, health infrastructure in the province comprised 116 health facilities- 11 hospitals, 8 sub district hospitals, 45 health centres, 102 dispensaries, 17 community units and 9 nomadic clinics. Ninety nine (99%) of the facilities were run by government and the rest by CBOs. Many lower level facilities lacked basic infrastructure such as vehicles and laboratory diagnosis capacity. The public health personnel in North-eastern province (1,233) represent 2.6% of the total national health personnel. The three counties had a total of 1,233 public health staff, of which 90.7% are employed in the public health facilities (**Appendix 3**). Of the total, trained community health workers (CHWs) accounted for 33%. Public health and animal health service capacities were challenged by large distances to local health facilities in some cases 60km away. A comparison between the two sectors shows that the public health sector has a higher personnel capacity; the ratio of trained public health to animal health personnel was 10: 1.

Unfavourable policies and underfunding: The community animal health workers complained of being outlawed by the Kenya Veterinary Board and therefore local staff of the department of veterinary services used their services on a limited basis (for disease reporting and vaccinations). On the other hand, community health workers in the public health sectors were recognised and supported. In public health, community health workers (CHWs) accounted for 33% of the total personnel. Respondents felt that the positive policy by public health allowed the sector to further strengthen their personnel capacity while the negative policy on CBAHWs denied the local veterinary staff in using local solutions to strength their already weak capacity.

Key informants also pointed to another disparity between the two sectors- use of locally collected revenue. Unlike public health services, the animal health services submitted all locally collected livestock revenues to Central Government while public health were allowed to plough back the money into service delivery which allowed them to meet 70% of operating costs from the revenues. Already, the veterinary services were under funded, evidenced by low vaccination coverage for key diseases (Appendix 5). Communities cited that veterinary vaccination campaigns had stopped dramatically in the late 1980's. This can partially explain the differential capacities between the two health sectors. The national development policy framework vision 2030 categorizes public health as a social sector (public goods) while livestock and animal health are placed in the economic sectors. A policy shift in 1986, reclassified veterinary services all previously considered as public goods into private, public or mixed goods. Consequently, budgetary allocation for public animal health services and staffing levels reduced. While privatisation was fairly well adopted in high and medium potential areas, it was not the same in the pastoral and agro pastoral (PAP) areas such as Garissa County (FAO, 2009).

Weak interfaces and it was worse for animal health: This was best illustrated at Fafi Village. In 2007, the village was hardest hit by RVF epidemic. At the time, the village had a nomadic (weekly) public health clinic and 1 CHW and no mobile network. For animal health service, they travelled to Garissa, about 100km away. At the time of the study, 5 years later a permanent health facility had been established supported by 1 CHW, 1 Nurse, and a health committee that brought together community leaders, the health providers (including NGOs). On animal health services, the area now fell under a new created district, Fafi whose headquarters were more than 100km (on road) away, the DVO had a broken down vehicle, no CAHWs to work with communities, no mobile telephone network yet, and neither had any animals been given preventive vaccination against RVF despite that there had been two predictions of potential RVF outbreaks between 2007 and 2012. The community perceived that lack of formal structures through which community engaged animal health services providers compared to public health sector was a major reason for the weak interface. To address the weak interface, DVOs, livestock keepers, community leaders and CBAHWs suggested establishment of livestock committees.

Knowledge capacity gaps: This study triangulates a position advocated by FAO, OIE and WHO - the need to build the community's capacity for disease reporting and response in order to strengthen national OH capacity. Inadequate community knowledge on animal health issues was evidenced by responses citing low adoption of peace time (prevention) measures, drug misuse and misdiagnosis. Livestock keepers did not see the need to vaccinate healthy animals and also perceived animal vaccination as purely a government role and during disease outbreaks only. To increase coverage levels, DVOs provided incentives such as dewormers and treatments of animals. Another practice that reflected low knowledge on zoonoses risk was consumption of raw camel milk.

Low incentives: livestock producer behaviour or practices of: rarely reporting disease outbreaks (unless in case of high mortality), citing inadequate response to disease reports by service providers and high transactions costs reflected low incentives to effectively play their roles. Service providers in both sectors also cited high transaction costs. Surveillance officers based at health facilities and CBAHWs reported high monthly costs of delivering regular disease information. Vastness of the areas, poor telephone and road infrastructure were largely blamed for high transport costs and transactions costs. Two of the four RVF hot spot villages (Fafi and Mbalabala) visited lacked telephone connectivity while all roads were impassable during rains.

Increased vulnerability to shocks: The impacts of animal diseases on livelihoods were perceived to be lower than those of drought and floods. Chapter six corroborates this by showing that drought impacts are higher on livelihoods compared to RVF shocks. This implies that a holistic approach to livestock issues might be a better approach to addressing the community's capacity gaps.

4.4.1.3 Mobilisation for OH

There were only two types of coordination and communication platforms enhanced cross-sectoral and within-sector cooperation's at sub-national level. The platforms (not considered as separate stakeholders) included (i) a multisectoral district steering group (DSG) supported by a donor funded cross-sectoral development project: Arid Lands Resource Management Project (ALRMP). The DSG had several sub-groups among them a public health sub group (HSG). (ii) Public health stakeholder forums at all levels of health facilities; at the lowest level were the health committees.

The DSG brought together District public sector heads, NGOs and private sector organisations for purposes of coordinating development activities and response to multisectoral emergencies such as RVF outbreaks. The ALRMP's drought monitoring or early warning officers collected household and community level information that included disease status in animals and people. The local office of World Health Organisation (WHO) analysed the public health information to share with local public health heads. Joint public and animal health activities were rare. The HSG coordinated only public health issues, though DVOs were invited to meetings.

The public health stakeholder platforms provided opportunities for private sector to engage and support public health services. The health committees brought together community leaders, community health workers (CHWs) and health officers for purposes of enhancing community participation in health management and disease reporting. In case of unusual health events, communities informed the leaders who in turn informed service providers. The latter used the leaders as an entry point to the community. Unlike in the public health sector, livestock and animal health stakeholders had no sectoral collaboration platforms amongst themselves; with livestock keepers or with public health sectors.

4.4.1.4 Sub-national network properties

Sub-national network degree centrality measures and sociogram are presented in Table 0-1, Table 0-2 and Figure 0-4 respectively. The sociogram demonstrates how the different stakeholders described in the previous sub-section are related. The computed overall binary network density was 0.21 which implied that only 21 % of the possible ties were present. The sociogram is dense around the public health stakeholders and less dense around animal health stakeholders. Two livestock stakeholders (FAO and milk traders) had no relationships with the rest of the stakeholders, while the local wildlife office had no direct link to DVO. The sociogram shows minimal links between the animal and public health sectors. The ALRMP, community and community leaders (chief and councillor) played an important cross-sectoral role as nodes linking public and animal health sectors. The sociogram confirms that there is no institutionalization of OH at sub national level. Even more so, if the KWS is completely isolated from the network.

The degree centrality measures are consistent with the local mobilisation efforts described above. The public health actors, ALRMP and the community had more relationships and more pairs compared to animal health actors (Table 1 column 3, figures in brackets). In and out between-ness centrality measures of 239 and 32 respectively identified ALRMP as the actor who linked clusters, acted as broker and having the highest power within the network. This was attributed to the DSG and HSG collaboration platforms and the fact that the project supported multiple sectors. Other stakeholders who linked clusters included District Veterinary Officers (DVO), community, WHO and Ministry of Health (MOH). Also, ALRMP emerged as the actor demonstrating highest in and out closeness at 23 and 29 respectively, followed by MOH (22, 28), WHO (21, 27) and other human health NGOs (21, 26). Degree centrality measures confirm that public health actors, ALRMP and community had more ties compared to livestock/animal health actors. The MOH had strong linkages to other public health stakeholders, ALRMP and the community while the DVO had weak linkages with very few actors in the animal health sector.

Table 0-1: Centrality statistics measures for Garissa County stakeholders (public health actors)

Actor and (Acronym)	Cluster coefficient	Degree		Farness		Closeness		Between	nBetween
		In	Out	In	Out	In	Out		
United Nations High Commissioner for Refugees (UNHCR)	0.92 (36)	9	8	147	120	20	24	1	0.1
The Danish International Development Agency (DANIDA)	0.84 (45)	10	9	137	110	21	26	14	2
Centre for disease control (CDC)	0.80 (10)	5	3	151	132	20	22	0.2	0.03
Provincial Director of medical services (PDMS)	0.78 (36)	9	9	147	121	20	24	5	1
Provincial Director of public health and sanitation (PDPHS)	0.78 (36)	9	9	147	119	20	24	6	1
Human Health NGOs (HHNGO)	0.76 (55)	8	11	138	108	21	27	19	2
Aids, Population And Health Integrated Assistance Program (APHIA)	0.75 (55)	10	11	144	108	20	27	12	1
United Nations International Children's Emergency Fund (UNICEF)	0.74 (55)	10	9	143	110	20	26	12	2
World Health Organisation (WHO)	0.74 (55)	11	11	136	108	21	27	35	4
Local Government	0.65 (10)	4	2	143	121	20	24	4	0.5
Community health workers CHW	0.45 (28)	7	6	143	115	20	25	20	2
District medical officer of health- public health and sanitation DMOH-PHS	0.43 (105)	12	15	132	102	22	28	74	9
District medical officer of health- medical services DMOH-MS	0.43 (105)	12	14	132	104	22	28	61	8

Source: Study Computation. * Number in brackets refer to the number of pairs

Table 0-2: Centrality statistics measures for Garissa County stakeholders (community leaders and livestock sector)

Actor and or Acronym	*Cluster coefficient*	*Degree*		*Farness*		*Closeness*		*Between*	*nBetween*
		In	Out	In	Out	In	Out		
Councillors	0.57 (15)	3	3	146	126	20	23	3	0.4
Chief	0.41 (28)	7	6	140	110	21	26	34	4
Kenya livestock marketing council KLMC	0.55(10)	4	3	144	123	20	24	17	2
CBAHW	0.55 (10)	3	4	153	122	19	24	4	1
Livestock traders	0.50 (6)	4	2	158	142	18	20	2	0.2
KDLDP	0.43 (21)	6	5	140	117	21	25	31	4
Chief	0.41 (28)	7	6	140	110	21	26	34	4
District livestock production officer DLPO	0.37 (15)	4	4	146	122	20	24	26	3
CARE International in Kenya CARE	0.35(10)	3	4	147	116	20	25	6	1
ALRMP	0.28 (105)	14	13	129	101	23	29	259	32
District Veterinary Officer DVO	0.24 (36*)	7	8	139	113	21	26	84	10
community	0.30 (78)	7	10	139	106	21	27	92	11
Milk traders	(0)	0	0	870	870	3	3	0	0
Food and Agriculture organisation FAO	(0)	0	0	870	870	3	3	0	0
Kenya Wildlife service (KWS)	(0)	1	1	154	127	19	22	0	0
Pharmacy and agro vets	(0)	1	1	164	132	17	22	0	0
Provincial Director of veterinary services	(1)	1	2	164	137	18	21	3	0.4
Provincial Director of livestock production	1	2	0	139	870	21	3	0	0
Mean		6 (3.9	6 (4.4)	193 (181)	193 (226)	19 (4)	23 (7)	27 (50)	3.4 (6.2)

Source: Study Computation. * Number in brackets refer to the number of pairs

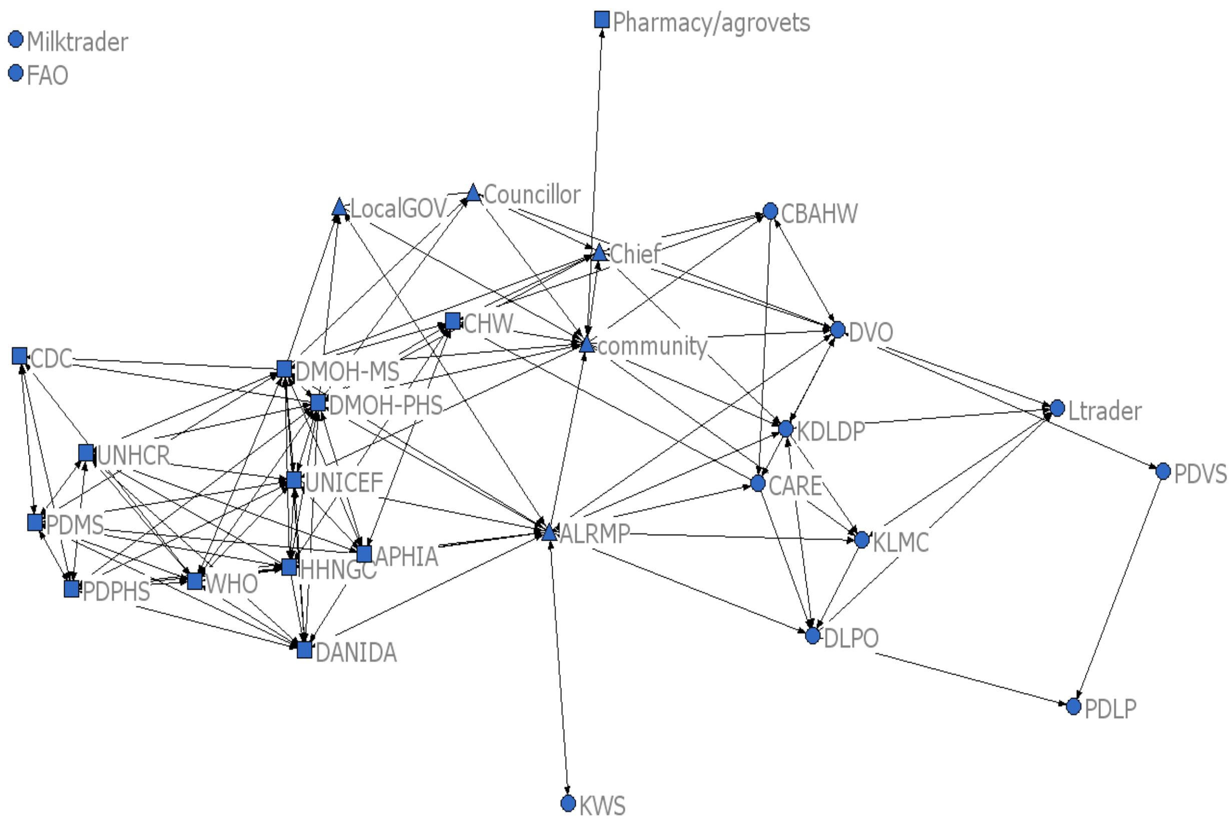


Figure 0-4: Sociogram of the Garissa County OH network.

Key: Square (public health); circle (animal health); upward triangle (others). Arrows show stakeholders with relations. Direction of arrow reflects direction of relations.

4.4.2 National level analysis,

4.4.2.1 Stakeholders and roles

A total of 32 international, regional and national public and private sector organisations relevant to RVF and OH were identified (Figure 0-2; national and international and regional segment). They can be grouped into three sectors: animal (livestock and wildlife), public health and others (environment or climate prediction agencies). The majority, (21; 65%) were national organisations, of which 11 addressed animal health; nine concerned public health; and one, the Kenya Meteorological Department (KMD), worked on climate prediction issues. Eleven (11), representing a third were international or regional organisations, based in Nairobi.

Activities of the national organisations included regulation and policy setting, delivery of services, academic, research, training, and regulatory and professional organisations. The Department of Veterinary Service (DVS), the two ministries in charge of health and Kenya Wildlife Services were the lead agencies (mandate provision described in law) in livestock health, public health and wildlife RVF related OH issues, respectively.

The Department of Veterinary of Services (DVS[5]) had a legal mandate for prevention and control of animal diseases and pests. The Kenya Veterinary Vaccines Production Institute (KEVEVAPI) produced animals vaccines (including for RVF) while Kenya Agricultural Research Institute (KARI, renamed KALRO) undertook research in disease vectors, livestock vaccines (including RVF), diagnostic kits and vaccine trials. Kenya Wildlife Services (KWS) has been active in control of two zoonoses (highly pathogenic avian influenza and RVF) in partnership with the DVS and National Museums of Kenya (NMK). Three universities and five (5) mid-level colleges offering animal health training are considered important in the development of the OH workforce.

Private sector animal health service providers are numerous and come in several forms such as agro vet shops, registered veterinary clinics, private animal health technicians, and, pharmaceutical companies. The private services are mostly located in mixed farming systems and are nearly absent in pastoral and agro-pastoral systems (PAP). Of the livestock producer and trade organizations, Kenya Livestock Marketing Council (KLMC) plays an active role during RVF outbreaks as traders as shall be seen in chapter six are heavily affected by RVF associated trade bans.

In 2011, public health services were mostly funded by government through two Ministries in charge of Health (MOH[6]), also responsible for health regulation and policy setting. Since 2013, public sector health funding is channelled through a single MOH and county Governments. The NGOs and private sector service providers were other implementers of public health services. The Kenya Medial Research Institute (KEMRI) provides important diagnostic support to the MOH's public health laboratories while the Kenya Medical Training Centres (KMTC) and the universities support service providers with training workforce and research outputs (universities). The Institute of Primate Research (IPR) is a WHO collaborating centre in human reproduction and tropical disease research and

[5] Since, 2013, delivery of veterinary services was devolved to County Governments while the national government has been left with policy and regulation.

[6] At the time of the survey two twin ministries – public health and sanitation and that of medical services were handling health issues but were merged as one – Ministry of Health in 2013. The study considers them jointly as Ministry of Health

develops diagnostics, prophylactics and therapeutics against tropical diseases, including some zoonotic diseases.

Rainfall and unusual weather information from KMD supported early warning for outbreaks of diseases associated with the climate events. Following prediction of excess and unusual rainfall, KMD has been involved in preparedness and contingency planning meetings for potential RVF outbreaks.

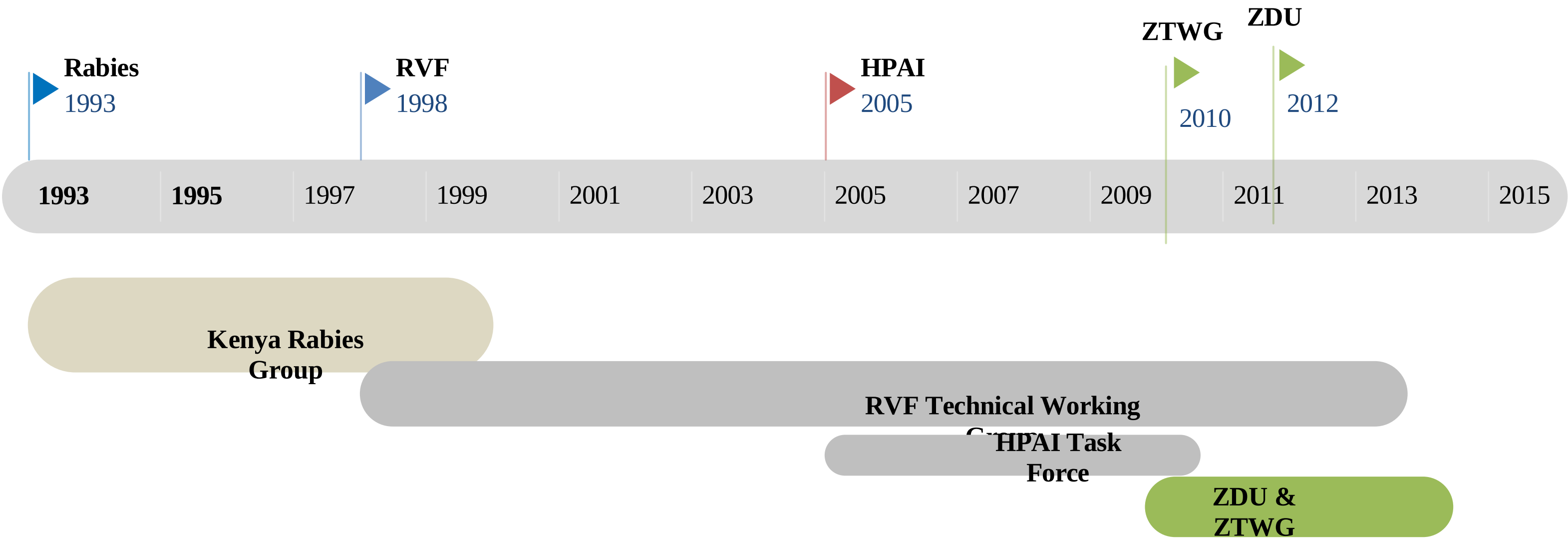
On the other hand, roles of the international and regional organisations included (i) financial and technical support to national organisations, (ii) regional coordination of respective health activities through donor-funded sectoral or cross-sectoral initiatives, networks, and projects. The Food and Agriculture Organisation of The United Nations (FAO), World Health Organisation (WHO), Centre for Disease Control (CDC), emerged as most active in OH followed by Intergovernmental Authority on Development (IGAD) and African Union Interafrican Bureau for Animal Resources (AU-IBAR). The FAO, WHO, CDC and the International Livestock Research Institute (ILRI) supported the national cooperation efforts and regional coordination of OH and the networks. Thirty one (31) different NGOs working on animal and public health were identified. They implemented wide-ranging multiple sector activities harmonious with OH that include: emergency relief; response to disasters (including health ones); and resilience building. Most NGOs operate mainly in under developed areas where the capacity of the health sectors is comparatively lower. Two centres of IGAD - Climate Predictions and Applications Centre (ICPAC) and Centre for Pastoral and Livestock Development (ICPALD) mostly provided regional climate and livestock early warning data. The Kenya Meteorological Department_(KMD) which works closely with IGAD-ICPAC was the only national organization involved in climate prediction. The National Aeronautics and Space Administration's (NASA) Goddard Space Flight Centre is a key information source for RVF; it had predicted the 2006-2007 outbreaks 1-2 months prior to the first human cases (Anyamba, *et al.,* 2010).

During the 2006/2007 RVF epidemic, most of the international and regional organisations enhanced national response capacity by assisting with procurement, diagnosis, training, coordination and assessment of outbreak as detailed in ILRI, (2008) and summarized in Appendix 4. Ongoing activities showed that the organisations have continued to build national capacity in RVF control that includes: development of the RVF contingency plan and protocols, surveillance and implementation of animal vaccination services. Global and regional networks in which the international or regional organisations participated included: (i) FAO, OIE and WHO's Global Early Warning System (GLEWS) for major animal diseases; (ii) the FAO and OIE's (plus AU-IBAR in Africa) Global framework for the progressive control of transboundary animal diseases (GF-TADs); (iii) Nairobi-based multi-sectoral Inter-Agency Working Group (IAWG) on disaster preparedness, which had previously established ad hoc multi-sectoral subgroups addressing avian influenza and Rift Valley fever; and (iv) nine regional networks namely:

i. Cysticercosis Working Group for Eastern and Southern Africa (CWGESA),
ii. Eastern Africa Regional Laboratory and Epidemiology Networks (EARLN and EAREN),
iii. African Field Epidemiology Network (AFENET),
iv. Participatory Epidemiology Network for Animal and Public Health (PENAPH),
v. East African Community's (EAC) Integrated Disease Surveillance Network (EAIDSNet),
vi. EAC's multi-sectoral Task Force of Experts on RVF,
vii. Southern and Eastern Africa Rabies Group (SEARG),
viii. Central and East Africa (OCHEA) network of schools of public health, medicine, nursing, and veterinary medicine,
ix. AU-IBAR, Integrated Regional Coordination Mechanism (IRCM).

4.4.3 Historical progression of mobilisation for OH at national level

Current and past initiatives towards mobilisation, alliance building, social acceptance and institutionalisation of OH at national level are summarised in Figure 0-5. They provided a basis for understanding current network. Three zoonotic diseases (rabies, RVF and HPAI) drove the initiatives. Formation of the regional network, SEARG in early 90s called for establishment of national rabies groups. Twelve (12) scientists/technical officers drawn from DVS, MOH and other animal and human health institutions established an informal platform named the Kenya rabies group (KRG) in 1993. The group's activities included collection and sharing of rabies information to advocate for both joint control efforts and increased resource-allocation.



RVF – Rift Valley Fever
HPAI – Highly Pathogenic Avian Influenza
ZDU – Zoonosis Disease Unit
ZTWF – Zoonosis Technical Working Group

Figure 0-5: Schematic diagram of national level OH institutionalisation process and in Kenya

The efforts led to a 440% rise in allocation of rabies control funds in 1997/98 and increased private sector participation in control. However, the activities were not sustained and ceased in 2000, attributed to failures in alliance-building and social acceptance by heads of institutions involved. Other factors cited included re-deployment of founding members, and imbalanced composition as animal health experts accounted for 83% of KRG members. As a result, funding for rabies dropped by 92% in 2001 despite a focal person based at DVS maintaining a link to SEARG.

Some members of KRG and other scientists formed a second informal platform, named, multisectoral and multidisciplinary RVF scientific working group (RVF-SWG) after the 1997/98 RVF epidemic. Their activities focused on RVF research and generation of evidence. When NASA predicted the 2006/2007 RVF epidemic, the group technically supported multisectoral response efforts and had continued to do so in the post-epidemic period. The 15-year plus continuity of RVF-SWG was largely attributed to both support by CDC (showing that institutional support is critical) and increased prioritisation of RVF in the country.

The formal process to institutionalise OH begun with a highly pathogenic avian influenza (HPAI) multisectoral taskforce formed in late 2005 after recommendations from FAO and WHO. Through the taskforce, technical heads of veterinary and medical services mobilized and built alliances with many OH stakeholder organisations in preparation for an influenza pandemic. However, in 2007, an RVF epidemic occurred and the multisectoral taskforce and RVF-SWG joined hands to support and coordinate response. In 2010, noting usefulness of the HPAI taskforce in zoonoses control, policy makers transformed it into a Zoonoses Technical Working Group (ZTWG) and established a joint animal and public health Zoonoses Disease Unit (ZDU) in 2012.

The institutionalisation activities have been largely funded by CDC and line ministries. The period also coincided with the FAO/OIE/WHO calls for national OH platforms. By mid-2014, ZTWG and ZDU had identified priority zoonoses; developed a 5-year strategic plan; updated RVF's contingency plan; implemented joint zoonoses surveys and investigations; and were developing OH strategies for rabies and brucellosis.

Two policies provided a basis for the initiatives; the draft Veterinary Policy (VP) and the Kenya Public Health Policy 2012-2030. The VP has an explicit policy statement stating that the two health sectors will establish cooperation platforms. The Public Health Policy adopted a wider policy objective of strengthening collaboration with other sectors that impact on health.

In 2010, ZTWG members were drawn from 17 (53%) out of the 32 identified national stakeholders of which 35 % had roles in public health, 29 % in livestock, 12 % in wildlife health, and 24 % in cross-sectoral thematic areas. Missing stakeholder groups included: private sector service providers, non-governmental organisations, donors, regulatory and professional associations. Disciplinary orientation of ZTWG showed dominance (of 74%) by medical or veterinary epidemiologists and public health experts making it a multidisciplinary team of two disciplines (veterinary and medical health professionals).

4.4.3.1 Current national network and properties

The national level sociogram (Figure 0-6) represents a network (of national, regional and international stakeholders based in Nairobi) that had evolved from the historical progression. Computed overall binary network density was 0.35 (0.662[7]), showing that only 35% of the possible relationships existed. The overall clustering coefficient was estimated at 0.56 (0.48 "weighted") showing fairly dense local neighbourhoods. Seven stakeholder organisations or groups – CDC, FAO, AU-IBAR, OIE, universities, NGOs and International Centre for Insect Physiology and Ecology (ICIPE) had cluster coefficients that ranged from 0.51 to 0.95 (Table 0-3). This means that they had achieved more than 50 % of possible ties in the neighbourhood, attributed to their networks and mandates in OH as well as their resource endowments from donors. The University of Nairobi was a lead coordinator of the OCHEA network mentioned earlier.

The DVS had the highest out and in ties followed closely by MOH, FAO, CDC, ILRI and AU-IBAR, while NGOs (both HHNGOs and AHNGOs) and whose activities are mostly community-based were one of those with least ties. The sum of geodesic distances from the other actors (in farness) within the network had less variability for all actors except for KMD. The values of actor between-ness of DVS, WHO, ILRI, MOH and CDC imply that more actors depended on them to make connections with others, placing them in a powerful position.

[7] Standard deviation, which is irrelevant as the standard deviation of a binary variable is a function of its mean.

Table 0-3: National OH actor network centrality measures.

Actor and or Acronym	*cluster coefficient*	Degree		Farness		Closeness		*Betweenness*	*n-Betweenness*
		In	*Out*	*in*	*out*	*in*	*out*		
Non-Governmental Organisations (NGOs)	0.95(10)*	15	13	42	59	44	33	0.8	*0.3*
World Organisation for Animal Health (OIE)	0.7(15)	25	32	39	48	46	38	2	0.6
AU-IBAR	0.66 (28)	29	37	38	46	47	39	6	2
University of Nairobi-Veterinary (UON-VS)	0.63(15)	25	23	34	50	53	36	7	2
National Museums of Kenya (NMK)	0.58 (6)	14	8	34	81	53	22	1.4	0.5
Food and Agriculture Organisation FAO	0.56 (55)	42	47	32	42	56	38	18	6
ICIPE	0.52 (28)	24	19	32	47	56	38	18	6
Centres of Diseases Control (CDC)	0.51 (36)	38	42	29	46	62	39	24	8
Kenya Wildlife Service (KWS)	0.47 (78)	28	36	37	41	49	44	10.5	3
International Livestock Research Institute (ILRI)	0.46 (66)	36	41	30	45	60	40	37	20
Kenya Medical Research Institute (KEMRI)	0.44 (36)	34	34	31	47	58	38	17	5
Ministries in charge of Health (MOH)	0.41(45)	42	47	30	46	60	39	27	9
University of Nairobi-Public Health (UON-PHM)	0.4 (10)	24	21	41	55	44	33	3	1
Department of Veterinary Services (DVS)	0.37(78)	53	52	27	40	67	45	61	20
World Health Organisation (WHO)	0.32 (36)	38	32	30	51	60	35	44	14
Institute of Primate Research (IPR)	0.25(10)	23	15	36	65	50	28	20	6
Kenya Agriculture Research Institute (KARI)	-	15	15	38	55	47	33	0	0
Kenya Meteorological Department (KMD)	-	4	4	342	44	5	41	0	0
Mean (# in brackets = standard deviation) (n=19)		28 (12)	28(14)	51(69)	51(9)	51(13)	37(6)	16 (17)	-5

Source: Study Computation. * Number in brackets refer to the number of pairs

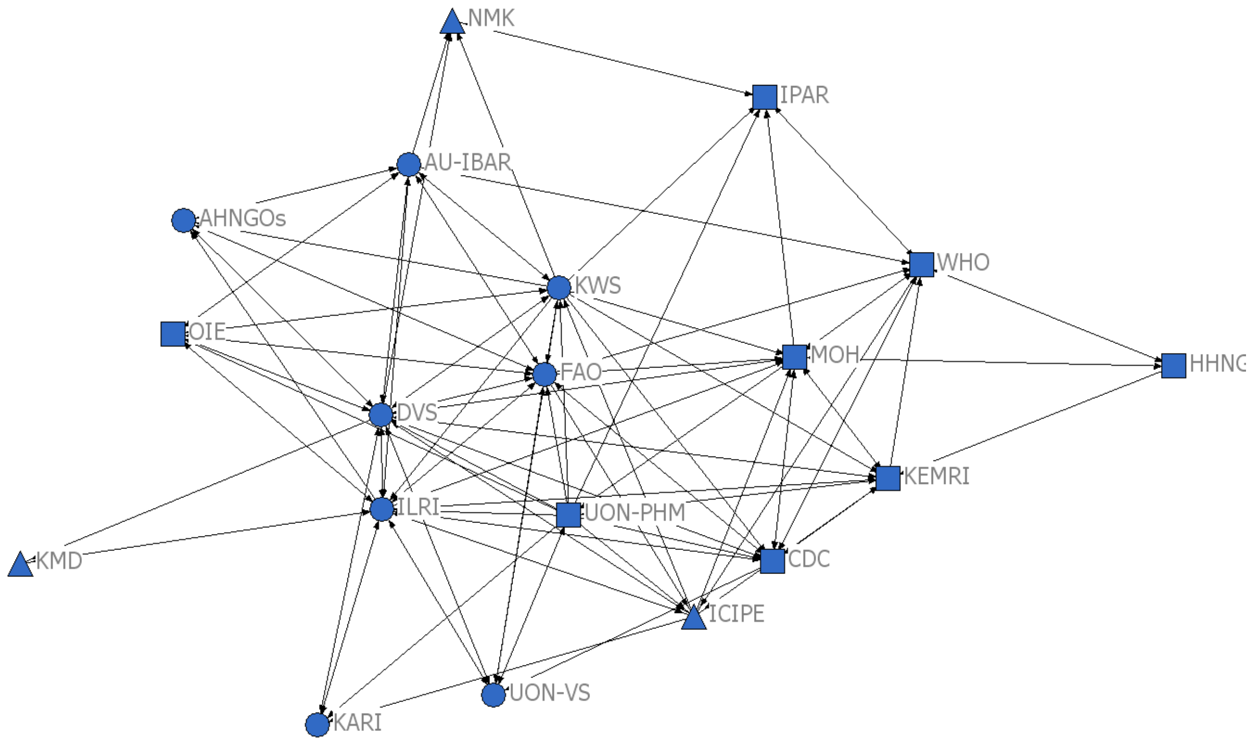


Figure 0-6: Sociogram of the national level actors.

Square (public health); circle (animal health); upward triangle (others). Arrows show stakeholders with relations. Directions of arrow reflect direction of relations.

4.5 Chapter discussions and conclusions

This study sought to better understand both the formal and informal institutional/organisational collaboration arrangements processes and the OH network properties as a basis of guiding and strengthening processes at country level. One Health was conceptualised as policy or innovation where stakeholders (who needed to cooperate to resolve a cross-sectoral problem) with diverse roles and networks were a central component. The stakeholders and their networks would be required to undertake activities towards mobilisation, alliance building, social acceptance and institutionalisation of OH.

The study applied SNA methods namely snowballing, sociograms, and statistical measurements of relationships to identify the OH stakeholders, roles, cross-sectoral relationships, and extent to which they had institutionalised OH. To focus the analysis, a specific cross-sectoral health problem, RVF, was identified. The SNA snowball method facilitated mapping of 32 and 21 public and private RVF and OH stakeholders at national and sub-national levels respectively, drawn from animal and public health sectors and climate prediction agencies. At national level, each stakeholder played a unique role but the ones critical for cross-sectoral cooperation were those with the highest betweenness and included DVS, WHO, ILRI, MOH and CDC. Identification of climate prediction agencies at national level and a cross-sectoral steering group (DSG) of ALRMP at sub-national show that cross-sectoral collaborations for zoonotic diseases may go beyond the two health sectors.

The sociogram for the sub-national stakeholders revealed a denser network among public health stakeholders which was attributed to more stakeholders and existence of within-sector multi-level coordination platforms. Network density measures showed that a significant number of relationships were missing at both levels but more so at sub-national level. While saturated networks were not expected and, considering that small world networks have better cost-benefit relations (cost of linking, information conduction and reliability), poorly linked stakeholders evidenced by high variability of degrees is a gap that needs attention.

These together with the limited efforts to institutionalise OH at sub-national level despite policy support, can be attributed to failure to establish cooperation platforms among livestock sector stakeholders, between them and the community, and with public health actors. Considering weaker response capacity of the animal health stakeholders occurred close to communities and where outbreaks occur, then, concerted OH actions to stop zoonosis at source would be challenging. The between sectors gate-keeping roles played by ALRMP, chiefs and communities illustrates the necessity to include the latter two in OH to ensure participatory actions.

Despite missing ties at national level, collaborating stakeholders led by line ministries with support from development and technical partners had mobilised for and institutionalized OH through formal structures. The mobilisation had evolved from informal to formal cross-sectoral (OH) mixed (top-down and home grown) collaborations, driven by a few zoonotic diseases, regional networks and global technical agencies. It had mostly been based on arguments and lessons learnt on cross-sectoral projects and issues. This is attributed to fact that only a few studies (Schelling *et al.,* 2005; Roth *et al.,* 2003; Worldbank, 2012) explicitly demonstrate economic, social and environmental benefits of OH. Yet, in evidence-based innovations, mobilisation to institutionalisation activities is designed to link stakeholders with scientific evidence and technologies amongst other things (Young *et al.,* 2010).

The missing ties at national level were attributed to the 'on invitation' alliance-building where nearly half (47 %) of identified stakeholders were not involved in OH cooperation. While this may reflect possibility of missed resource flows, it goes to show that the OH network can progress to institutionalisation as long as key stakeholders are looped in. However, the impacts of the missed opportunity to bring all (and their resources) on board might be evident when major disease events occur.

Applying SNA proved useful in understanding power and influence of different stakeholders. For example, ALRMP (and its DSG and HSG) emerged as a stakeholder who connected most sub-national stakeholders and whom also many stakeholders sought to influence. This implies that platforms with cross-sectoral mandate and coordination are critical in OH networks. The centrality measures findings show that such cross-sectoral mandate and coordination is critical in networks. At both levels, high ties (in and out) of the MOH and DVS can be attributed to their legal mandate to implement prevention and control of diseases, which made other stake holders want to exert their influence on them. On the other hand, high ties of CDC, WHO and FAO reflect their global mandates in OH and their networks. The OIE's weak ties can be attributed to the fact that the organisation had just established an office in the country. Five organisations, (CDC, WHO, FAO, MOH and DVS) can be said to enjoy an advantage of having alternative ways to access resources and are able to call on more resources if needed, evidenced by them rallying others around ZTWG and ZDU. The presence of regional and international community actors seem to have offered an opportunity for the national-level OH mobilisation as well as the link between local OH initiatives with global OH and regional platforms/ networks. Through support from these organisations, the country had made direct and indirect links with major global and regional networks.

While this analysis was limited to national and sub-national level, the many regional networks linked to the national and international stakeholders were identified. There may be need for a cross-network regional platform to rationalise and coordinate the networks and initiatives which are likely duplicating roles and memberships, and thus efforts.

In conclusion, the need to institutionalise OH at sub-national level is emphasised particularly in order to address the low networking between the healths sectors considered as critical drivers of OH. The critical role and contribution of communities and local leaders should be acknowledged. Including them in OH institutional set-ups would exploit their position (entry point to the community), resources, and information. Isolation of pharmacy/agro vets, FAO, and KWS from the existing local network despite their important role in opinion shaping is noteworthy. Wildlife-livestock-human interface health risks from hunting and consumption of wild meat could be overlooked. Also, the national OH can be strengthened to pull more resources. To strengthen both networks, this study recommends

(i) Shortening the OH institutionalisation process at sub-national by creating formal OH platforms that build on existing cross-sectoral coordination platforms, such as HSG, and other public health forums in order to exploit MOH's higher influence in the network; but bearing in mind that diversification of power has potential to lower the influence and cause resistance.

(ii) Increasing capacity of the sub-national animal health sector to participate in OH by supporting DVOs to network livestock clusters through community and district livestock committees, and stakeholder forums. Similar to public health sector, animal health NGOs could be encouraged to support DVOs.

(iii) Extending membership of the Zoonosis Technical Working Group (ZWTG) to incorporate remaining stakeholders and other experts such as wildlife ecologists, trade experts, zoologists, communication for development experts, sociologists and health economists.

(iv) Improving the response capacity of the animal health public sector and addressing the causes of the disincentives to report diseases by the community.

At regional level, OIE, FAO and WHO need to exploit their OH tripartite arrangements to strengthen regional OH coordination that is linked to national OH platforms that are in turn linked to sub-national networks.

Finally, we note that the data collection and analysis methodologies used had limitations. First, the strength of relationships though based on frequency and intensity of relationships were subjective and could have introduced respondent bias. Collapsing measurements of the three relationships implied that evidence on which category was stronger could not be provided. Secondly, inherent to SNA methods, creating a binary variable from the relationship strength data led to some information loss. Thirdly, the data was collected in a one off snowballing method focusing on relationships as they were. Reconstructing previous relationships would have shown how the network had evolved.

Despite these shortcomings, SNA proved useful as a tool to: map stakeholders, visualise existing networks; and generate network mathematical properties which may not have been archived through other approaches of stakeholder mapping. Information generated provides a baseline for future analysis of OH institutionalisation in the country and generation of temporal sociograms. Also, identified were benchmarks for OH institutional analysis that include: number and type of stakeholders; types of relationships and their strength; extent to which sectoral stakeholders connect to each other and to other sectors; reciprocation of links; centrality measures of power and influence; density of the network; and clustering coefficient.

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CHAPTER FIVE

BASELINE AND ALTERNATE RIFT VALLEY FEVER LIVESTOCK CONTROL STRATEGIES AND ASSOCIATED COSTS

5.1 Introduction

At national level, design and management of public animal health programs largely depend on (i) broad objectives of control (NAS, 1994) (ii) disease epidemiology and (iii) range of available options. Ideally, objective and strategies should be guided by risk analysis and costs and benefits of the available control options. Key objectives of RVF control revolve around mitigation of its impacts on livestock trade, livelihoods, national economy and public health (FAO and OIE, 2004). In RVF endemic countries such as Kenya, impact minimization is rational considering that it's impossible to prevent epidemics (FAO, 2002). This chapter presents the process used to identify the baseline and alternate integrated strategies (combination of different options) that are/could be used and the associated costs.

5.2 Literature review

This review highlights the epidemiology of RVF as well as available control options.

5.2.1 The Epidemiology of Rift Valley Fever

Epidemiology of RVF links environmental factors, mosquitoes, animals and people (Figure 0-1). Epidemics are reliant on presence of susceptible animals (sheep, goats, cattle and camels) and people; virus presence; and occurrence of above normal rainfall with prolonged flooding of habitats suitable for production of immature *Aedes* and *Culex* mosquitoes (Linthicum *et al.*, 1991 and 1999; Davies *et al.*, 1985; Swanepoel and Coetzer, 2004). More than 40 species of mosquitoes and biting flies are involved (Meegan and Bailey, 1988; Fontenille *et al.*, 1998; McIntosh *et al.*, 1980). Female Aedes mosquito transmits RVF virus (RVFV) vertically to their eggs (Linthicum *et al.*, 1985).

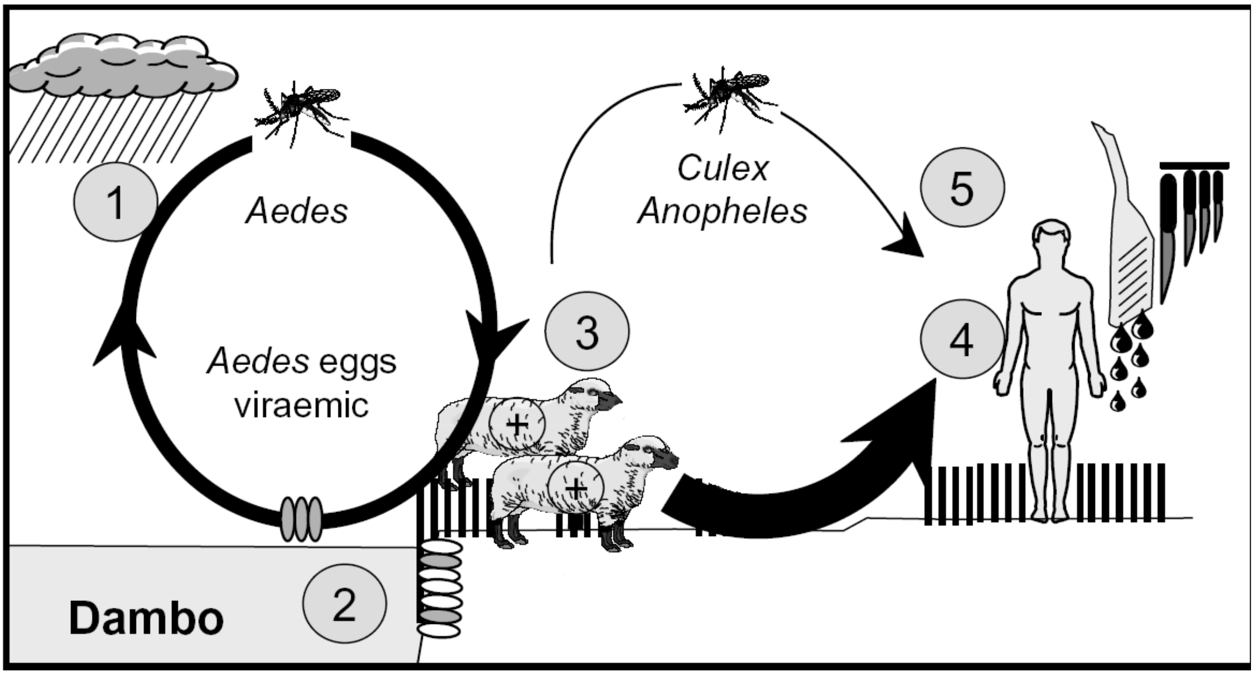


Figure 0-1: Transmission of Rift Valley Fever Virus
Source: WHO, 2009

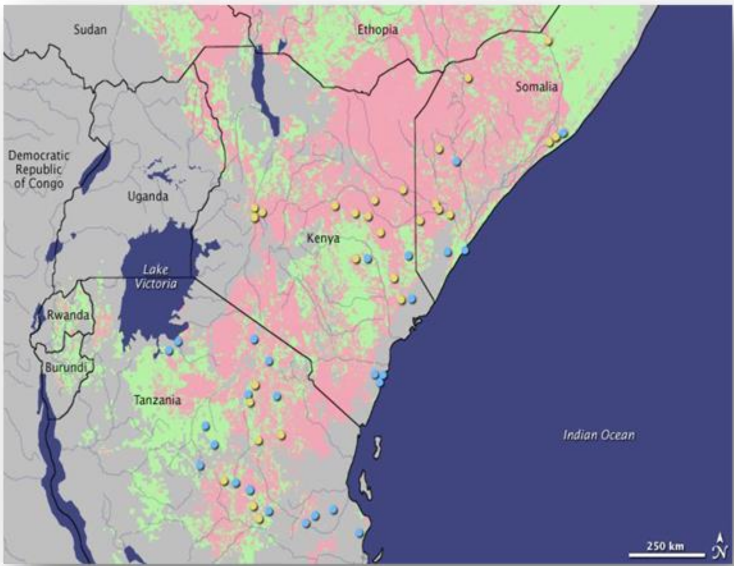
When infected females lay eggs in flooded areas, transovarially infected adults emerge and transmit RVFV to nearby livestock (Davies and Highton 1980; Linthicum, *et al.,* 1985). High viraemic animals may also infect secondary anthropod vector species (Culex mosquitoes) that in turn transmit to other animals (Davies *et al.,* 1985; Davies, 1975; Miller *et al.,* 1989). Transmission to people occurs through direct contact with infected animals or animal materials, although bites by infected mosquitoes have been mentioned (Laughlin *et al.,* 1979; Velden *et al.,* 1977). Extension of RVF through movement of infected animals has been blamed for outbreaks in Egypt (Abd el-Rahim *et al.,* 1999) and in the Arabian Peninsula (Miller *et al.,* 2002).

5.2.2 Animal RVF prevention and control options

Reducing or stopping RVF transmission requires control measures that seek to reduce (i) mosquito population (targeting larva and adults); (ii) population of susceptible animals and people through vaccination/immunisation (iii) contact between infected mosquitoes and animals/people and, (iv) contact between infected animals/animal products and people. The animal RVF control measures include: surveillance and diagnostic mechanisms for early detection; vaccination/immunization of susceptible species; vector/reservoir control;

treatment of cases; movement restrictions and sanitary bans as well as behavioural change communication.

Reporting of RVF outbreaks to OIE and WHO is mandatory (WHO, 2008; OIE, 2011[8]). This makes surveillance a critical RVF control option. Three types of surveillance are identifiable: surveillance for climatic factors, entomological (mosquitoes), and human/animal cases. An international climate RVF link early warning system system for outbreaks takes advantage of the association of RVF, climate and vectors (Anyamba *et al.*, 2002). The system successfully predicted the 2006/2007 RVF outbreak in Eastern Africa three (3) months before confirmation of human disease (Anyamba *et al.*, 2009). The system provides a near real-time RVF risk map on monthly basis (Figure 0-2). Regular monthly bulletins of relative RVF risk were posted on the Global Emerging Infections Surveillance and Response System (GEIS) website and further disseminated by FAO, OIE and WHO.



A risk-assessment map shows the areas of increased risk of Rift Valley Fever (RVF) in eastern Africa from fall 2006 to spring 2007. Pink areas depict increased risk of disease, while pale green areas reflect normal risk. Yellow dots represent reported RVF cases in high-risk areas, while blue dots represent occurrences in non-risk areas.
Credit: Assaf Anyamba and the NASA Earth Observatory

Figure 0-2: An RVF map of East Africa.
Source: http://www.nasa.gov/topics/earth/features/riftvalley_fever.html accessed on 18th July 2012.

Entomological surveillance (vector identification, density mapping and detection of RVFV in vectors) support implementation of mosquito control programs/insecticide

[8] OIE, Animal Health Code Volume 1 of 2011 Article 1.1.3,

treatments (Sang *et al.*, 2010; Anyamba *et al.*, 2010; ILRI and FAO 2009; FAO, 2002, 2003). Animal RVF surveillance can be passive or active (sentinel herds; participatory disease search; outbreak investigations; and, epidemiological surveys) (Munyua *et al.,* 2010). The value of surveillance lies in the measure's ability to facilitate/support outbreak containment measures. The surveillance programmes should be supported by well-functioning laboratories with capacity to undertake OIE and WHO recommended RVF diagnostic approved tests (OIE, 2011).

Mosquito control programs include: treatment of animals, non-animal targets, and mosquito breeding sites with insecticides and draining of standing water. Applied to cattle, deltamethrin[9] formulations knock down 59% to 86% insects for a period of 5 to 24 days in hot months and 24–55 days in cooler seasons (Vale *et al.,* 1999). Larvicidal treatment of breeding sites is recommended following early warning for RVF to kill immature mosquitoes/larvae and/or pupae.

Since the 1950s animal RVF vaccines have been used in Africa (Swanepoel and Coetzer, 2004). Two vaccine categories include modified live attenuated[10] (Smithburn, Clone 13, and MP12 strains) and formalin inactivated[11] (M/S/258 and ZH-501) viruses. A third category, under evaluation is based on live viral vectors such as poxviruses (Soi *et al.,* 2010; FAO, 2011).

The Smithburn vaccine (SMLVV), widely used in Africa and Middle East (Swanepoel and Coetzer, 2004), has a shelf life of 4 years and a single inoculation confers good/protective immunological response in 5-7 days (Barnard, 1979) that lasts lifelong (Abd el-Razek, *et, al.,* 2011). However, it's associated with pathogenic side effects such as abortions and still births in pregnant animals, and defects in offspring (Botros *et al.,* 2006; Coetzer and Barnard, 1977; Hunter *et al.,* 2001). Clone 13 used in South Africa is considered to have a better safety profile, is cost-effective and efficacious (Dungu *et al.,* 2010; Hunter and Bouloy, 2001). The RVF MP12, a mutagenized strain (ZH548) is safer than Smithburn (Morrill *et al.,* (1991). The formalin inactivated RVF vaccines have a better safety profile, confer colostrum immunity but have poor immunogenic properties and therefore requires

[9]Decatix, SpotOn and an experimental variant of SpotOn), alphacypermethrin (Renegade) and cyfluthrin (Cylence)

[10] An attenuated vaccine is a vaccine created by reducing the virulence of a pathogen, but still keeping it viable (or "live")

[11] An inactivated vaccine (or killed vaccine) consists of virus particles which are grown in culture and then killed using a method such as heat or formaldehyde.

booster doses (three to six months after) and annual re-vaccinations limiting its use (Coetzer, 1982; Barnard, 1979; Lubroth *et al.*, 2007). All the vaccines have one disadvantage, inability to differentiate infected from vaccinated animals (DIVA).

Sanitary and biosecurity measures recommended by OIE[12] and WHO include: control of animal movements (to prevent extension of disease); slaughterhouses controls (to minimize human exposure); and, non-consumption of fresh blood and raw milk or animal tissue. Effective communication is a critical tool in influencing acceptance of and compliance with sanitary measures.

5.3 Methodology

5.3.1 Delineation of animal RVF control options and integrated strategies

Baseline and alternate integrated control strategies combined from different levels of animal vaccinations, surveillance and early warning, and vector control were identified/defined and through a stepwise process.

(i) Review of national contingency (ROK, 2010) and RVF decision making tool (ILRI and FAO, 2009). The review focused on options recommended, adopted or specified.

(ii) Definition of baseline practice through collection of primary data on surveillance, vaccinations, vector control options (and their combinations) applied during four specific periods; inter-epidemic period 1998-2006; post 2006/2007 RVF epidemic prediction; epidemic and post epidemic (2007 to 2011) . Data was collected alongside stakeholder and institutional analysis using a checklist

12 http://www.oie.int/fileadmin/Home/eng/Animal_Health_in_the_World/docs/pdf/RIFT_VALLEY_FEVER_FINAL.pdf

(iii) : section two. Data on associated costs was also collected.

(iv) Two round table technical discussions with 46 key multi-disciplinary and multisectoral RVF subject matter experts. The discussions focused on laying out feasible options of up to three alternate levels of improved control options (compared to baseline) under prevailing circumstances. The options were combined to generate different alternative integrated strategies. The experts were asked to comment on perceived efficacy and extent to which each option can be realistically applied putting into consideration public sector and livestock keepers' response capacity and farming systems. This was critical in developing assumptions for impacts of measures on RVF epidemics in simulation modelling.

In defining scope or coverage levels of alternative options, five issues were considered.

(i) In Kenya, RVF is endemic and high impacts-epidemics occur irregularly; the inter-epidemic period has been 3.6 - 10 years (Murithi *et al.*,(2010). This was viewed as a possible setback for implementation of sustained heavy cost control actions in a resource constrained economy. Base practice was seen as an indicator of the relative importance of RVF to decision makers and therefore the study considered only realistic incremental improvements.

(ii) As evidenced by actor behaviour during the 2006/2007 epidemic, different stakeholders react differently to outbreaks and control actions, perceive and accept different levels of risk. During the last outbreak, traders sought legal redress in order to have market bans lifted. On the other hand, consumers shunned livestock products due to health concerns. Options to minimize consumer and supply shocks were considered in the formulation of alternative options.

(iii) Key RVF hot spots located in pastoral and agro pastoral systems are economically marginalized, have limited access to basic health (public and animal health) services while livestock keepers' capacity to play effective roles in control was low. Measures to increase community participation were considered critical.

(iv) Complexity of RVF epidemiology ~ multiple species (human, wildlife and livestock), multiple vectors (primary and secondary), ecological issues, information gaps and inadequate diagnosis and control tools, was assumed to complicate success of control measures. Realistic impacts of the measures were adopted.

(v) A comparatively weaker animal health services compared to medical services implied that it's difficult to stop RVF outbreaks at animal level. However due to modelling challenges, control measures to control human epidemics were not considered.

5.3.2 Identification and estimation of control costs

Key cost elements*:* the costing process involved: estimation of number of animals that received measures; delineation of key cost elements, units required and unit costs.
Figure 0-3 illustrates categories of full cost of animal RVF control considered. The categories were further grouped into: (i) **Fixed expenditure** on equipment (vehicles, motorcycles, fridges, cool boxes, computers, communication gadgets, sprayers, centrifuges, automatic syringes)

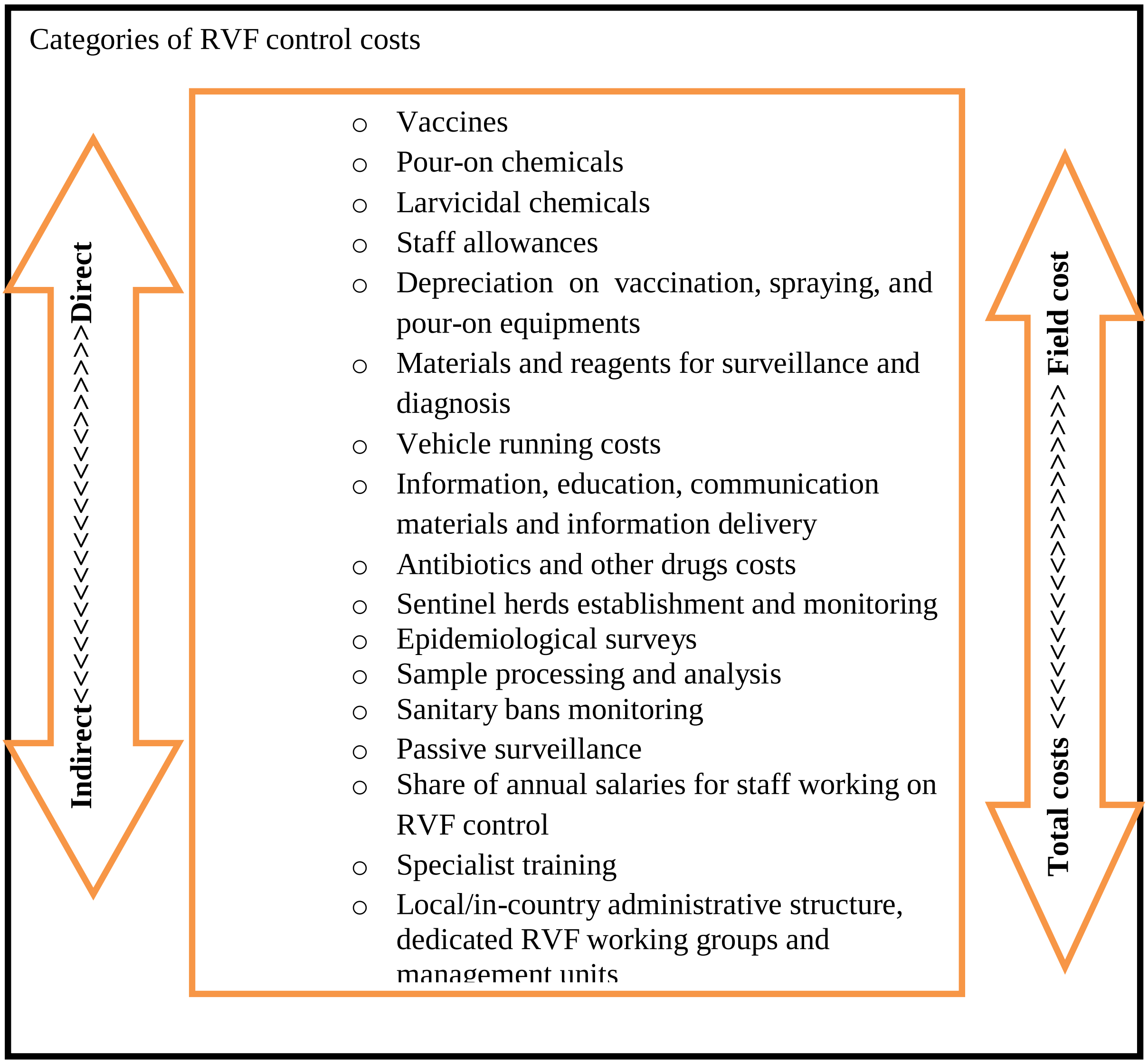


Figure 0-3: Categories of RVF prevention and control costs

(ii) **Recurrent expenditures** on: procurement of drugs (antibiotics, dewormers and multivitamins); insecticides; vaccines; ear tags; field and sampling equipment (syringes, needles, sample bottles); laboratory materials and reagents; communication for behaviour change and compliance (workshops, print and electronic media); fuel and vehicle maintenance; electricity, stationery; communication costs (airtime and internet); and staff allowances.

Estimation of costs: The costs were estimated using Microsoft Excel as a product of units of materials, reagents, equipment and personnel required and unit costs. Fixed expenditure on equipment was estimated as a product of units used, annual depreciation costs and number of days the equipment was used. Fixed expenditures on personnel were estimated as a product of number of staff involved in planning and executing RVF control, their annual salary and proportion of time spent on control activities. The recurrent expenditures were estimated as a product of units and unit price.

5.4 Results and Discussions

5.4.1 Measures implemented prior to and during the 2006/2007 epidemic (1998-2012

Prior to the prediction of 2006/2007 epidemic, no RVF control activities had been implemented, except preparation of an information brochure by DVS. Following prediction, non state actors conducted animal sentinel surveillance in North Eastern Kenya. The outbreak caught the health sectors unprepared. Outbreak containment by the Health sectors was delayed by one (public health) to two (animal health) months (ILRI, 2008). Despite the delays, a mix of measures summarised in Table 0-1: were applied; they largely agree with the recommended outbreak containment measures except (i) use of Smithburn vaccine strain (which is not recommended during epidemics) and (ii) they were applied at lower than recommended intensities. Based on secondary data, only 50% of households in Baringo, Nairobi, Nakuru, Maragwa and Thika districts reported veterinary assistance to contain the outbreak (ROK, 2009). Column 4 of **Table 0-1** shows the proportion of households who received assistance on specific measures.

A total of 2.6 million animals were vaccinated with Smithburn strain in 36 districts (27 infected; 9 uninfected). Of the 2.6 million, 50%, 19%, 29%, 0.5% and 1% were cattle, sheep, goats, camels and donkeys respectively. About 61% of the vaccine doses were supplied from external sources through donors while the rest was sourced locally from Kenya Veterinary Vaccines Production Institute (KEVEVAPI).

The surveillance activities implemented during the epidemic period included (i) outbreak investigations targeted (risk- based) surveys by 11 government teams in 41 districts (Munyua *et al.,* 2010. (ii) A wildlife (eland, buffalos, warthogs, giraffes, gerenuks and waterbucks) RVF serological survey by KWS in 6 districts. (iii) Vector surveillance and entomological studies undertaken by KEMRI, US Army Medical Research Unit Kenya, CDC, and other partners (Sang *et al.,* 2010).

Table 0-1: RVF control measures implemented during 2006/2007 outbreak by animal and public health sectors.

Activity	Animal health			Human health	
	Private	Public	% of households who received	Private	Public
Communication and education		X	12		X
Vector surveillance and entomological studies					X
Mosquito control – ground spraying				X	X
Animal treatments with insecticides	X	X			
Management of sick people				X	X
Management of sick animals	X	X	15		
Vaccination of animals (Smithburn strain)		X	13.5		
Animal RVF surveillance	X	X	22.5		
Human RVF surveillance				X	X
Diagnosis		X		X	X
Movement restrictions for animal and animal products		X			
Slaughter bans/closing slaughter houses		X			X
Raw milk marketing bans					X
Coordination and compliance monitoring		X			X
Deworming treatments and vaccination for other diseases		X	7.5		
Capacity building for technical staff		X			X
Laboratory capacity building		X			X
Planning and coordination		X			X

Source: compiled from key informant data, ILRI (2008); ROK (2009); the American journal of tropical medicine and hygiene vol 83 August 2010 supplement number 2, Workshops and line ministry reports. X/shaded boxes (denotes the respective sector that implemented the measure).

A total of 1,326,877 animals were treated with 5,720 litres of synthetic pyrethroids. Each animal received a single treatment applied alongside vaccinations. Sanitary bans implemented included: ban on live animal movement, livestock markets and slaughter (home and commercial). Sale of raw milk and or milking of animals was banned in some infected areas. District Veterinary Officers in 19 districts reported an average of 25 compliance monitoring trips during the epidemic. Main communication activities focused on sensitization of: technical staff and members of the public through workshops, electronic and print media. At total 7,160 veterinary technical staff, 4.3 million members of the public were reached. Key informants described some communication and messages as initially uncoordinated and conflicting. A multisectoral Rift Valley fever technical working group supported by two sectoral committees (Department of Veterinary Services (DVS) RVF management committee and a Ministry of Health (MOH) RVF coordination committee) coordinated the outbreak management.

Both the delays and inadequacy of measures implemented was attributed to lack of no RVF contingency plans, resource constraints, and inaccessibility of livestock keeping areas (pastoral, agro-pastoral and marginal areas) excessive flooding. After the outbreak ended**,** DVS developed a contingency plan (ROK, 2010) in order to improve response to future outbreaks. The financial resources required to implement the contingency plan (CP) has been estimated at KES 16 Billion (177.9 million US$), which is far beyond the KES 1.7 billion annual (financial year 2009/2010) total budgetary allocation for the DVS. Consequently, only limited animal RVF health activities recommended in the contingency plan (CP) were implemented. At the time of this study most RVF prevention activities were funded by development partners. In addition, clone 13 vaccine trials in cattle, sheep and goats were undertaken.

5.4.2 Post –epidemic baseline practice (2007-2011) and alternate strategies (2012-2014)

Identification of alternative strategies sought to replicate realities of RVF prevention, improved surveillance and vaccination options were assumed to be implemented for the inter-epidemic period (2012 to November 2014). Improved vector control activities would be implemented during the post prediction and the epidemic period. Sanitary measures and information, communication and education actions implemented during the 2006/2007 are assumed for the 2014/2015 hypothetical outbreak. Integrated strategies combine different levels of vaccination, surveillance and vector control.

5.4.2.1 Vaccination options

Baseline practice: Based on data it was defined as an annual vaccination of an average of 7% of the total small ruminant population in RVF high areas. During the post epidemic period 2008-2011, a total of 2.3 million sheep and goats had been vaccinated. No cattle or camels were vaccinated. Key informant attributed the low coverage to a combination of high costs of vaccination, the Smithburn safety profile, irregularity of outbreaks and inadequate national vaccination policies.

Alternate vaccination option 1: One annual mass vaccination with Smithburn targeting all ages of cattle, sheep, goats and camels in 2012, and continued in young animals for next two years (2013 and 2014). Achievable annual vaccination levels: 35% in PAP; 70% in MFM and MFHP. In PAP and MFM, the coverage levels were assumed to be achieved with complementary activities of (i) communication (ii) provision of *"goodies"* (treatments for active cases of disease and deworming of animals) (iii) ear tagging to reduce probability of being revaccinated.

Alternate vaccination option 2: A two year mass vaccination in 2012 and 2013 targeting all ages of cattle, sheep, goats and camels at similar levels as option 1.

5.4.2.2 Animal and vector surveillance options

Baseline practice: the baseline practice comprised of (i) passive surveillance - compulsory monthly reporting (zero-reports are made in case of no suspects) by field staff. (ii) sentinel surveillance (9 herds in high risk areas monitored three to four times) (iii) one annual active disease search/survey following heavy rains (iv) limited vector surveillance; (v) monitoring climate weather alerts for *El Niño/*unusually high rainfall and/or RVF outbreak alerts

Alternate enhanced animal and vector surveillance option: Comprised of (i) Sentinel surveillance (9 herds) monitored 4 times a year, (ii) inclusion of vector surveillance activities alongside wet season sentinel monitoring and epidemiological surveys. (iii) A community based surveillance system (a disease control committee with a focal person linked to District Veterinary Office (DVO) and existing health facility public health committees to increase community participation in disease reporting). The impact of the enhanced animal and vector surveillance option was assumed to be a 50% reduction of the time lag between incursion of outbreaks and implementation of sanitary bans; from 6 weeks observed during 2006/2007 to 3 weeks.

5.4.2.3 Vector control options

Alternate Vector control option 1: Described as three animal treatments with pour-on insecticides (during outbreaks) at an interval of 2 weeks, targeting only unvaccinated animals (untagged). First application would be funded by public sector and the other two by individual farmers. About 50%, 30% and 10% of the targeted animals would be treated in MFHP, MFM and PAP respectively.

Alternate Vector control option 2: Use of larvicides (insect growth regulators), applied in mapped dambos before flooding. The dambos surface area was assumed to be 2 million $m^{2,}$ but due to logistical difficulties only 5,000 m^2 (0.25% of the total area) would be treated with larvicides applied weekly for 2 months at rate of 5g per m^2.

5.4.2.4 Sanitary and movement restrictions

Sanitary bans in infected districts would include: live animal movement restriction from infected areas, bans on slaughter and raw milk marketing.

5.4.2.5 Information communication and education (IEC)

Enhanced IEC actions were assumed to include: establishment of a cross-sectoral communication subcommittee to coordinate multisectoral messages. Activities of the committee would be sensitization meeting/workshops in each high risk district; radio spots in vernacular radio stations; production and distribution of 2000 brochures and 1000 posters.

5.4.2.6 Coordination and planning

Multisectoral coordination of the management of future outbreaks would through the multisectoral zoonosis technical working group (ZTWG) and the zoonosis disease unit (ZDU)

5.4.2.7 Eleven integrated RVF control strategies (10 alternate and 1 baseline practice)

The different baseline and alternate options of: surveillance (baseline and enhanced); vaccinations (baseline, option 1, and option 2); and, mosquito control options (pour-on and larvicidal) were combined to generate 11 different strategies summarized in **Table 0-2**.

Table 0-2: Summary of eleven prevention and control strategies

Strategy	**Inter-epidemic vaccination option** 0 = Baseline 1= option 1 2= option 2	**Surveillance option** 0= Baseline 1= Intensified Surveillance	**Larvicide treatment of mosquito breeding sites After an early warning.** 1=with treatment 0= without treatment	**private-public sector pour on animal treatments** 1= with treatment 0 = without
Strategy (S1)	0	0	0	0
Strategy (S2)	1	1	1	1
Strategy (S3)	2	1	1	1
Strategy (S4)	0	1	0	1
Strategy (S5)	1	1	0	1
Strategy (S6)	2	1	0	1
Strategy (S7)	1	1	0	0
Strategy (S8)	2	0	0	0
Strategy (S9)	0	0	0	1
Strategy (S10)	0	1	1	1
Strategy (S11)	0	1	0	0

5.4.3 Estimated number of animals targeted and reached with each option and associated costs

Table 0-1 and Table 0-2 present the population targeted by the strategies. The actual number of animals vaccinated or treated with insecticides in each farming system was generated from herd dynamics and RVF simulation model[13] based on the assumed levels of reach for each strategy. The herd dynamics and RVF simulation model produced, for each vaccination option (baseline (0), 1 and 2) and livestock systems, the proportions of cattle, sheep, goats and camels vaccinated annually during the period 2007 to 2014 (Table 0-3). In an Excel framework[14], the proportions were applied to simulated annual populations to generate numbers of animals that would be vaccinated (Table 0-4). Estimates show that about 2.5 million animals vaccinated nationally in 2007, 1.3 million animals were in RVF high risk areas. In subsequent years about 4-8% (0.76 to 1.4 million) of sheep and goats in high risk areas were assumed to be vaccinated annually for the period 2008 to 2014. The model estimates agree largely with the key informant data reported in section 5.3.2. A total of 8.5 million would be vaccinated through base practice for the 10 year period.

Changing from baseline practice to vaccination option 1 during 2012 to 2014 would result in a 460%, 67% and 78% increase in the number of animals vaccinated in 2012, 2013 and 2014 respectively. On the other hand, changing to vaccination option 2 would be result in a 512% and 368% increase in the number of animals vaccinated in 2012 and 2013. During the three years prior to epidemic, a total of: 3.3; 12, 9; 15, 4 million animals would be vaccinated under baseline practice, option1 and option 2 options respectively

[13] Mentioned in methodology chapter and described in detail in chapter six

[14] Mentioned in methodology chapter and described in detail in next chapter

Table 0-3: Proportion of total population for each species and livestock system vaccinated during the period 2007 to 2014- Baseline option and in vaccinations options 1 and 2

Vaccination option	Year	PAP				MFM			MFHP		
		Cattle	Sheep	Goats	Camels	Cattle	Sheep	Goats	Cattle	Sheep	Goats
Baseline practice	2007	11	4.8	5.9	1.2	14.1	7.8	7.9	12.8	8.6	7.8
	2008	0	4.4	6.3	0	0	4.9	6.5	0	7.3	3.8
	2009	0	6.7	7.6	0	0	7.7	8	0	8.7	6.4
	2010	0	7	7.5	0	0	8.4	8.2	0	8.6	7
	2011	0	6.7	7	0	0	7	7.2	0	7.6	6.6
	2012	0	7.2	7.2	0	0	7.6	7.4	0	7.7	7.2
	2013	0	7.4	7.6	0	0	7.4	7.5	0	7.6	7.3
	2014	0	8.3	8.3	0	0	9.5	8.6	0	9.2	8.6
Vacc 1	2012	37.3	35.7	34.6	43.1	69.3	65.9	60.9	65.6	62.7	57.3
	2013	8.4	11.1	9.8	7.8	15.4	19.5	16.6	13.1	15.5	12.4
	2014	7.3	8.1	7.4	8.4	16.2	20	15.9	13.2	15.1	11.9
Vacc 2	2012	44.5	42.2	41	51.2	69.1	65.7	61.1	65.6	62.7	57.5
	2013	27.4	32.9	30.5	30.3	31.9	41.6	39.8	31.2	42	35.8
	2014	0	0	0	0	0	0	0	0	0	0

Source: Estimated from simulation model outputs

Table 0-4: Estimated number of animals (thousands) that was or would be vaccinated annually under each option in each system

Species/ System	Vaccination strategy/year												
	Baseline								option 1			option 2	
	2007	2008	2009	2010	2011	2012	2013	2014	2012	2013	2014	2012	2013
PAP													
Cattle	303	0	0	0	0	0	0	0	824	206	195	984	670
Sheep	171	179	316	243	178	171	209	286	847	315	279	1,001	931
Goats	273	348	510	470	400	394	494	622	1,882	636	555	2,229	1,989
Camels	9	0	0	0	0	0	0	0	391	81	96	464	315
MFM													
Cattle	138	0	0	0	0	0	0	0	662	169	205	660	351
Sheep	41	29	53	52	40	41	48	73	356	127	154	355	271
Goats	106	93	133	129	110	110	137	195	908	306	361	910	733
MFHP													
Cattle	163	0	0	0	0	0	0	0	991	222	252	991	529
Sheep	88	87	109	102	85	86	100	150	700	203	247	700	549
Goats	42	23	47	52	47	54	69	100	431	116	138	432	334
ALL													
Cattle	604	0	0	0	0	0	0	0	2,477	598	652	2,635	1,550
Sheep	300	294	477	398	303	298	357	509	1,903	645	680	2,056	1,751
Goats	420	464	690	651	557	558	700	917	3,220	1,059	1,054	3,571	3,057
Camels	9	0	0	0	0	0	0	0	391	81	96	464	315
Total	**1,333**	**758**	**1,168**	**1,049**	**859**	**856**	**1,056**	**1,426**	**7,992**	**2,382**	**2,483**	**8,726**	**6,673**

Source: Estimated from simulation model outputs

Depending on the year, annual costs of implementing baseline vaccination option range from KES 24.3 to 42.5 million; with a 10 year annual average of KES 30.3 million (Table 0-5). Changing to option 1 or 2 in year 2012 would require heavy investment, a 3 year annual average of KES 160.7 million and KES 254.1 million, (Table 0-6); an increase of 438% and 466% respectively. Recurrent expenditure accounted for 52% of the expenses for the base practice; of which 40% (or 21% of total costs) were for procurement of vaccines. When vaccination option1 and 2 are assumed, recurrent expenditure increased significantly to 70% to 72% mainly attributed to costs of ear tags and deworming/treatment goodies. The ear tags and dewormers/treatment accounted for 39% and 43% of recurrent costs in option 1 and 2 respectively while vaccines accounted for 23% and 25%. Staff salaries accounted for 95% of the fixed costs. The average unit cost of vaccine and delivery was estimated to be KES 28, 33 and 37.5 for baseline, option 1 and 2 respectively.

Table 0-5: Estimated annual costs (KES, hundred thousands) of baseline vaccination strategy

SUMMARY OF COSTS	2007	2008	2009	2010	2011	2012	2013	2014	8 year Total
Recurrent costs									
Procurement of vaccines	80.0	45.5	70.1	62.9	51.6	51.4	63.4	85.6	510.3
Staff allowance vaccine delivery	86.9	34.1	48.4	44.3	37.6	37.5	44.5	57.5	390.8
Electricity, communication, needles	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	33.9
Fuel and vehicle maintenance costs	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	278.6
Stationery	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	49.3
Total recurrent costs	212.2	124.8	163.7	152.4	134.4	134.1	153.1	188.3	1,263.0
Fixed costs									
Cold storage, cold chain	0.9	0.7	0.7	0.7	0.7	0.7	0.7	0.8	6.0
Transportation	8.6	3.6	5.0	4.6	4.0	4.0	4.6	5.8	40.2
Computers	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	6.8
Vaccination equipment	0.9	0.3	0.5	0.4	0.4	0.4	0.4	0.6	3.9
Lab diagnosis -PCR	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1.3
Staff salaries	202.2	112.4	136.8	129.7	118.4	118.2	130.1	152.1	1,100.1
Total fixed costs	**213.6**	**118.1**	**144.0**	**136.5**	**124.5**	**124.3**	**137.0**	**160.4**	**1,158.3**
Total vaccinations costs	**425.8**	**242.9**	**307.7**	**288.9**	**258.9**	**258.4**	**290.1**	**348.6**	**2,421.3**
Unit cost of vaccination (KES)	32	32	26	28	30	30	27	24	

Source: Computed by the study

Table 0-6: Estimated annual costs (KES hundred thousands) of vaccination option 1 and 2.

SUMMARY OF COSTS	Option 1				Option 2		
	2012	2013	2014	Total	2012	2013	Total
Recurrent costs							
Procurement of vaccines	479.5	142.9	149.0	771.4	523.6	400.4	923.9
Costs of ear tags and dewormers	813.9	242.8	252.9	1,309.5	889.1	680.5	1,569.6
Staff allowance vaccine delivery	458.4	130.8	138.8	727.9	500.0	355.6	855.6
Electricity, communication, needles	7.0	7.0	7.0	21.0	8.7	8.7	17.4
Fuel and vehicle maintenance costs	181.4	181.4	181.4	544.3	150.1	150.1	300.1
Stationery	6.2	6.2	6.2	18.5	6.2	6.2	12.3
Total recurrent costs	1,946.3	711.1	735.2	3,392.7	2,077.6	1,601.3	3,679.0
Fixed costs							
Cold storage, cold chain	69.4	23.2	24.3	116.9	2.1	1.7	3.7
Transportation	61.7	19.4	20.4	101.4	67.1	48.4	115.5
Computers	1.3	1.3	1.3	3.8	1.3	1.3	2.6
Vaccination equipment	4.0	1.1	1.2	6.2	4.3	3.1	7.4
Lab diagnosis -PCR	0.2	0.2	0.2	0.7	0.2	0.2	0.5
Staff salaries	675.6	258.0	268.2	1,201.8	728.7	544.6	1,273.2
Total fixed costs	**812.1**	**303.2**	**315.6**	**1,431.0**	**803.7**	**599.2**	**1,402.9**
Total vaccinations costs	**2,758.5**	**1,014.4**	**1,050.9**	**4,823.7**	**2,881.3**	**2,200.5**	**5,081.8**
Unit cost of vaccination (KES)	35	43	42	38	33	33	33

Source: Study Computation

5.4.3.1 Estimated number of animals treated by pour-on insecticides and costs

During the assumed 2014/2015 epidemic only unvaccinated animals would be treated. Table 0-7 presents the proportions that would be untreated under each vaccination option. More animals (about 5 million compared to 4 million) would be treated in strategies that assumed baseline vaccination.

Table 0-7: Proportions and estimated number of animals treated with pour-on insecticides during the assumed 2014/2015 epidemic in each farming systems

System	*Species*	With baseline vaccination options				With enhanced vaccination option			
		% treated			**# treated**	**% treated**			**# treated**
		1	**2**	**3**		**1**	**2**	**3**	
PAP	cattle	0.05	0.04	0.03	293,886	0.06	0.04	0.03	232,231
	sheep	0.03	0.03	0.03	374,964	0.04	0.04	0.04	273,356
	goats	0.03	0.03	0.03	1,237,866	0.05	0.06	0.06	601,568
	camel	0.02	0.01	0.01	109,775	0.03	0.03	0.03	57,258
MFM	cattle	0.35	0.27	0.21	1,040,523	0.44	0.32	0.24	865,387
	sheep	0.05	0.05	0.05	178,812	0.07	0.07	0.07	120,682
	goats	0.004	0.004	0.004	61,048	0.009	0.01	0.01	23,178
MFHP	cattle	0.31	0.29	0.27	1,460,627	0.31	0.26	0.22	1,597,253
	sheep	0.02	0.02	0.01	192,353	0.05	0.05	0.04	67,689
	goats	0.003	0.002	0.002	46,868	0.013	0.013	0.013	8,436.00
Total					**4,996,722**				**3,847,038**

1= First treatment, 2= second treatment, 3= third treatment

Source: Estimated from simulation model outputs

The estimated costs of pour on and other insecticide treatments during the 2006/2007 were estimated as KES 42 million of which 84% (65% insecticide and 19% allowances) were recurrent costs. Estimates for the three insecticide treatments during a next assumed outbreak would be KES 307 Million and KES 266.4 million when implemented alongside baseline and enhanced vaccination strategies respectively. Of the total, recurrent expenditures accounted for 97% (insecticide 93.5% and 3.5% allowances). The difference between 2006/2007 and 2014/2015 costs is that two of the latter's treatments were assumed to be applied by the farmers themselves, which reduced the costs of staff time and equipment such as vehicles. The public sector was assumed to meet the costs of the first treatment.

5.4.3.2 Estimated costs of larvicidal treatments

Larvicidal costs were estimated at KES 10, 6 million; recurrent costs were highest at 53.6% (44% larvicidal chemicals; 9.6% allowances). Of the 46.4% that were fixed costs, 36% were staff salaries while the rest were equipment depreciation costs. However, the costs must be interpreted with consideration that a heavy investment of KES of 53.8 million to purchase vehicles, tractors and other spraying equipment must first be made. This cost estimation only considered depreciation costs during the 2 months they would be used for RVF control.

5.4.3.3 Estimated costs of surveillance options

Estimated surveillance (including laboratory diagnosis) costs are summarized in Table 0-8. Fixed costs represented the highest proportion at 75% - 86% (10 year baseline) and 82% (in 3 year enhanced options). Of the fixed costs, 92% to 97% were attributed to personnel costs. This is because surveillance is a public good undertaken by all public veterinary staff.

5.4.3.4 Estimated of information, communication and education

The estimated costs of 2006/2007 RVF epidemic IEC costs were estimated as KES 19 million (61% recurrent and 39% fixed). The 2014/2015 enhanced outbreak information, communication and education costs were estimated to rise by 217% to KES 60.7 million. The increase was associated with staff costs that accounted for 64% (of the increased amount). The communication activities implemented to support vaccination and surveillance during the peace time were included in the respective option costs.

Table 0-8: Estimated costs (KES) of animal RVF surveillance options during epidemics

	2006/2007RVF outbreak period	*Annual baseline strategy 2007-2014*	*Annual Enhanced strategy (2012 to 2014)*
Fixed costs			
Subtotal: Fixed personnel costs	**49,986,783**	**73,010,206**	**82,691,594**
Passive surveillance	41,259,546	68,547,229	68,547,229
Active surveillance	6,690,431	1,613,905	11,295,292
Coordination and data analysis by VEEU	621,691	1,036,152	1,036,151
Laboratory diagnosis in CVL	596,709	994,514	994,514
Active vector surveillance	818,407	818,407	818,406.
Subtotal: Equipment depreciation	**1,367,674**	**6,048,785**	**6,048,784**
Passive surveillance	1,134,761	5,706,022	5,706,022
Active surveillance	109,850	219,700	219,700
Data management unit	123,063	123,063	123,063
Total fixed costs	**51,354,457**	**79,058,991**	**88,740,379**
Recurrent expenditure			
Subtotal: staff allowances	**3,060,000**	**1,772,550**	**3,178,500**
Active surveillance	2,205,000	1,772,550	2,335,500
Active vector Surveillance	855,000	-	843,000
Subtotals: Materials and reagents	**7,304,840**	**5,060,600**	**9,607,000**
Laboratory analysis	5,696,940	4,488,600	8,315,000
Sample collection and transport	1,607,900	572,000	1,292,000
Subtotal: Other costs	**6,822,808**	**6,298,538**	**6,298,538**
Operations	1,572,808	1,048,538	1,048,538
RVF meetings and workshops	3,250,000	3,250,000	3,250,000
RVF fuel and vehicle maintenance	2,000,000	2,000,000	2,000,000
Total recurrent	**17,187,648**	**13,131,688**	**19,084,038**
Grand total	**68,542,104**	**92,190,680**	**107,824,417**

Source: Study computation

5.4.3.5 Estimated costs enforcing sanitary bans and treating sick animals

Sanitary bans enforcement's fixed and personnel costs were captured while estimating costs of passive surveillance costs. The additional recurrent costs were estimated as KES 1, 7 million and represented staff lunch allowances and fuel costs for monitoring stock route, slaughter houses and live animal markets. We assumed only a small proportion (5%) of the infected animals would receive a dose of antibiotics at an estimated average cost of KES 450 (camel), KES 300 (cattle) and KES 150 (sheep and goats). The costs covers drug, veterinary fee (where it applies), and transport costs. Based on the number of infected animals, total treatments costs ranged between KES 15 to 23 million depending on the control strategy. During the 2006/2007 RVF outbreak, a rapid appraisal report showed that farmers in outbreak areas purchased vector control acaricides, antibiotics, antihistamines and vitamins in an attempt to treat sick or at risk animals (ROK,2009). In addition, some sought the services from veterinarians incurring further costs in transport and consultation. In some areas, farmers paid an extra KES 50 per animal to cover costs of vaccine delivery. Slightly more than a quarter (29%) of the farmers interviewed in 2007 incurred treatment costs of an average of KES 2,716.

5.4.3.6 Total costs for each prevention and control strategies

The livestock sector containment costs for 2006/2007 RVF outbreak were estimated as KES 192.7million (Figure 0-4).

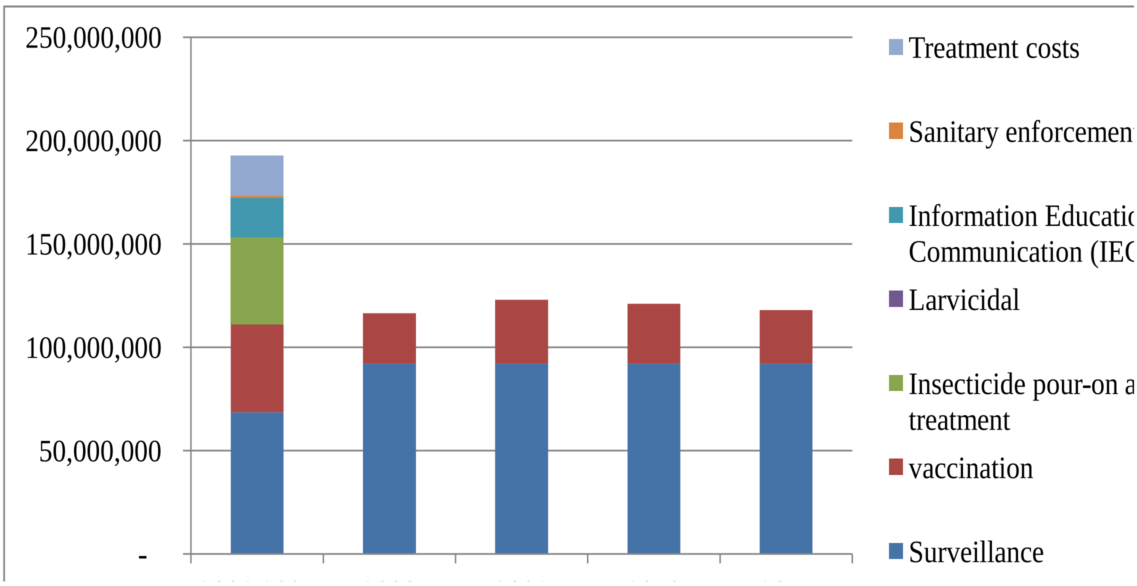


Figure 0-4: Estimated annual costs (million KES) of various RVF prevention and control options (base practice) for the period 2006 to 2011

Surveillance, animal treatments with insecticides and animal vaccination accounted for 36%, 22% and 22% of the costs respectively. This excludes fixed costs as well as donor supported capacity building at the Central Veterinary Laboratory (CVL). In subsequent years (2007 to 2011), annual costs of RVF activities reduced by 36-40% while surveillance (mainly passive surveillance) accounted for 74-79% of the costs and vaccination accounted for the rest. This is an indication that resource allocation decisions were more focused on early detection and early warning compared to reducing the proportion of susceptible populations.

During the period 2012 to 2015, annual costs increased significantly depending on the strategy (Table 0-9; Figure 0-5) except with S1. The total 10 year costs by strategy from KES 1.2 billion in S1 to KES 1.96 billion in S3. Annual average costs of integrated strategies with enhanced vaccination (S2, S3, S5 and S6) increased by 134% to 140% over the 2007-2011 costs. Annual average costs of integrated strategies with baseline vaccination (S4, S7, S8 and S9-11) increased by 69% to 85%. The differences were attributed to vaccination strategies and animal treatments with insecticides. During the 2012-2015 period, and with S1 (baseline strategy), surveillance accounted for 68% of the costs. When vaccination was enhanced or vector control incorporated in strategy, surveillance contribution to total costs dropped to 33% to 47%. When vector control replaced enhanced vaccination, surveillance costs contribution to total costs remained less than 50% while those of vector control accounted for 33% to 36%.

.

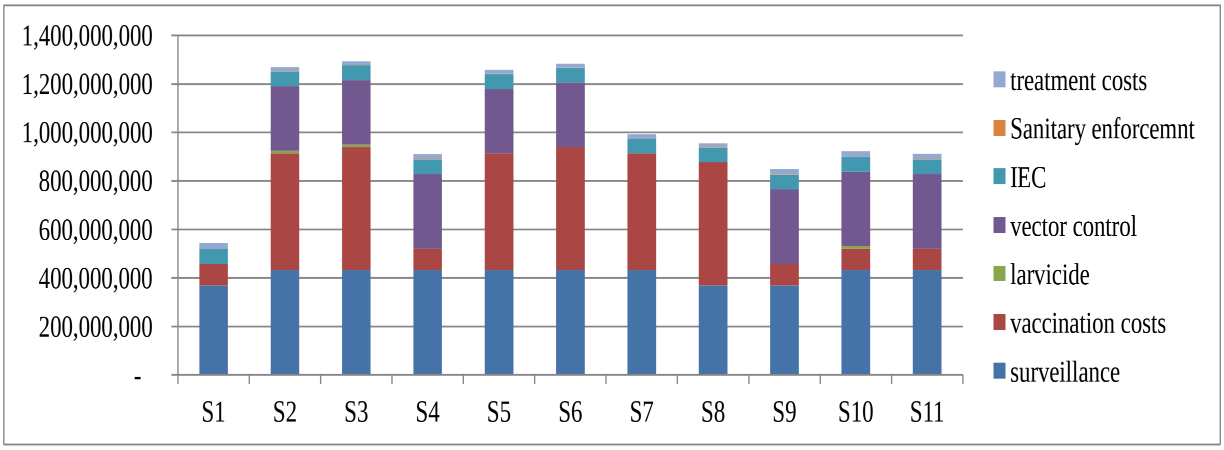


Figure 0-5: Estimated total costs for the period 2012 to 2015 for the 11 alternate strategies

Table 0-9: Estimated total costs (KES Million) of the 11 prevention and control strategies

S	2006/2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
S1	193	116	123	121	118	118	121	169	135	1,215
S2	193	116	123	121	118	384	209	391	286	1,941
S3	193	116	123	121	118	396	328	285	285	1,964
S4	193	116	123	121	118	134	137	338	303	1,582
S5	193	116	123	121	118	384	209	385	280	1,929
S6	193	116	123	121	118	396	328	280	280	1,954
S7	193	116	123	121	118	384	209	252	147	1,664
S8	193	116	123	121	118	380	312	131	131	1,626
S9	193	116	123	121	118	118	121	323	288	1,521
S10	193	116	123	121	118	134	137	343	309	1,594
S11	193	116	123	121	118	134	137	338	303	1,584

Source: Study computations. Strategy

5.5 Summary and conclusions

Review of past and current RVF control approaches show that during the 1998 to 2006 inter-epidemic period no preparedness measures were put in place and consequently response to the 2006/2007 epidemic was characterised by delayed detection and response constrained by inadequate resource mobilisation. Measures implemented during the epidemic include: vaccination of 2.5 million animals; treatment of 1.33 animals with vector control insecticides; surveillance for risk factors, vectors and animal and human disease; human case management; animal treatment; communication and education; and sanitary bans. In the post-epidemic period, preparedness for future outbreaks had improved to include annual vaccination of 4 to 8% (less than 1 million) of sheep and goats in high risk areas leaving out cattle and camels; passive and active (investigations, sentinel, surveys) animal surveillance, risk mapping and contingency planning. Also, the budgeting process had seen establishment of an RVF budget-line. However, only limited funds were allocated explaining the low vaccination coverage and exclusion of cattle and camels from the exercise. More than 50% of the RVF control costs were attributed to direct or indirect (staff salary costs) surveillance activities. The strategy would provide for early warning but probably would not reduce the size of animal outbreaks.

In order to improve decision making, this study in consultations with key informants, livestock keepers, and RVF technical experts identified improved options for vaccination (two), surveillance (one) and vector control (two), which were combined into 11 integrated strategies costs for which have been summarised in this chapter while benefits are explored in the next chapter. Reality of the prevailing human resource and funding environment informed the levels adopted. Implementation of improved measures was assumed to start in year 2012. The costs elements included fixed and recurrent costs. One improved vaccination option assumed one mass vaccination that increased coverage by 460% over the year 2011 followed by two year annual vaccination targeting young animals that increased vaccination coverage by 67% - 78% over the 2011 coverage levels. In the second vaccination options, two year mass vaccination was assumed that saw vaccination levels increased by 512% and 368% over the 2011 figures. Annualised (2006-2015) costs of baseline strategy (S1) were KES 121.5 million which increased by 25-31% in strategies without enhanced vaccination and by 34-62% in strategies with enhanced vaccination with or without vector control during epidemics. With enhanced strategies, the proportion of surveillance costs to total costs was reduced to less than 50% as proportion of vaccination and vector control costs which would contribute directly to reduction of outbreak increased. Since the strategies were designed to reflect the near real (not ideal) Kenyan situation, it is expected that benefits explored in next chapter would reflect near true position.

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CHAPTER SIX

COST-BENEFIT ANALYSIS OF ELEVEN (11) RVF PREVENTION AND CONTROL STRATEGIES

6.1 Introduction

In animal health economics, the objective of a cost benefit analysis of (CBA) is to aid decision making by providing epidemiological and economic information associated with control. The epidemiological data represents biological effects (mortality and morbidity rates) and, how control measures affect the rates. Part of the economic information includes impacts of the disease in monetary and non-monetary terms as well as the avoided losses arising from control activities. This chapter presents the losses associated with 2006/2007 RVF epidemic and the impacts of control measures on a next hypothetical epidemic assumed to occur in 2014/2015.

6.2 Literature review

6.2.1 Economic costs of Animal 2006/2007 RVF epidemic in Eastern Africa.

The monetary losses associated with RVF have been documented (Wanyoike and Rich, 2008; Rich and Wanyoike, 2010; ROK 2009; ILRI, 2008; Schelling and Kimani 2008; and FAO, 2008b). Insights on RVF morbidity and mortality rates in animals have been documented (Munyua *et al.*, 2010). The losses accrued to (i) livestock producers, (ii) other actors along the entire livestock value chain, (iii) connected sectors, and (iv) public health.

During 2006/2007 epidemic in Kenya, losses reported by households (about US$ 500 per household) resulted from animal deaths, reduced milk production, control costs (KES 2,716 per household) and income loss from marketing bans. Reduced milk production was attributed to: decreased output from infected animals (up to 75% in 3 months); milking abstinence due to fear of anima-human RVF transmission; premature drying up of lactating animals and abortions. Marketing bans were associated with price effects. Income from milk sales dropped by 63%. The households perceived the losses. In pastoral systems, market bans and decreased household incomes were most important. In mixed farming systems, more important losses were reduced milk output and market bans. Compared to Kenya, household monetary losses to livestock keepers in Tanzania were estimated at US$ 330 to 5,940 (FAO, 2008b).

Other value chain actors impacted by the losses include: raw milk and live animal traders; red meat processors and retailers; and, employees and petty traders depending on the livestock businesses. More than three quarters (81%) of red meat related businesses in infected areas experienced severe business threatening impacts at 63% to 100% income losses depending on extent of idling (Rich and Wanyoike, 2010; ROK, 2009). For a period of 3 months, Garissa livestock market and slaughter house forgone income/revenues were estimated at US$ 6.8 million while Nairobi slaughter houses each lost a monthly revenue of KES 1 to 1.4 million (Rich and Wanyoike, 2010). Petty traders depending on slaughter houses reported a 67% to 82% decline in business (ROK, 2009). About 43% of red meat associated businesses laid off 11% of employees (mostly casuals) for an average of 80 days while daily revenues of those retained dropped by 75% (Rich and Wanyoike, 2010).

Demand shocks results in lower live animal and product prices; a decline of 25-29% in cattle and 35% in sheep and goats (FEWSNET, 2008; ROK, 2009). However, meat prices did not fluctuate with the demand and supply shocks, while hides and skin prices dropped by an average of 17% (ROK, 2009). Meat spoilage was widely reported. Impacts on milk trade varied; prices and volumes of raw milk dropped by 15-33% and 40-42% respectively. On the other hand, processors recorded a 31% increase in volumes traded (ROK, 2009). Inputs service providers were not spared; they reported a 50% to 67% decrease in sales of dewormers, acaricides and animal feeds. Recovery for the businesses was slow as many (28% to 75%) traders could not resume operations immediately after lifting quarantines as a result of depletion of trading capital during the bans while slaughterhouses operated at 50% capacities (ROK, 2009; Rich and Wanyoike 2010). In uninfected areas, about 8% of red meat outlets closed down, while operating businesses recorded 60% to 86% declines in quantities sold (ROK, 2009; Rich and Wanyoike, 2010).

Private and public expenditures in RVF outbreaks have been reported. In Tanzania government spent an estimated US$ 4 million on surveillance and containment while development partners (FAO and WHO) supported with the equivalent of US$ 657,369. In Kenya, households spent about US$ 40 on RVF prevention and control. The public expenditure in Kenya was also high where both health sectors spent more than KES 200 million.

However, RVF outbreaks have beneficiaries, namely traders in processed milk and red meat substitutes such as fish, pork, poultry, and eggs (ROK, 2009). In 2007, nearly all (93%) businesses selling the substitutes reported a 54% increase in sales. Quantities of poultry, eggs, fish, and pork sold during the outbreak increased by 64%, 33%, 100% and 47%

respectively. The highest price increase was reported in poultry (24% to 75%), followed by eggs (30%), pork (28%) and fish (5%). Impacts on prices of substitutes for red meat in Tanzania included price increases by 38% to 74%

6.2.2 Economic impacts of Animal RVF epidemic on international trade

Impacts of RVF on regional and international trade are best demonstrated by disruption of the Horn of Africa (HOA) and Gulf countries trade links. Following the 1997/98 RVF outbreak Gulf States banned livestock imports from nine HOA countries. Consequently, exports from the major livestock port of Berbera in Somalia dropped by a third leading to a loss equivalent to US$100 million while prices of livestock fell by around 30% in Ethiopia, Eretria and Somalia. Before the ban could be lifted, the 2006/2007 outbreak occurred further affecting the international trade. The 2006/07 outbreak disrupted the 2004 to 2006 trade between Kenya and Mauritius of an annual value of US$ 2.7 million and trade between Tanzania and Comoros during the months of December 2006 to June 2007. Even after trade resumed, recovery was slow as was the case in Tanzania which operated at only 20% of the pre-outbreak level. Overall, Tanzania lost 54% of its export trade to the Comoros islands in 2007 estimated to be equivalent to US$ 50,417 while local trade decreased by 33% (cattle) and 77% (goats) over the same period. Live animal prices also decreased by 33% (FAO, 2008b, Tanzania). Closure of Garissa and Moyale markets impacted on cross border trade between Kenya, Somalia and Ethiopia.

6.3 Methodology

The study applied a cost benefit analysis process described by Ramsay *et al.,* (1999) that includes:

(i) Identifying base control practice and alternatives for comparison and quantifying expected costs of each over time. The process and results are presented in chapter five.

(ii) quantifying outbreak losses experienced under each control strategy and expected benefits of the alternative interventions over time;

(iii) comparing the base control practice and alternatives using standard measures (net present value, benefit–cost ratio or internal rate of return)

(iv) Undertaking sensitivity analyses.

6.3.1 Quantifying costs/losses and benefits of interventions

Based on literature review in section 6.2 above and Figure 0-1, the categories of costs or estimated in this study can be summarized as: (i) control/containment costs; (ii) value of production (milk) losses from infection and abortion; (iii) value of animal deaths (iv) sanitary bans associated forgone revenues from lost opportunity to value add; and (v) reduced demand of goods and services. Conversely, the benefits of alternative control measures were estimated as saved or avoided losses compared to the baseline strategy.

Two models were used

(i) a demographic herd growth and RVF simulation model

(ii) Kenya Social Accounting Matrix (SAM) model.

The demographic model produced input data for CBA Excel framework which estimated the value of livestock sector losses. Value of losses was in turn used as input data for the SAM model. The demographic herd growth and RVF simulation model considered a total of 33 scenarios (11 control strategies by 3 farming systems).

6.3.1.1 The individual based (IBM) animal –based demographic herd growth and RVF simulation model.

The model: the C++ language with Borland C++ builder 6 models described in Fuhrimann S. (2011) and (Figure 0-1) reflected in simplified way cattle, sheep, goats and camel population dynamics during three specific periods (normal, drought and RVF epidemics). The structure consists of host-specific states. According to these states, the model performed dynamic processes to include new hosts to the livestock population (gains) or to remove animals (losses) due to turnover processes. With the model, animals were tracked over days and years (10 year period). The model simulated demography with and without RVF disease for alternating drought and normal year situations over the years. In the model, livestock population was disaggregated into species, sex and age. During RVF epidemics defined periods in the model, the general principles of an S-E-I-R model (Keeling and Rohani 2008) were followed where animals are dissagregated into 4 disease states (SEIR). The rationale was to gain detailed information on RVF induced morbidity, mortality and abortion on an individual livestock level. The model also generated how many infected animals were sold or slaughtered and, therefore, pose risks to human infection.

The choice of an individual model was based on the fact that the RVF epidemic period is long (8 years in our case), and therefore herd dynamics during the period were of interest to the study. Herd dynamics have major influence on the disease during and between epidemics. In view of the rather high number of host classes, the individual based model was preferred to simulate the the demographic dynamics and the RVF-specific impacts on livestock

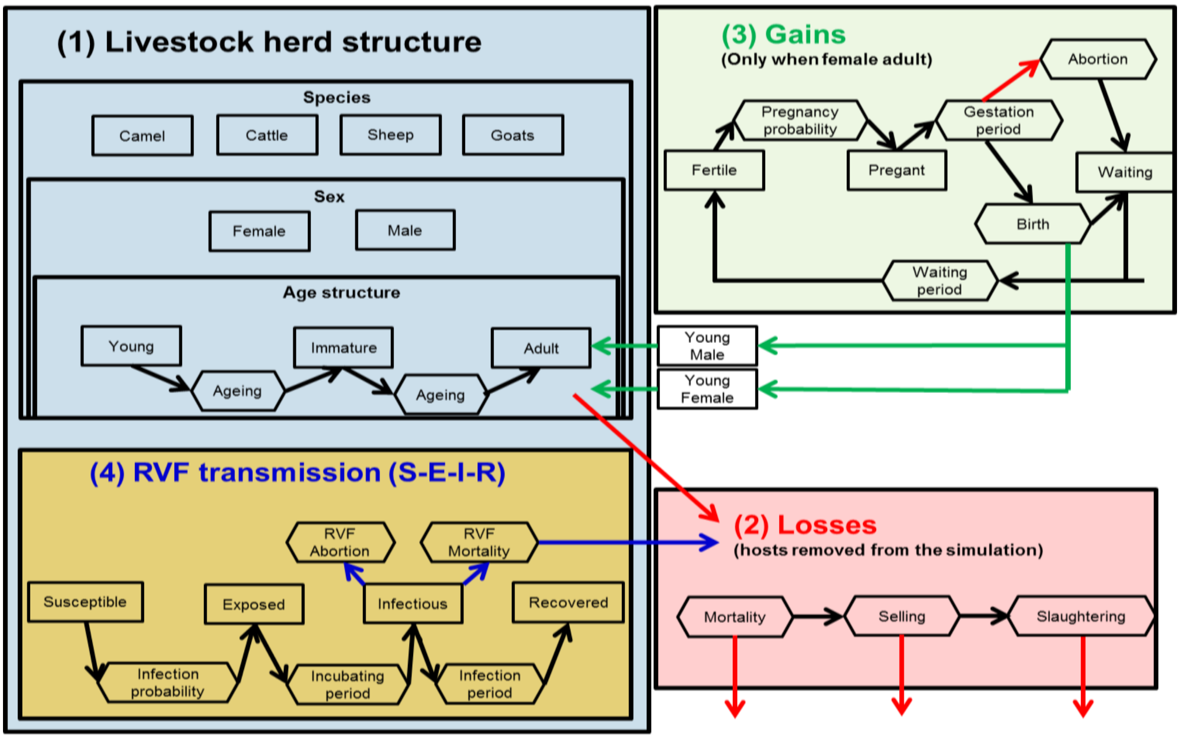

Figure 0-1: Flow chart (simplified outline) of the individual-based demographic livestock and RVF transmission model.
Source: Fuhrimann S. (2011)

The model description was divided into static rules which summarise entities, state variables and scales of the model and dynamic rules, which give an overview about processes which were executed. IBMs operate with individual state variables, which change over time and are not easily explainable with mathematical equations (Grimm and Railsback 2005). All dynamic processes which simulate the progression of the disease depended on the age class and the sex of the host. To obtain a reasonable livestock herd structure, each host is first defined as species, then assigned a sex, and finally its age in days. Hosts are categorised in three different age classes (young, immature and adult).

It is important to keep track of the losses (deaths and selling) and gains (births) to the herds. Losses are simulated by the probability of dying or of being otherwise removed from the model (dynamic herd) given the turnover processes, mortality, selling and slaughtering. These probabilities differ in different gender, age classes and infection statuses. Gains of new hosts occur after a pregnancy of a female adult host. First there is a probability that the female gets pregnant. If a female host is pregnant, it will go through a period of pregnancy during which it has a probability to abort and thus loose the offspring. If the pregnancy is successful, the female gives birth to a new young host which will either be female or male. Finally, after delivery or an abortion the female host has to wait for a certain time to recover and become fertile again.

If a susceptible **(S)** host becomes infected, an infection counter starts and the host can become exposed (**E**) to the disease during the incubation period until it is infectious (**I**). During the period of infectiousness, the host has a higher probability to die or to abort if it is pregnant. If the host survives an infectious period it becomes immune (lifelong) to RVF (**R** = recovered). Vaccination status in the model was considered as, each host has a probability of being vaccinated with a live vaccine (Smithburn vaccine) during specified time periods. After a vaccination susceptible hosts become immune (lifelong) to RVF.

To model impacts of the 11 strategies on the herd dynamics, assumptions of the biological impacts of the measures (presented in detail in chapter five) were incorporated. For example, vaccinated animals were removed from susceptible populations. The impacts of the 11 strategies were modelled for the 2014/2015 epidemic period only.

Data to parameterise the model: Three sets of data to parameterise the herd dynamics and RVF simulation model included i) primary data: drought and normal year livestock herd dynamics (herd compositions disaggregated by species, sex and age categories (young, immature and adults); annual inflows (birth); abortion rates; annual exits rates (sale, slaughter and death); ii) secondary data: RVF epidemiological (morbidity, mortality and abortion rates). The data was obtained from literature. iii) Realistic achievable parameters/impacts of the 11 control measures that were elaborated during stakeholder discussions and expert opinions. Herd increase (gains) was assumed to be through births while decrease (losses) occurred through deaths, sale and home slaughter. The field data was assumed to have inherently accounted for constraints to expansion such as available feed and capital.

Simulation process: Similar to Fuhrimann S. (2011) and for all three farming systems and each species, simulations were run with a start animal population of 2000 animals. The choice of 2,000 was based on the fact that, compared to 1,000 animals, with 100 simulated runs, the maximum and the minimum values included most of the outliers. Also, the standard deviation did not change much. The RVF epidemic period simulation used a constant infection pressure. Due to insufficient data on vector dynamics and the omission of mosquito-animal transmission in the model, the simulation assumed a homogenous distribution of vectors (mosquitoes or other arthropods) and a constant infection rate in livestock. Model outputs were stored in output and do Stata software files. Running the Stata files produced 21 simulation data outputs tables, for each of the 33 scenarios, for each species and RVF epidemic. Information on simulation output data is collapsed and summarized in Table 0-1.

Table 0-1: Variables (outputs) generated from simulations- based on start population of 2000 animals

Variables generated by simulation model
Annual livestock populations by species.
Number of livestock population at the start and end of each RVF epidemics (for years with epidemics)
Herd structure by year, species, age and sex
Proportion of livestock by species, age, sex at the beginning and end of RVF epidemics
Mortality, sales and slaughter during RVF epidemics by age and sex and RVF status
Mortality, sold, slaughtered disaggregated by age and sex during peace times
Proportion of adult females that birth, abort (base) and RVF by epidemic
Proportion of adult females that are pregnant or waiting
Proportion of animals vaccinated animal
Number of RVF infected animals
Simulated proportion of vector treated animals

These outputs of the individual-based simulation model were directly used in the economic benefit-cost analysis as input parameters.

6.3.1.2 Livestock and economic cost benefit analysis (CBA) framework

The Excel- based economic benefit cost analysis (CBA) framework estimated livestock sector losses at producer and post-producer (live animal trade to meat at retail outlet) levels. The Stata simulation output data in the 21 tables was transferred into 33 different Excel workbooks; each comprised of four sheets namely population, losses, births/abortions/fertility status and infected/mortality/received measures. Before the simulation outputs summarized in Table 0-1 (which were based on a start population of 2000 animals for each species) were used as inputs into the economic model, they were extrapolated (using mathematical equations) to actual animal populations for each species. The following are examples of the extrapolation

(i) Ten (10) year annual population growth rates for each species and year were first calculated from the 2000 based simulated annual livestock populations.

(ii) Year 2009 census based livestock populations for each species were divided by year 2009 annual growth rate to estimate livestock populations for 2008. On the other hand, the year 2009 population were multiplied by year 2010 growth rates to estimate year 2010 livestock populations.

(iii) Ten (10) year annual populations were applied to simulated proportions of animals infected to generate number of animals infected.

In each farming system, the input data was similar for the period day 1, 2006 - day 288, 2014 differing only during the hypothetical 2014/2015 RVF epidemic. This is attributed to two assumptions

(i) the 2006/2007 epidemic was modelled to reflect a real world scenario where only outbreak control strategies or measures were applied

(ii) The alternate 10 strategies were assumed to be implemented during 2012-2014 and with impacts of any control measures to be judged by changes in magnitude of the assumed outbreak in 2014/2015.

6.3.1.2.1 Estimation of mortality and production losses (losses to producers)

Using mathematical equations in Excel, the transformed input data was combined with cattle, sheep, goats and camel production indices and farm gate prices to compute annual quantities of milk and live animals produced, lost (not produced) and the associated values for each of the 11 prevention and control strategies by farming systems. The production and price data used included: annual individual animal milk off take by species and farming systems; proportionate reduction of milk off take due to drought, abortions (baseline and

RVF) and RVF infections; annual average farm gate and market prices for livestock outputs namely milk (goats, camels and cattle) and live animals (disaggregated by species, sex and age). The data was obtained from secondary (published and grey literature) and primary sources. Ten year farm gate milk price data was obtained from FAO STAT. The national average live animal year 2005-2012 prices data for 15 livestock markets was obtained from Kenya Livestock Marketing Council (KLMC).

Based on Karanja, (2003), annual milk production (and losses) was considered for goats, camels and cattle; sheep milk was ignored. Three causes for milk production losses were considered, abortions, RVF (infection and abortions) and drought. Abortion associated milk losses are the result of prolonged calving rate and calf loss (Thurmond *et al.,* 2005). Losses in live animal production were estimated as value of mortality losses disaggregated into baseline, drought and RVF caused.

The annual value of milk production (Vmilk) during a normal year was estimated as:

Vmilk = Vmilk cattle + Vmilk goats+ Vmilk camels

$$Vmilk\ cattle = \sum (QCmilk_{pap}+QCmilk_{mfm}+QCmilk_{mfhp})*FPCmilk$$

$$= \sum [(MC_{pap}*MYC_{pap}) + (MC_{mfm}*MYC_{mfm}) + (MC_{mfhp}*MYC_{mfhp})] *FPCmilk$$

Where:

Vmilkcattle = Value of cattle milk production in all farming systems

QCmilk = Quantity of cattle milk produced

Pap = Pastoral and agro pastoral systems

Mfm = Mixed farming marginal systems

Mfhp = Mixed farming high potential systems

FPCmilk = Farm gate price cattle milk

MC = Number of milking cattle

MYC = Annual cattle milk yield

Value of annual milk yield for normal years in goats (Vmilk goats) and camels (Vmilk camels) was estimated in a similar way. Net present value of production and losses was estimated by discounting at 20% after consideration of the risks involved.

To estimate milk production losses, the following assumptions (based on ROK, 2009; Shelling and Kimani, 2008; and expert opinions) were made:

(i) drought reduced annual per cow milk production by 50% (in PAP and MFM) and 40% (in MFHP);

(ii) An RVF outbreak would result in an overall 50% milk loss in PAP and MFM as infected lactating animals were assumed to dry off despite stage of lactation. In MFHP, only 25% loss was assumed as lactation was assumed to return to normal for recovered animals, while milk from uninfected animals would not be consumed or sold during RVF outbreaks.

(iii) Baseline (other) abortions occurred in the 4^{th} month in cattle, camels and 2.5 month in goats leading to an extension of the calving interval by 4.5 months for goats and 7 months for cattle and camels. This would result in annual production loss of 23% in camels, cattle in MFM and PAP, and 37% in MFHP. In goats a 50% loss was assumed to represent loss of lactation in a year.

(iv) In absence of good data on RVF abortions (stage of pregnancy and impacts on calving interval) the study assumed that RVF abortions would result in 50% (PAP), 30% (MFM) and 15% (MFHP) milk loss in aborting females. Annual value of off take (slaughter and sell) and mortality was estimated as a product of number of animals slaughtered, sold, dead categorized by species, age and sex and annual farm gate price for respective categories.

(v) Based on AU-IBAR and NEPDP (2006), farm gate price was computed as 75% of national average live animal price.

6.3.1.2.2 Estimation of marketing and processing or value added losses of the livestock products during RVF epidemics.

Milk value addition losses resulted from reduced quantities of milk sold attributed to reduced production in infected animals; raw milk marketing bans affecting the informal marketing channels; and reduced demand credited to consumer shocks. Based on ROK (2009) proportions of milk purchased by processors were not affected by raw milk bans. Milk forgone value added due to RVF was estimated as the difference between values added without RVF and with RVF. To estimate milk value added loss, the following assumptions were made

(i) During peace time, only about 5% (cattle) and 10% (goats and camels) of annually produced milk was sold in PAP. In MFM and MFHP only 30% and 55% of cattle milk was assumed to be sold respectively. Goat milk sale in the latter systems was ignored.

(ii) With RVF, a three month milk market disturbance (bans and consumer shocks) would result in a 70% reduction in quantities sold.

Based on AU-IBAR and NEPDP (2006) a value added margin of KES 10 per litre of milk was assumed. Milk price reduction due to consumer shocks was ignored. Secondary data collected in 2007 by Department of Veterinary Services[15] and primary data obtained in a cross-sectional survey with 252 red meat value chain actors (Appendix 6 to Appendix 6: List of data sourced from literature and expert opinions

Variables	Values used/assumptions			
Duration of outbreak (days)	160			
	Cattles	sheep	goats	camels
Carcass weight of in Kg				
male young	15	5	5	50
male immature	80	10	10	100
male adult	150	15	15	250
female young	15	5	5	45
female immature	70	9	9	100
female adult	130	12	12	200
off takes rates normal years	0.05	0.08	0.06	0.05
reduced in off takes during RVF outbreaks	0.87	0.65	0.65	0.9
proportion of annual off take sold during Jan to APRIL	0.36	0.36	0.36	0.36
Period of market shut downs	3	3	3	3
live animal price reduction during RVF	0.27	0.27	0.27	0.27
Length of Lactation	305 (MFHP); 235(MFM,MFHP)		180	365
Milk off take (kg) per Lactation	1733(MFHP); 465(MFM); 250(PAP)		24 (PAP,MFM); 281 (Dairy goats)	600

[15] The Author of this thesis was the team leader of the appraisal (ROK, 2009) and undertook the analysis and report writing
The Author also participated in the appraisal (ILRI, 2008) and was responsible together with Esther Schelling (one of the supervisors) for the response capacity assessment and estimation of the public health costs.

proportion of goats milked				0.05 (MFHP); 0.5(MFM);0.1(PAP)	
proportion of goat milk sold				0.33	
Percent reduction of milk due to RVF			0.5 (PAP and MFM); 0.25(MFHP)		
Percent reduction of milk s due to base abortion			0.23 (PAP and MFM); 0.37(MFHP)		
Percent reduction of milk due RVF abortion			0.5 (PAP); 0.3 (MFM); 0.15(MFHP)		
Percent reduction of milk due to drought			0.5 (PAP); 0.5 (MFM); 0.4(MFHP)		
Estimation of average farm gate of milk and live animals price-50% of market	Milk -50% less of market price; live animals, 30% less of national average market price				
cost of slaughter	675	285	285		700
proportion of home slaughter skins and hides sundried	0.81				
proportion of home slaughter skins and hides wet cured	0.12				
proportion of home slaughter skins and hides sold raw	0.072				
proportion of slaughter house slaughtered animals with usable skins	0.7				
proportion of hides and skins sold from home slaughter	0.5				
proportion of home slaughter hides sold as sundried	0.405				
proportion of home slaughter hides sold as raw hide	0.06				
proportion of home slaughter hides sold as salted	0.036				

Price (KES) Sundried (producer; trader primary; trader secondary	300;500;700	25;50;100		100;225;300
Price (KES)Raw skins(producer; trader primary; trader secondary	400	35		225
Price (KES)Wet salted(producer; trader primary; trader secondary	500;1150;1600	60;65;70		450;550;450
county council levy on hides and skins (KES)	10	5	5	10
proportion of milk sold without RVF		0.05(PAP); 0.3(MFM);0.55(MFHP)	0.1(PAP)	0.1(PAP)
proportion of milk sold with RVF		0.015(PAP); 0.09(MFM);0.165(MFHP)	0.03(PAP)	0.03(PAP)
Value addition-milk (KES) 2006/2007	10.33333333		10.33333	10.33333
Value addition-milk (KES) 2014/2015	15.5		15.5	15.5

Appendix 7: National Average Live Animal Market prices

		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Cattle	male young	6,708	10,658	11,433	7,570	10,352	14,455	14,455	14,455	14,455	14,455
	male immature	7,338	12,136	13,446	9,496	16,834	17,384	17,384	17,384	17,384	17,384
	male adult	13,843	18,062	20,318	17,510	24,490	30,342	30,342	30,342	30,342	30,342
	female young	6,114	10,161	8,570	6,836	10,893	11,534	11,534	11,534	11,534	11,534
	female immature	6,594	10,619	13,768	9,763	11,666	18,697	18,697	18,697	18,697	18,697
	female adult	10,104	12,688	14,297	12,830	21,441	24,351	24,351	24,351	24,351	24,351
Sheep	male young	1,116	1,984	1,346	1,174	1,451	1,671	1,671	1,671	1,671	1,671
	male immature	2,012	2,085	1,611	1,695	1,885	2,296	2,296	2,296	2,296	2,296
	male adult	2,708	2,754	2,717	2,186	2,888	4,149	4,149	4,149	4,149	4,149
	female young	1,024	1,126	1,329	1,147	1,461	1,260	1,260	1,260	1,260	1,260
	female immature	1,124	1,216	1,389	1,815	1,563	2,029	2,029	2,029	2,029	2,029
	female adult	2,604	2,047	2,763	1,881	2,587	2,838	2,838	2,838	2,838	2,838
Goats	male young	944	1,910	1,491	1,539	1,561	1,492	1,492	1,492	1,492	1,492
	male immature	1,235	2,142	1,732	2,272	1,953	1,866	1,866	1,866	1,866	1,866
	male adult	2,066	2,304	2,573	3,254	3,577	3,653	3,653	3,653	3,653	3,653
	female young	783	1,147	1,411	1,776	1,464	1,526	1,526	1,526	1,526	1,526
	female immature	1,088	1,493	1,538	2,659	1,772	1,938	1,938	1,938	1,938	1,938
	female adult	1,242	1,898	2,538	2,036	3,022	3,081	3,081	3,081	3,081	3,081
Camels	male young	12,622	11,802	12,622	11,802	15,297	17,215	17,215	17,215	17,215	17,215

male immature	12,622	12,472	12,622	12,472	16,757	18,810	18,810	18,810	18,810	18,810
male adult	23,266	27,507	23,266	27,507	37,959	36,927	36,927	36,927	36,927	36,927
female young	15,714	12,472	15,714	12,472	20,779	21,510	21,510	21,510	21,510	21,510
female immature	15,714	16,653	15,714	16,653	27,075	25,312	25,312	25,312	25,312	25,312
female adult	18,118	24,247	18,118	24,247	29,941	30,224	30,224	30,224	30,224	30,224

Appendix 8) was used. In absence of data from primary and secondary sources, some probable values were used based on researcher's expert opinion.

Value added loss to the red meat value chain: The forgone revenue from meat industry was taken as the difference between the value of a live animal at farm gate price and the end value of the animal. The latter was estimated from the slaughter house value of red meat, hide or skin, offal's, liver, tongues/head, heart, lungs and kidneys obtained from immature and mature animals. The value added was estimated for a with and without RVF; the difference represented the marketing level value addition losses.

To estimate red meat value added losses the study assumed

(i) Reduced number of off takes during RVF outbreaks was attributed to bans on slaughter, animal movement and marketing. Modelling forgone value addition revenues associated with RVF outbreaks deviated from the normal practice. The study treated the losses associated with meat value addition forgone in the post-farm marketing and processing chain to result from reduced off take due to deaths and market bans. Ideally, the post-farm value addition losses during the outbreak could be limited to those associated strictly with the animals that are lost (mortality) and with idled capacity. The losses associated with idled capacity may be expected to be less than the value addition of the normal animal throughput. Unlike milk production which is constant and cannot be postponed, and so likewise the value addition activities cannot be postponed, closed live animal markets just mean that animal sales are postponed and value addition can be recovered at a later date. However, as explained in the respective chapter, RVF is a zoonotic disease associated also with severe consumer shocks. The shocks combined with supply shocks (from bans and deaths) almost shutdown the red meat economy for a quarter of a year. It is unlikely that livestock markets can absorb the animals that could not have been sold. This is considering that consumer confidence does not return to normal immediately bans are lifted. The study also did not estimate extra costs feed and management costs associated with maintaining animals that could have been sold and were not until the markets re-open. . These studies therefore considered the revenue loss from forgone (delayed) sales as significant and were therefore considered.

(ii) All immature and mature animals were sold for immediate slaughter while calves were sold for further rearing. The latter were excluded from estimation of forgone value added losses.

6.3.2 The SAM model: Estimation of economy wide impacts

A SAM represents a whole economic system. It depicts the interlinkages and the flow of payments and receipts among different components of the system (Figure 0-2) based on national income and product accounts; national input-output tables; and monetary flows between institutions

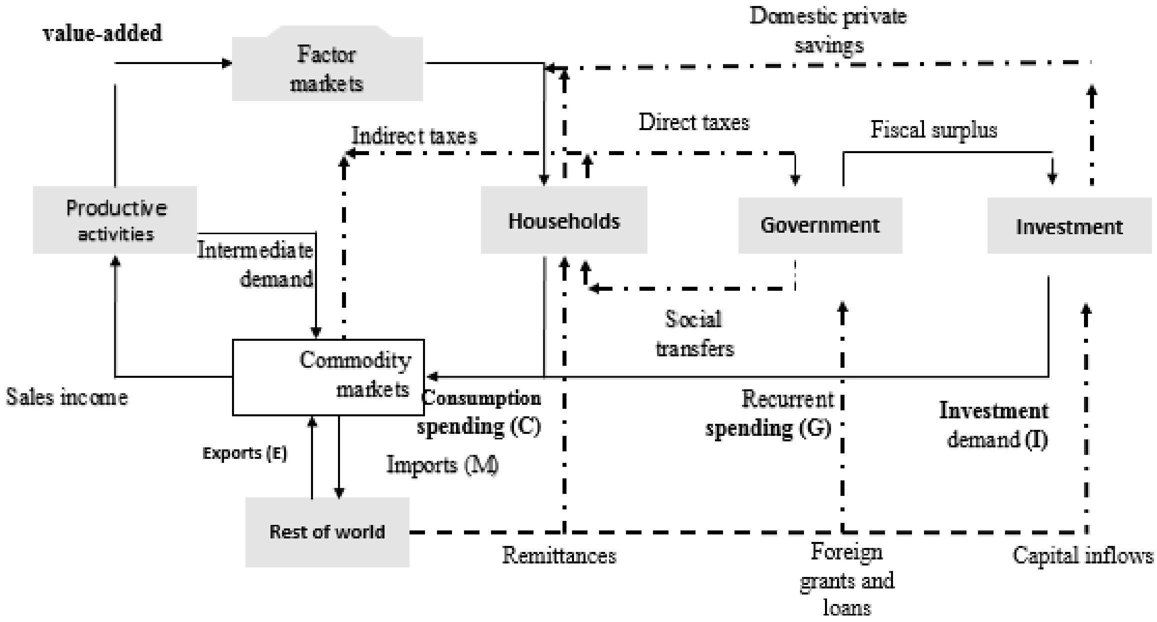

Figure 0-2: Flow chart diagram of a national economy.

Each element in SAM matrix (S), is indicated by S_{ij}. Where i = 1,2….n; is the row index. J= 1, 2,…n is the column index. The formula below represents equations for given account. Expenditures are equal to receipts. The sum of the row is equal to the sum of the column.

$$\sum_{i=1}^{n} Sih \quad = \quad \sum_{j=1}^{n} Shj$$

Total expenditure in account h
(Column sum)

Total expenditure in account h
(Column sum)

A 2003 Social Accounting Matrix (SAM) of the Kenyan economy described in detail by Kiringai *et al.*, (2006) was used to estimate the economy wide and multiplier effects of RVF shocks. As mentioned in the chapter two, **a** latest Kenyan SAM of 2009 (Omolo, 2014**)** was available. However compared to the SAM 2003, the 2009 is highly aggregated. It captures only one agriculture, fisheries and forestry sector.

The SAM 2003 is disaggregated across 50 commodity sectors - 22 agricultural, 18 industry and 10 service sectors. Of the 22 agricultural sectors - five (i) beef, dairy; (ii) poultry; (iii) sheep; (iv) goats and lamb for slaughter and other livestock; and (v) meat and dairy were of interest to this study. This study therefore prefered the 2003 SAM over the 2009 one.

It assumed that rural households consume beef, poultry, goats, dairy, other livestock, while urban households consume meat products derived from meat and dairy sector. The factors are disaggregated into labour, land and capital while institutions are divided into households, enterprises, and government. Twenty (20) household groups are distinguished based on location (rural, rural/urban or urban) and income deciles.

This study computed multipliers that represented the direct and indirect effects of a single demand shock to the livestock sector as described in Garner and Lack (1995). From a livestock perspective, direct effects were those pertaining to the livestock activities and commodities that are directly affected by the shock while indirect effects stem from livestock sub-sectors linkages to other sectors and parts of the economy.

To examine impact of the 2006/2007 RVF outbreak on the economy and potential impacts of a next assumed 2014/2015 epidemic under different control scenarios, estimated proportional reductions in marketed live animals (cattle, sheep, goats and other livestock); milk production and proportional decline in the value of dairy and decline in value of meat produced were applied to the SAM model. The direct losses (in the livestock sub sector) and indirect losses (other linked sectors) were estimated. The differential impacts on households (rural versus urban) were also estimated.

6.4 Results and Discussions

This section is organized in such a way that the 2006-2015 population dynamics (annual populations, births, abortions, mortality and off takes by farming systems are first presented. In each farming system, dynamics for the period day 1 2006 today 288, 2014 are similar irrespective of the control measures implemented during the period. This is due to the fact that no inter-epidemic period (2008-2013) RVF transmissions was assumed and therefore impacts of the strategies could only be observed under a next assumed epidemic in 2014/2015. Herd dynamics and the impacts of the 2014/2015 epidemic period are by presented not only by farming system but also by each of the 11 control strategies. The subsequent sections present quantified 10 year production (and losses and monetary values) derived from the herd dynamics, production and price data. Post production value added losses attributed to the two RVF shocks as well as the economy wide impacts are thereafter presented. The saved losses compared with costs of control (presented in chapter five) provide inputs for cost-benefit analysis presented thereafter. The key decision criteria in evaluating the strategies- the net present value of production and losses for the 11 strategies is presented in the last part of the chapter.

6.4.1 Herd Dynamics and Production (outputs) – 2006 - 2015.

Herd dynamics and output trends reflected consequences of climate (normal and drought years), biological shocks (RVF epidemics pressures) and baseline factors such as breeds and other production practices.

6.4.1.1 Ruminant-Livestock Population Trends- 2006-2015 (with Baseline strategy)

Table 0-2 and Table 0-3 summarize annual herd expansion (or compression) including changes over the 2006/2007 RVF epizootic. The more than eight year period (2006-2014) was characterized by shocks; only three years (2008, 2012 and 2013) were free of any shock. Years/periods with RVF or droughts shocks showed negative growth rates.

Table 0-2: Proportional livestock growth rate by year, farming systems and species

Species	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Annualized
						PAP					
Cattle	-16.3	-2.0	5.0	-16.0	-17.4	-6.9	10.7	9.9	-15	-2	-4.2
Sheep	-24.1	6.7	15.1	-26.0	-24.0	-10.6	19.3	21.8	-27	19	-2.9
Goats	-18.2	6.5	21.8	-7.1	-8.6	-4.8	19.9	15.5	-9	18	3.4
Camels	0.5	-8.5	10.4	6.6	1.1	1.0	14.6	10.1	7	3	4.6
						MFM					
Cattle	-8.3	4.6	9.9	-5.2	-8.8	-3.1	15.1	15.2	-11	10	1.8
Sheep	-16.9	3.6	17.9	-8.9	-9.0	-4.8	20.3	18.4	-10	17	2.8
Goats	-9.6	4.1	16.2	-5.1	-3.4	-2.0	23.5	23.0	2	30	7.9
						MFHP					
Cattle	-6.4	5.9	10.0	-1.1	-3.4	3.1	12.1	12.4	-3	5	3.4
Sheep	-23.6	2.6	5.7	-5.8	-5.7	0.2	17.2	25.5	-6	8	1.7
Goats	-6.9	8.4	23.6	-0.4	-3.5	5.4	24.2	24.1	-1	8	8.3

Source: Estimated from simulation model outputs

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In PAP systems, cattle and sheep populations show fastest drought associated decrease followed by goats and camels. Drought decreased annual cattle population growth by between 7 to 17%. Cattle showed a slight growth ranging 5% to 11% in normal years. Sheep were the most sensitive species to both normal and drought periods showing a decline of 24 to 26% during severe droughts and a positive growth of up to 22% during normal years. Goats were the opposite of cattle, with a rapid increase in population size during normal periods (up to 30%) and a gradual decrease during drought (up to 18%). Camel population growth increases slowly but steadily in normal time and is not much influenced by drought periods.

The drought year cattle decline rates for the PAP are slightly lower than the 29% reported in Ndikumana, (2000). The differences could be attributed to the fact that this study reports 12 months average and therefore recovery is factored in, while Ndikumana focused on specific months when the event occurred. The estimated annual decline of 2% for year 2007 for cattle is also lower than flood associated 19% reported in the same study. However, the

PAP system annualized growth rates of -3.1% cattle, -2.7% sheep, +3.1% and + 4.5% for cattle, sheep, goats and camels respectively are lower and sometimes higher than the 0.1% estimated by Otte and Chilonda (2002), for pastoral systems in SSA.

Compared to PAP, population changes in MFHP and MFM imply relatively lesser impacts of drought particularly in the former system. Annualized growth rates in both systems are all positive; less than 5% in sheep and cattle and 6% and 9% in goats in MFM and MFHP respectively. The rates are higher than Otte and Chilonda's all systems weighted annual population growth rates of 1.4%, cattle, 2.5% sheep and 4.5% goats. This study's specificity in modelling, where field data was used to parameterize the model could imply that though slightly different from published estimates, the rates more or less reflect real life situations in Kenya.

Years with combined shocks (drought and RVF) higher negative growth rates of 2-4% in cattle; 5-11% in sheep; 0.3-7% in goats are shown compared to those with drought shock only. Growth in camels slowed down by 0.8 during years with combined shocks (Table 0-3**:**). During the RVF epidemics only, cattle and sheep population decreased in PAP while other systems and species showed mixed changes.

Table 0-3: Proportion (%) by which population changed during RVF epidemics (2014/2015 under baseline control scenario)

	During RVF epidemic only				*Annually*	
	2006/2007	2014/2015 (S1)	drought with RVF	drought without RVF	normal year with RVF epidemics	normal year without RVF epidemics
			Pastoral systems			
Cattle	-8.9	-8.7	(15.65)	(13.43)	(2.00)	8.53
Sheep	-15.1	-13.2	(25.55)	(20.20)	12.85	18.73
Goats	-3.0	-1.1	(13.60)	(6.83)	12.25	19.07
Camels	1.8	1.0	3.75	2.90	(2.75)	11.70
			MFM			
Cattle	-8.1	-6.4	(9.65)	(5.70)	7.30	13.40
Sheep	-21.5	-5.8	(13.45)	(7.57)	10.30	18.87
Goats	-2.8	-4.2	(3.80)	(3.50)	17.05	20.90
			MFHP			
Cattle	-5.5	-2.0	(4.70)	(0.47)	5.45	11.50
Sheep	-8.6	-1.1	(14.80)	(3.77)	5.30	16.13
Goats	-5.0	-4.0	(3.95)	0.50	8.20	23.97

Source: Estimated from simulation model outputs

6.4.1.2 Inflows-Births - 2006-Day 288, 2014

Figure 0-3 and Appendix 9**Error! Reference source not found.** to Appendix 11, summarise estimates on births. As expected, higher proportions of adult females gave birth during years with no shock compared to those with RVF or drought (Figure 0-3). In normal years all species except cattle and camels in PAP exhibited higher fertility rates of above 50 explaining the higher numbers of births. Years with drought and or RVF had the lowest number of births attributed to lower conception, higher baseline abortion rates and additional RVF associated abortions. The lower conception rates are related to the nutritional status of the female animals. Reduction in pasture and water availability leads to poor nutrition and trekking long distances in search of the feeds which in turn lead to weight loss, reduced fertility rates, and disruption of the timing of conception.

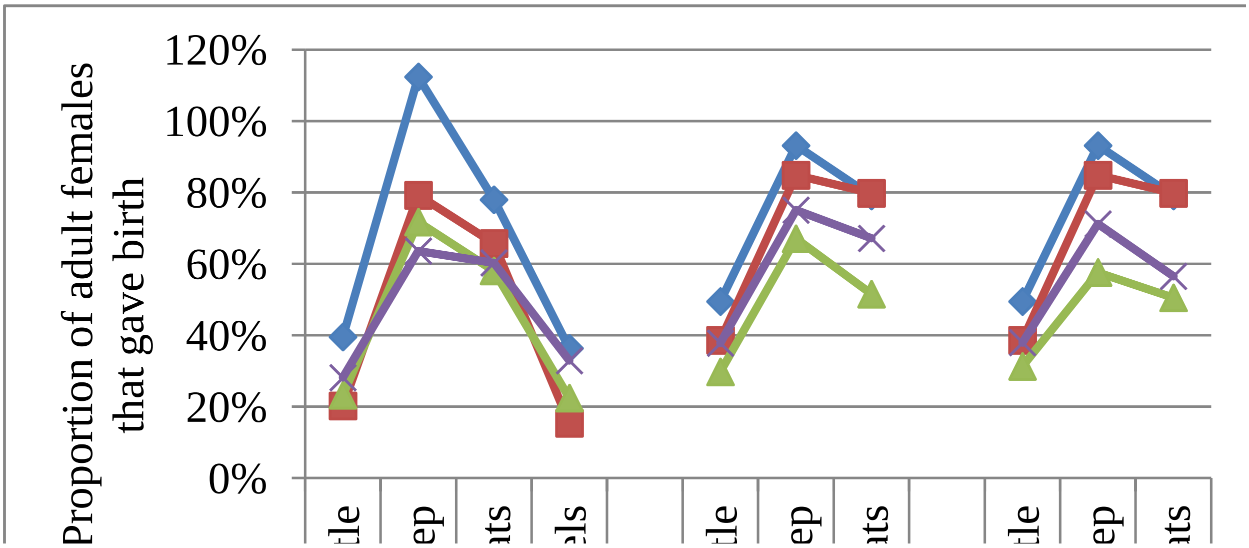

Figure 0-3: Average proportion of adult females that gave birth during years with no shock and with specified shocks

Source: Estimated from simulation model outputs

Generally except in camels and cattle in PAP systems, years with drought only showed the highest decline in birth rates (26%-40%) followed by years with drought and RVF (10-43%) and RVF shocks only (0-29%). This is attributed to the fact that RVF and drought cannot occur concurrently and therefore the lower impacts of RVF on fertility compared to those of drought moderate the annual impacts in years when both impacts occur. The relatively higher decline during years with RVF shocks in PAP for cattle and camels could be attributed to concurrent impacts of floods on the two species. Proportion of adult cows that calved during years without drought in PAP is almost 10% lower compared to the other systems. During drought years, fertility rates dropped by, 50%, 29% and 27% in cattle, sheep and camels respectively while the rates in goats remain more or less.

6.4.1.3 Abortions (baseline and RVF) - 2006-2015

Baseline abortions were as a result of other causes while RVF associated abortions occurred only during epidemics. The number of abortions annually was derived from the number of pregnant females and probability that abortion would occur. Model simulation showed in all systems and species, a lower proportion of adult females aborted during years with drought shocks only (Figure 0-4). Higher proportion of adult females aborted during years with both drought and RVF shocks. Abortion rates were higher during RVF epidemics. However, estimated number of abortions (Appendix 12 to Appendix 14) shows higher number of abortions during peace time (normal years). This was attributed to the fact that relatively more females were pregnant during normal years; a case of low abortion rate affecting many pregnant females compared to higher rate but only affecting few pregnant females. The fewer number of abortions during 2007 period without RVF is related to the fewer number of pregnant animals as most were recovering from both the impacts of drought, RVF and floods. The common causes of baseline abortions could include: infectious agents (such as brucellosis); genetic abnormalities; heat stress (also causes reduced conception); toxic agents. Heat stress and toxic agents are common during drought period probably explaining why abortion rates were relatively higher during drought.

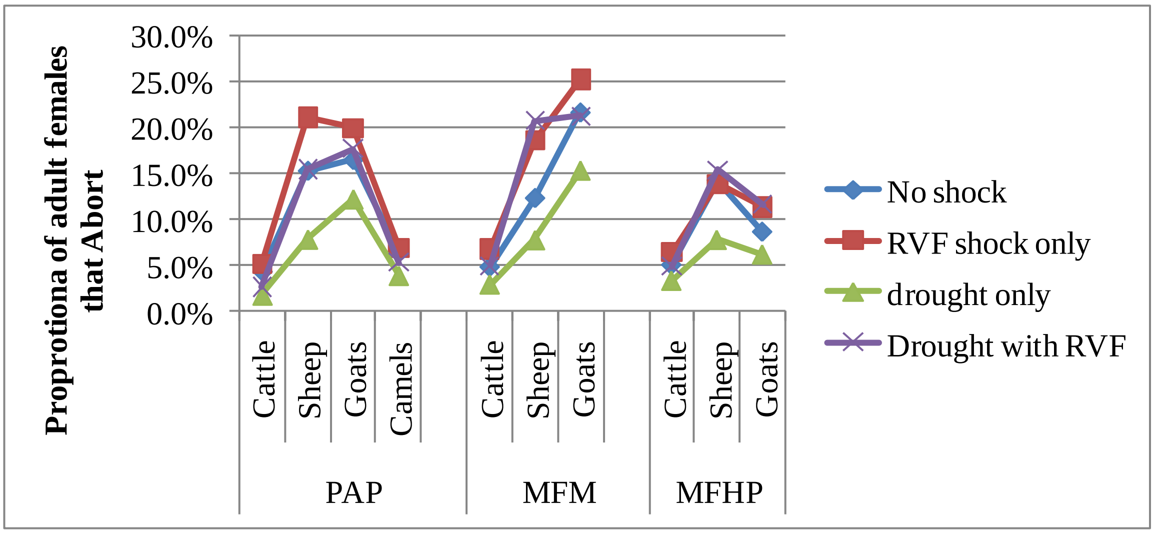

Figure 0-4: Proportion of adult females that abort by livestock system.

Source: Estimated from simulation model outputs

6.4.1.4 Mortality exits - 2006-2014

Table 0-4 summarizes computed total combined female and male mortality rates by age and species while Appendix 15 to Appendix 17 show the trends in absolute numbers for each species and farming system. In all systems, the mortality rate was higher during years with drought and was highest in PAP systems followed in decreasing order by MFM and

MFHP. In PAP, peak drought mortality is highest in young animals. Sex disaggregated mortality showed that in cattle more males compared to females died.

Table 0-4: Estimated total mortality rate during drought and normal years.

	PAP		MFM			MFHP
	Drought	Normal	Drought	Normal	Drought	Normal
Cattle						
Young	51.9	24.0	36.6	21.9	21.1	17.1
Immature	13.8	2.3	9.4	7.0	14.2	8.1
Adults	24.4	7.2	5.1	6.3	7.5	4.7
			Sheep			
Young	74.8	21.9	40.7	17.3	25.1	15.7
Immature	39.5	24.0	19.1	15.4	17.8	6.6
Adults	30.0	5.9	20.2	8.0	17.9	4.5
			Goats			
Young	62.8	14.6	42.5	18.3	15.4	12.7
Immature	19.9	7.7	21.8	9.7	10.6	11.0
Adults	24.3	6.7	7.5	6.1	6.8	4.5
			Camels			
Young	14.4	7.1				
Immature	8.2	6.8				
Adults	6.8	4.2				

Source: Estimated from simulation model outputs

These mortality rates trends more or less largely agree with published values. In PAP, Ndikumana, (2000) reports a normal period baseline all age combined cattle mortality of 5.0% that increased to 35.2% and 17.3% during drought and el-Niño rains respectively while Njanja (2007) reports a mean mortality prevalence of 22.9%, 50.3 % and 51.3 % in camel calves, kids and lambs. Onono *et al.*, (2009) report baseline cattle mortality rates in small scale dairy; small scale diary and meat, and large scale dairy and meat as: adult females (3.0-10.8%); immature females (5.0-8.4%); young females (20.0-25.0%); adult males (3.0-20.5%), immature males (5.0-20.0%) and young males (20.0-25.0%). Baseline mortality has been associated with: tick borne diseases, mange, worms, coccidiosis, predation, diarrhoea, trypanosomosis, lung infections, contagious bovine pleura-pneumonia and brucellosis (Onono *et al.*, 2009; Njanja, 2007). The number of animals that die during an RVF epidemic period is lower than those that die during drought.

6.4.1.5 Sale and slaughter

Table 0-5 presents proportions of animals sold (to markets and other producers) and slaughtered at home during drought and normal years. Appendix 18 to Appendix 20 summarise sale and slaughter trends in absolute numbers.

Table 0-5: Estimated off takes rates –Slaughter and Sold

		PAP			MFM			MFHP		
		Yg	Imm	Mat	Yg	Imm	Mat	Yg	Imm	Mat
						Sold				
Cattle	drought	3.2	13.7	23.6	2.7	24.3	24.5	8.1	14.6	11.6
	normal	0.0	6.7	7.3	3.4	12.6	5.6	9.5	36.5	7.8
sheep	drought	0.0	14.1	31.4	7.3	22.9	10.9	9.1	24.5	14.9
	normal	0.4	12.4	12.9	5.6	24.2	8.7	7.1	30.8	10.5
Goats	drought	8.8	21.2	29.0	0.0	25.5	23.0	3.5	23.2	12.7
	normal	1.6	5.5	11.9	0.0	21.3	6.0	1.0	21.0	5.5
Camels	drought	1.1	30.9	13.8						
	normal	2.3	12.0	6.9						
						Slaughtered				
Cattle	drought	0.0	0.0	0.0	0.0	0.2	0.8	0.0	0.0	3.4
	normal	4.7	2.3	2.8	0.0	0.0	3.1	0.0	0.0	0.9
sheep	drought	1.0	5.0	4.7	0.0	6.9	18.8	0.0	0.9	16.5
	normal	0.4	12.6	3.7	0.0	3.2	9.5	0.0	0.0	9.2
Goats	drought	0.0	4.7	0.6	0.0	8.1	5.2	0.0	0.3	17.9
	normal	1.3	5.2	4.8	0.0	5.0	4.6	0.0	0.0	8.0
Camels	drought	0.0	0.0	1.3						
	normal	1.8	10.7	0.1						

Source: Study computation. Yg= young, Imm = immature, Mat = mature.

As expected and in all farming systems, sale and home slaughter trends show relatively higher off takes during drought compared to normal years, which was attributed to distress sales. The difference between drought and normal year off takes is more conspicuous in PAP. In all farming systems, off take numbers dropped during the RVF epidemic as a result of associated slaughter and market bans. Ndikumana, (2000) that reports similar trends in PAP; a 44% (3.4% to 6.1%) increase in cattle off takes during drought periods. Home slaughter was mostly recorded for sheep and goats similar to Ndikumana, (2000) that reports minimal practice of slaughtering cattle in PAP.

6.4.2 Epidemiological parameters during 2006/2007 and 2014/2015 RVF epidemics and impacts on herd dynamics

6.4.2.1 Proportion and numbers of animals infected with RVF.

Infected proportions reflected the impacts of RVF prevention and control strategies on disease rates. In 2006/2007 a higher proportion of sheep (10-21%) and goats (9-14%) were infected compared to 7-9% of cattle. Higher infection rates occurred in MFM system. Camels were the least infected at 1.3%. In all farming systems, model results suggest that a continuation of the baseline or prevailing strategy (S1) would result in an RVF epidemic of nearly similar magnitude as the 2006/2007.

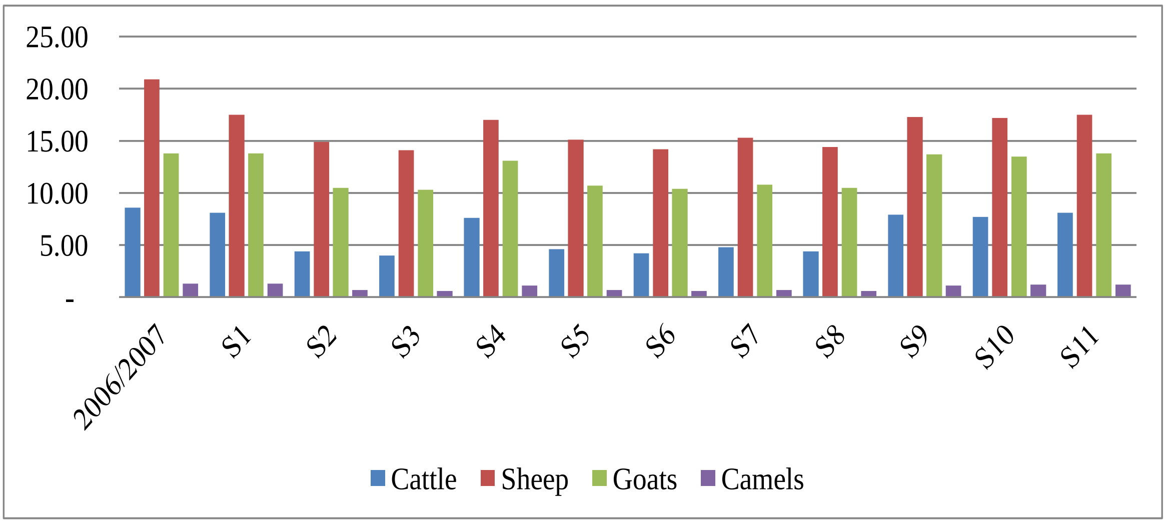

Figure 0-5: Proportion of animals infected by RVF in high risk areas-PAP

Source: Computed from simulation model outputs

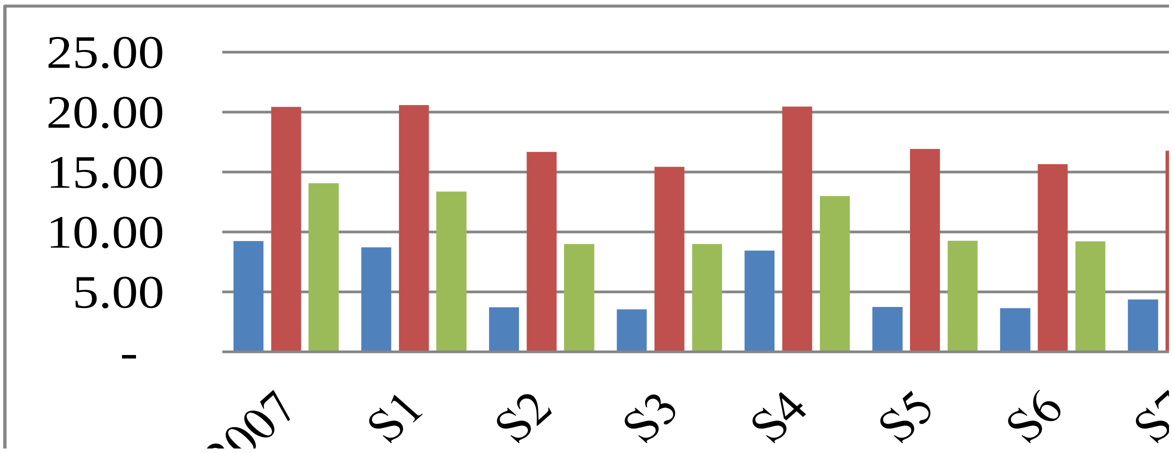

Figure 0-6: Proportion of animals infected by RVF in high risk areas-MFM

Source: Computed from simulation model outputs

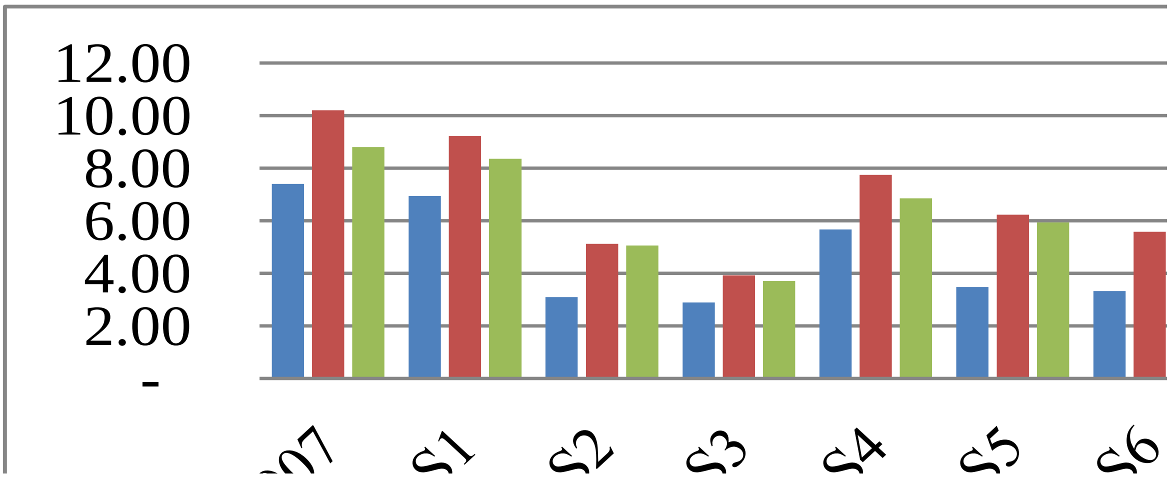

Figure 0-7: Proportion of animals infected by RVF in high risk areas-MFHP

Source: Computed from simulation model outputs

In all systems, the six strategies (S2, S3, S5, S6, S7 and S8) with improved vaccination coverage would result in significant reduction in proportion and absolute numbers of animals that would be infected (

Table **0-6**; Table 0-7). Two mass vaccination increased coverage by 512% and 368% in years 2012 and 2013, while one year mass vaccination followed by 2 years vaccination for young stock increased coverage by 460%, 67% and 78% in years 2012, 2013 and 2014 respectively over the base practice (2007-2011).

Comparisons of the two vaccination strategies in terms of reducing proportion of infected animals shows that two year vaccinations consistently performs better than the one year mass and two years young ones only strategy. In PAP, among the six strategies with improved vaccination, S3 showed the highest decrease in infected animals followed in by S6, S8, S2, S5 and S7. In other systems, S3 remained the strategy with the highest reduction while the order of the rest varied. With improved vaccination strategies, the impacts of larvicidal and pour-on treatments combined was small – about 5%.

In all systems, the highest infection rate reductions are achieved for cattle and camels, which are attributed to longer life spans and lower off take compared to goats and sheep. Higher turnover results in higher dilution of the immune levels. The higher reduction in MFHP is attributed to assumed higher vaccination and pour-on coverage in the farming system compared to the PAP and MFM systems.

Table 0-6: Proportion by which alternate strategies (S2-S11) reduced RVF infections compared to baseline (S1)

	PAP				MFM			MFHP		
S	Cattle	Sheep	Goats	camels	Cattle	Sheep	Goats	Cattle	Sheep	Goats
S2	45.7	14.9	23.9	46.2	57.2	19.0	32.7	55.5	44.5	39.6
S3	50.6	19.4	25.4	53.8	59.4	25.1	32.8	58.3	57.5	55.7
S4	6.2	2.9	5.1	15.4	3.2	0.6	2.7	18.3	16.0	18.0
S5	43.2	13.7	22.5	46.2	56.9	17.8	30.7	50.0	32.5	29.1
S6	48.1	18.9	24.6	53.8	58.2	23.9	31.1	52.2	39.5	34.7
S7	40.7	12.6	21.7	46.2	49.9	18.5	25.7	36.1	25.2	22.4
S8	45.7	17.7	23.9	53.8	52.5	22.8	26.5	48.9	29.2	24.5
S9	2.5	1.1	0.7	15.4	0.0	1.0	1.2	7.1	8.8	9.0
S10	4.9	1.7	2.2	7.7	14.0	0.9	8.4	11.0	14.3	13.1
S11	0.0	0.0	0.0	7.7	0.0	0.0	0.0	6.1	7.6	0.6

Source: Computed from simulation model outputs S= Strategy

Strategies without improved vaccination show minimal reduction in the proportion of animals that would be infected indicating that improved vaccination is the only strategy that can significantly reduce the size of infected populations. Table 0-7 presents estimated numbers of animals that were infected during the 2006/2007 RVF outbreak and those that would be infected in next hypothetical assumed 2014/2015 outbreak under different prevention and control strategies. The results show that the 2006/2007 epidemic could have infected about 2.1 million animals representing about 12% of the estimated 12.6 million start population in the RVF high risk areas and 4% of the total 2009 national population. If the next assumed outbreak occurs under the current baseline strategy (S1) and is preceded by a drought condition in 2014, an estimated 2.7 million animals would be infected. In all farming systems combined S3 would offer the highest reduction of the infected population followed by S6, S8, S2, S5 and S7.

Table 0-7: Summary of animals infected with RVF during the 2006/2007 and next assumed 2014/2015 outbreak under 11 alternate strategies

Species	*2006-2007*	*2014/2015*										
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
						PAP						
cattle	244,316	168,338	91,443	83,130	157,947	95,599	87,286	99,756	91,443	163,528	160,025	168,338
sheep	753,644	561,841	478,367	452,683	545,788	484,789	455,894	491,210	462,315	554,887	552,209	561,841
goats	569,043	998,085	759,413	744,948	947,458	759,413	752,180	744,948	759,413	984,469	976,388	998,085
camels	8,469	16,337	8,797	7,540	13,824	8,797	7,540	8,797	7,540	15,355	15,081	15,081
						MFM						
cattle	91,427	90,177	113,183	38,567	87,277	38,840	37,654	45,153	42,797	90,210	77,519	90,177
sheep	70,720	178,832	144,817	144,817	177,741	147,068	136,109	145,798	137,997	180,586	177,190	178,832
goats	163,368	295,311	198,760	198,760	287,248	204,709	203,614	219,392	217,033	291,740	270,619	295,311
						MFHP						
cattle	93,543	127,797	56,827	53,281	104,393	63,940	61,091	81,717	65,341	118,672	131,633	120,055
sheep	93,410	126,842	70,347	53,956	106,519	85,588	76,749	94,877	89,742	115,619	131,703	117,235
goats	45,964	100,506	60,722	44,556	82,396	71,287	65,636	78,020	75,855	91,477	94,444	101,077
Total	**2,133,903**	**2,664,067**	**1,982,676**	**1,822,238**	**2,510,591**	**1,960,030**	**1,883,753**	**2,009,668**	**1,949,476**	**2,606,542**	**2,586,811**	**2,646,031**
						% Total reduction compared to baseline						
			25.6	31.6	5.8	26.4	29.3	24.6	26.8	2.2	2.9	0.7

Source: Computed from simulation model outputs

6.4.2.2 Impacts of alternate control measures on population growths

During the 2006/2007 epidemic, in all farming systems, populations of all species declined. Sheep showed the highest negative rates (9 to 22%), followed in decreasing order by cattle (6 to 9%), goats (3 to 5%) and camels (1.8%). During the 2014/2015 epidemic varying population trends under different prevention and control strategies emerge. Cattle declined in PAP and MFM systems irrespective of strategy while in the MFHP; five strategies with improved vaccination (S2, S3, S5, S6 and S8) showed positive changes. Sheep population declined under all strategies in PAP while that of goats declined only in strategies that assumed baseline vaccination.

Table 0-8: Estimated changes (%) in livestock population over the 2006/2007 RVF epidemic and next assumed (2014/2015) by farming systems under 11 prevention and control strategies

Outbreak	Farming system									
Strategy	PAP				MFM			MFHP		
	Cattle	Sheep	Goat	Camel	Cattle	Sheep	Goat	Cattle	Sheep	Goat
					2006/2007					
	-8.9	-15.1	-3.0	-1.8	-8.1	-21.5	-2.8	-5.5	-8.6	-5.0
					2014/2015					
S1	-8.7	-13.2	-1.1	1.0	-6.4	-5.8	4.2	-2.0	-1.1	4.0
S2	-6.0	-10.1	1.0	2.0	-6.9	-3.2	7.3	0.4	6.0	5.2
S3	-6.0	-9.0	1.7	2.3	-2.9	-2.3	7.6	0.6	8.4	4.9
S4	-7.2	-10.8	-0.02	1.6	-5.9	-5.7	5.1	-1.2	3.0	4.1
S5	-6.2	-9.7	1.3	2.0	-3.0	-3.1	7.5	0.2	5.0	4.1
S6	-5.8	-8.7	1.5	2.3	-2.9	-2.4	7.5	0.3	5.6	5.2
S7	-6.5	-9.9	1.6	2.2	-3.2	-2.5	7.2	-0.2	5.9	3.1
S8	-6.7	-9.4	1.5	1.8	-3.6	-3.1	6.3	0.2	6.1	2.9
S9	-8.3	-12.5	-1.9	0.7	-6.0	-5.0	5.3	-1.5	2.5	3.6
S10	-7.6	-10.8	-0.2	1.7	-5.5	-6.1	5.5	-1.7	3.6	4.0
S11	-7.8	-10.8	-0.3	1.8	-6.0	-5.7	4.9	-1.5	5.3	6.8

Source: Computed from simulation model outputs

Both goats and sheep remained positive in other systems. Camels show positive growth rates in all strategies simulated. In each species, different rates of positive or negative growth in each farming systems as shall be seen later is determined by productivity (births), off takes rates and proportion of animals infected by RVF and subsequent RVF associated abortions.

The findings of higher 2006/2007 rates compared to those of 2014/2015 epidemic under the different control options provided an early indicator that control measures do have an impact on the herd dynamics. Generally in all species and farming systems, population changes show that prevention and control strategies S3, S2, S5, S6, S7 and S8 had the lowest decline (in case of negative growth) and highest growth (where change was positive).

6.4.2.3 Impacts of alternate control measures on births and abortions during the RVF epizootics

Table 0-9 summarizes, for the 2006/2007 epidemic, estimated proportions of total adult female population that: were pregnant at the beginning of outbreak; gave birth or aborted (RVF and non RVF causes) during the epidemic. In PAP system, the proportion of pregnant cows that abort due to RVF and other causes was equal unlike in sheep where the proportion of pregnant ewes that abort due to RVF is nearly double. The reverse is true for goats. Only 1% of pregnant camels abort due to RVF compared to 9% that abort due to other causes. In MFM, a lower proportion of pregnant cows and sheep aborted due to RVF and other causes while in the case of goats rates remained almost similar to PAP. In MFHP, more pregnant females aborted from other causes compared to RVF. Table 0-10 summarizes the number that aborted and gave birth during the 2006/2007 RVF epidemic.

In all systems combined, a total of 216,430 RVF abortions were estimated to have occurred in RVF high risk areas, of which 48%, 44%, 8% and less than 1% were in sheep, goats, cattle and camels respectively. During the same period an almost equal number of other abortions (265,034) were estimated, of which 63%, 26%, 8% and less than 2% were in goats, sheep, cattle and camels respectively. The estimates show that abortions caused by other causes are as important as those caused by RVF, at least based on numbers and therefore their mitigation is required as well. However, RVF abortions carry more weight in terms of zoonotic importance as handling aborted RVF foetus is likely to lead to human infection.

Table 0-9: Fertility and production rates (%) -2006/2007 epidemics –all systems

Species	Status Adult female	PAP Proportion	MFM Proportion	MFHP Proportion
Cattle	Pregnant	13.60	28.7	24
	Birth	5.73	6.9	10
	*Abortion (Other)	0.57 (4.21)	1.0 (3.5)	0.2 (4.9)
	Abortion- RVF	0.57 (4.21)	0.8 (2.83)	0.7 (2.7)
Sheep	Pregnant	30.70	35.7	35
	Birth	12.21	20.8	26
	Abortion (Other)	2.66 (8.65)	2.0 (5.61)	4 (11.3)
	Abortion- RVF	4.70 (15.31)	4.6 (12.9)	3 (7.4)
Goats	Pregnant	34.91	37.1	30
	Birth	18.77	24.4	14
	Abortion (Other)	5.57 (15.95)	5.7 (15.2)	4.7 (15.6)
	Abortion- RVF	2.92 (8.37)	3.1(8.2)	3 (10.09)
Camels	Pregnant	21.20		
	Birth	10.27		
	Abortion (Other)	1.95 (9.2)		
	Abortion- RVF	0.23 (1.1)		

*Figures in parenthesis represent estimated rates as a proportion of pregnant females

Actual number of births, abortions (RVF and other) during the 2014/2015 RVF epidemics under 11 preventions and control strategies are summarized in Figure 6-20 and Appendix 22 to Appendix 24. As expected the six strategies with improved vaccination showed higher number of births as fewer RVF abortions result from lower infection rates. In PAP system, the six strategies showed lower RVF abortions compared to baseline abortions while the reverse was true for the other five strategies. Similar to infection trends, the three strategies that assumed 2 year mass vaccination reduced RVF abortions to a higher margin (39-47%) compared to the one year mass and 2 years young only that reduced abortions by (26-36%).

Table 0-10: Number of births and abortions for the 2006/2007 RVF epidemic period

System	Status	Cattle	Sheep	Goats	Camels	Total
PAP	Births	98,021	458,327	633,021	35,474	1,224,843
	Base Abortions	7,582	46,771	126,016	6,216	186,585
	RVF Abortions	7,188	82,926	66,993	759	157,866
MFM	Births	44,921	56,440	210,619		311,980
	Base abortions	5,549	3,406	36,446		45,401
	RVF abortions	4,488	7,799	19,714		32,001
MFHP	Births	74,641	126,827	42,591		244,059
	Base abortions	8,730	19,282	5,036		33,048
	RVF abortions	4,889	12683	8,991		26,563
All systems	Births	217,583	641,594	886,231	35,474	1,780,882
	Base abortions	21,861	69,459	167,498	6,216	265,034
	RVF abortions	16,565	103,408	95,698	759	216,430

Source: Study computation

The strategies that assumed a baseline vaccination strategy reduced abortions by 0.1 to 7.0%. Similar to the 2006/2007 outbreak, baseline abortions are significantly higher than RVF abortions.

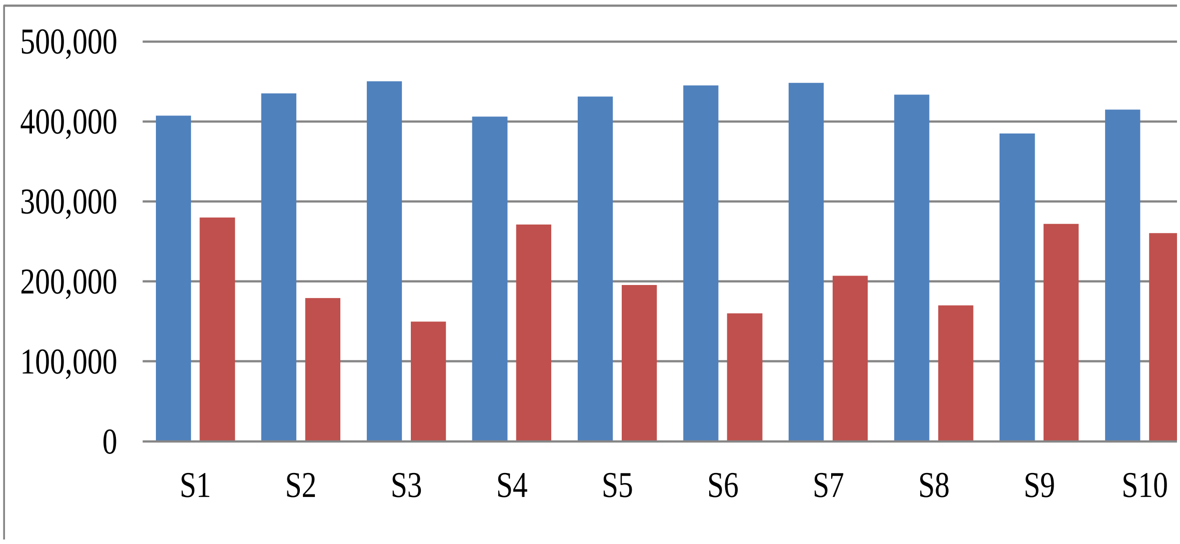

Figure 0-8: Total number of abortions in all farming systems combined during 2014/2015 RVF epidemic

Source: Computed from herd dynamics simulation model.

6.4.2.4 Baseline and RVF mortality during the epizootics and impacts of alternate control measures

Computed case fatality rates were: 52% (Cattle), 66.8% (sheep); 45% (goats) and 97% (camels). The rates are lower or slightly higher than the producer based data estimated rates of 88.3% (56.0%, 89.7%) in sheep 56.2% (38.1%, 74.3%) in goats and 36.5% (20.1%, 61.5%) in cattle reported for the 2006/2007 epidemic in Jost *et al.*,(2010). Table 0-11 and Appendix 21summarises number of animals that die from RVF epidemics and baseline conditions respectively.

Figure 0-9 to Figure 0-11 diagrammatically compares these two sets of mortalities. The study estimated that in 2006/2007 about 1.2 million animals died in RVF high risk areas. Rich and Wanyoike (2010) estimated that about 421,064 animals (36,094 cattle, 135,287 goats, 223,547 sheep and 26,136 camels) died from the 2006/2007 RVF episode in two districts, Garissa and Ijara of North Eastern Kenya.

Considering that high risk areas fall in eighteen districts all of which were infected, this study's estimates can be described as conservative. For the assumed outbreak in 2014-2015, the estimated total mortality for the baseline strategy (S1) is about 1.4 million animals. Improving vaccination coverage would result in substantial reduction in number of dead animals, although mortality would remain significant. This is attributed to assumed achievable lower vaccination coverage in the PAP and the shorter duration (3 years) in which improved strategies were implemented before the next assumed outbreak.

In 2006/2007, RVF accounted for 50% or more of the total mortality during the epidemic period, except for camels. As expected, strategies with improved vaccination show a much lower proportion of RVF compared to total mortality. Similar to infection and abortion trends, the three strategies that assumed 2 year mass vaccination reduced total RVF mortality to a higher margin (27-31%) compared to the one year mass and 2 years young only that reduced abortions by (24-26%). The strategies that assumed the baseline vaccination strategy reduced abortions by 1 to 6%. None of the RVF strategies will drop sheep RVF mortality to less than 50% of the total mortality. In goats, mixed performance of the strategies is observed where vaccination strategies reduce RVF mortality to less than 50% of total mortality. From a development policy perspective, the other causes for mortality (and similar to baseline abortions) seem to be significant and need attention considering that it happens all the time while RVF occurs after nearly 10 years. Resource allocation experts may question the rationale of spending resources on RVF which may cause lower mortality and only for a limited period while endemic problems continue to kill more animals.

Table 0-11: Estimated RVF mortality by species, farming system and strategy during the RVF epidemics

Strategy	*PAP*				*MFM*			*MFHP*			*Total*	*% Reduction relative to S1*
	cattle	**sheep**	**goats**	**camels**	**cattle**	**sheep**	**goats**	**cattle**	**sheep**	**goats**		
2006/2007	128,847	503,981	261,290	8,206	48,216	47,292	75,015	49,333	62,466	21,105	1,205,751	
S1	89,052	374,438	452,149	16,137	47,705	119,182	133,781	67,606	84,534	45,531	1,430,115	
S2	48,374	318,807	344,026	8,689	59,875	96,513	90,042	30,062	46,883	27,508	1,070,779	-25%
S3	43,977	301,690	337,473	7,448	20,403	96,513	90,042	28,186	35,959	20,184	981,875	-31%
S4	83,555	363,740	429,214	13,396	46,171	118,455	130,128	55,225	70,989	37,327	1,348,201	-6%
S5	50,573	323,087	344,026	8,689	20,547	98,013	92,737	33,825	57,040	32,294	1,060,831	-26%
S6	46,175	303,830	340,750	7,448	19,919	90,709	92,240	32,318	51,150	29,734	1,014,274	-29%
S7	52,772	327,366	337,473	8,689	23,886	97,167	99,388	43,229	63,231	35,344	1,088,547	-24%
S8	48,374	308,109	344,026	7,448	22,640	91,968	98,319	34,866	59,808	34,364	1,049,923	-27%
S9	86,508	369,804	445,980	15,167	40,559	103,813	107,649	62,779	77,054	41,440	1,350,753	-6%
S10	84,655	368,019	442,320	14,896	41,009	118,088	122,595	69,635	87,773	42,785	1,391,774	-3%
S11	89,052	374,438	452,149	14,896	47,705	119,182	133,781	63,510	78,131	45,789	1,418,634	-1%

Source: Computed from herd dynamics simulation model.

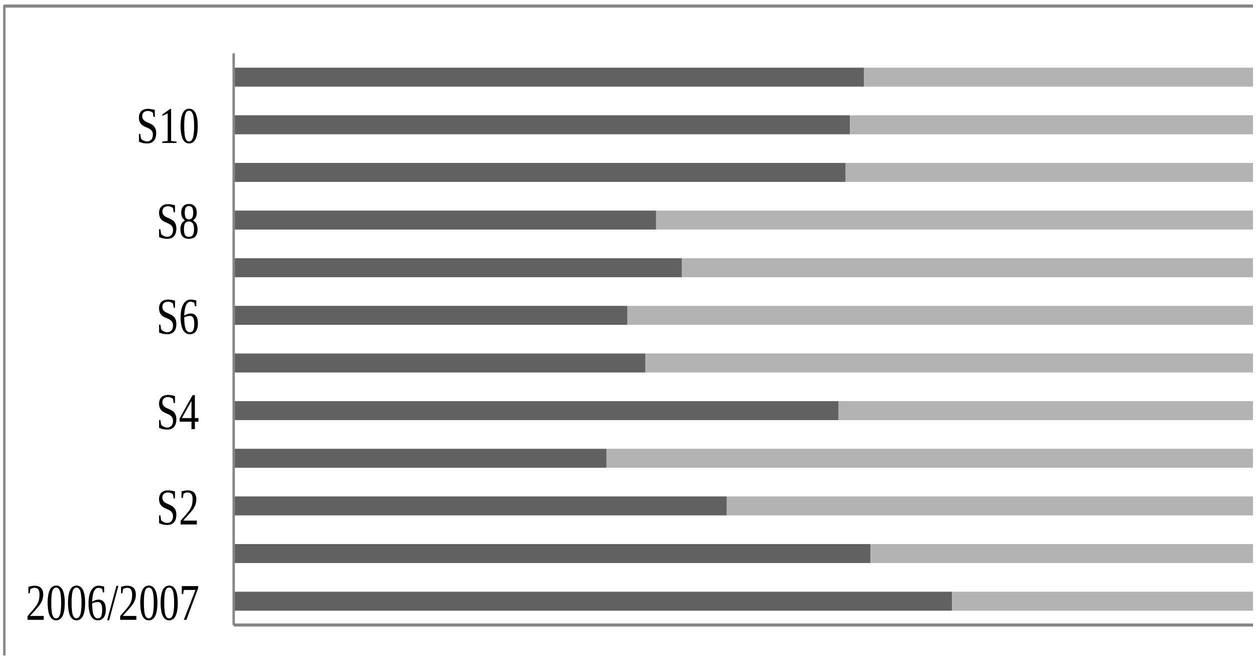

Figure 0-9: A comparison of cattle baseline (other) and RVF mortalities during the RVF epidemics

Source: Computed from herd dynamics simulation model.

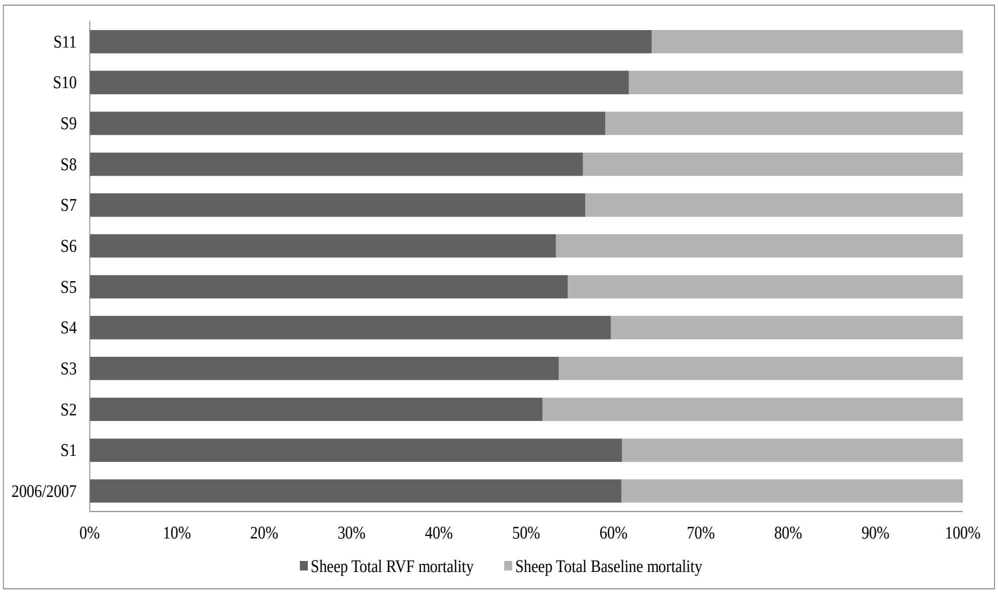

Figure 0-10: A comparison of sheep baseline (other) and RVF mortalities during the RVF epidemics

Source: Computed from herd dynamics simulation model.

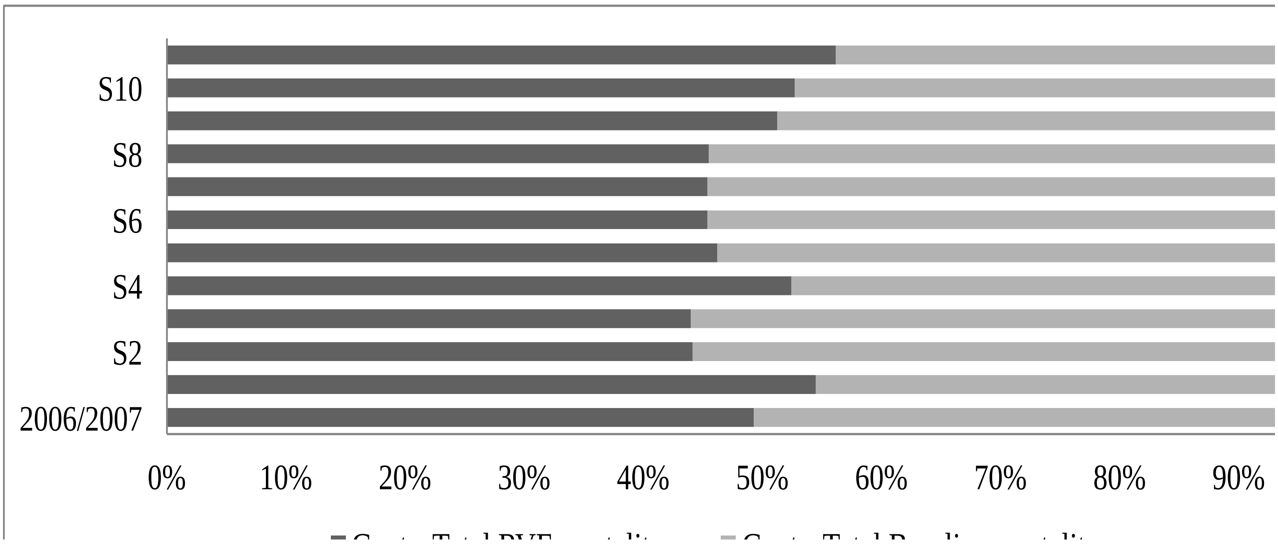

Figure 0-11 A comparison of goats baseline (other) and RVF mortalities during the RVF epidemics

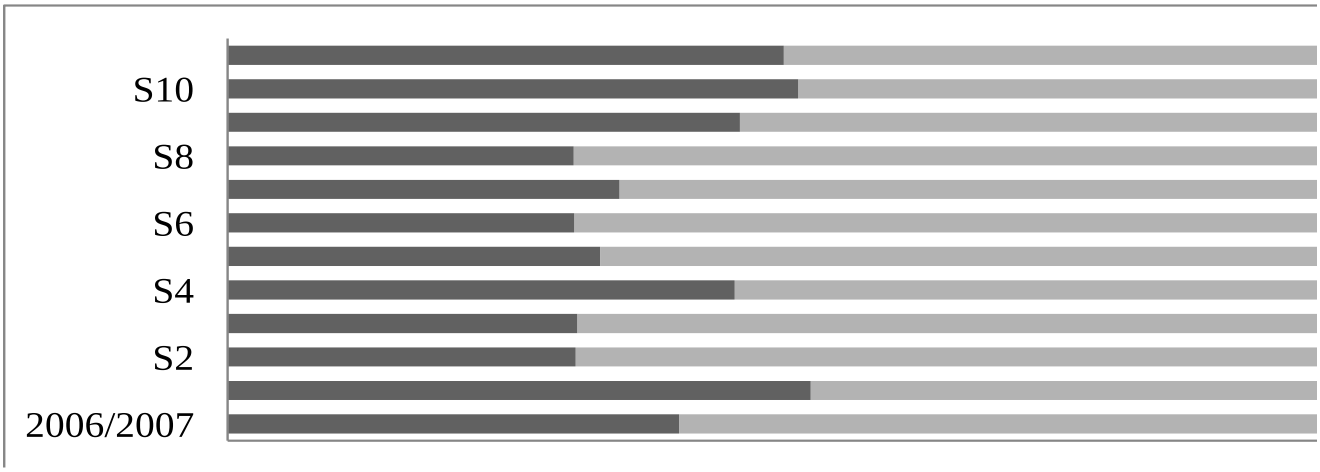

Figure 0-12: A comparison of camels' baseline (other) and RVF mortalities during the RVF epidemics

Source: Computed from herd dynamics simulation model.

6.4.2.5 Number of clean (RVF Free) and infected off takes (sale and slaughter) during RVF epizootics

Estimation of number of animals sold and slaughtered during the RVF epidemics and particularly those infected with the disease assists policy makers to understand magnitude of risk to public health and likelihood of outbreak extension through trade.

Figure **0-13** and Appendix 25 to Appendix 27 sumamrise number sold and slaughtered animals and their respective RVF status. Estimates show that in all systems combined, 0.3% to 1.7%; 2 % to 6%; and 1.7% to 3% of cattle, sheep and goats sold would be infected with RVF depending on the epidemic and strategy used. In addition, 1.4% to 4% of sheep and 1.6 to 5% goats slaughtered at home will be infected with RVF. No RVF infected camels would be slaughtered or sold while no RVF infected cattle would be slaughtered in all systems.

As expected, RVF prevention and control strategies that have incorporated improved vaccination and enhanced surveillance have fewer infected animals that enter the marketing chain or are slaughtered at home. Compared to the baseline, strategies with two year mass vaccination and enhanced surveillance (S3 and S6) reduced off take of infected animals by 54-61% while those that have one year mass vaccination and 2 years of young animal vaccination and enhanced surveillance (S2, S5 ,S7) reduced by 41-48%. When S6 and S8 reduction rates (54% and 32% respectively) are compared, the impact of enhanced surveillance compared to baseline surveillance is evident. S8 with improved vaccination and without enhanced surveillance reduces off takes of infected animal by a lower margin. Strategies S4, S10, and S11 that assumed baseline vaccination and enhanced surveillance, reduced off takes of infected animals by relatively higher margins (23-37%) compared to that of S9 (15%), which assumed baseline vaccination and surveillance.

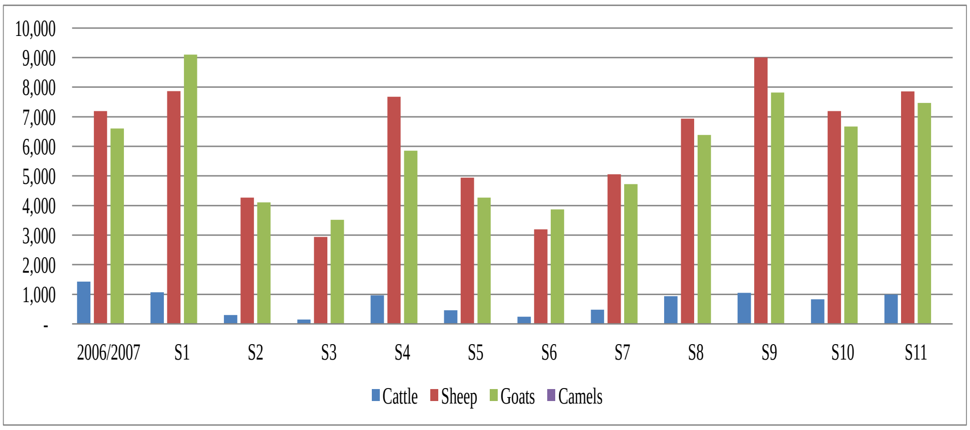

Figure 0-13: Number of RVF infected animals sold or slaughtered in all systems combined.

Source: Computed from herd dynamics simulation model.

The modelling assumed that the enhanced surveillance option would reduce the time lag to implement bans to 2 weeks compared to 4 weeks with the baseline surveillance strategy.

6.4.3 Estimated Milk Output and Impacts of Drought, RVF and Abortions on Production

Table 0-12 and Appendix 28 and Appendix 29 summarise the quantities of milk output and losses during the 2006-2013 and 2014-2015 periods under different control strategies. Annual normal year milk production in RVF high risk areas ranged between 1.2 billion to 1.5 billion litres. This implies that RVF high risk areas account for one third of the national milk output estimated at between 3.5 and 4 billion litres (in 2005 to 2009) and projected to reach 5 billion by 2014. Cattle account for most (87%) of the milk produced while camels and goats account for 12% and 1% respectively. Half of goat milk is produced in the PAP systems whereas the proportionate contribution of cattle and camel milk in the same system is nearly equal; 50.5% and 47.1 % respectively. In MFHP and MFM systems, cow milk accounted for nearly all (97.4 to 99.6%) the milk produced. The MFHP accounted for about three quarters of the total cattle milk. Similar trends are reported in Karanja, (2001) that estimates in Kenya, 59.8% of the total milk originates from dairy exotic and dual purpose breeds while zebu cattle, camels and goats account for 24.5%, 11.5%, and 4.1% respectively.

Table 0-12: Total annual milk production output and losses (million litres) by species and livestock systems -all systems combined

	2006	2007	2008	2009	2010	2011	2012	2013	2014/2015
Cattle off take	623.3	1,082.2	1,058.5	364.7	326.5	658.7	1,073.3	1,223.8	2,523.3
Cattle: loss	296.0	40.0	32.7	380.2	337.9	340.5	24.5	27.9	344.7
Goats off take	9.3	18.4	16.8	3.9	4.1	4	14.7	16.2	51.4
Goats: loss	6.4	5.1	4.9	6.2	6.4	5.6	6.2	7.3	14.1
Camels off take	49.7	128.2	161	32	32.9	67.1	218.3	217.1	337.9
Camels: loss	19.4	5.3	4.4	33.5	34.3	34.7	5.0	5.1	52.4
Total off take	**682.3**	**1,228.8**	**1,236.3**	**400.6**	**363.5**	**729.8**	**1306.3**	**1,457.1**	**2,912.6**
Total loss	**321.8**	**50.4**	**42**	**419.9**	**378.6**	**380.8**	**35.7**	**40.3**	**411.1**

Source: Study computations

Compared to normal year production, drought shocks (2006, 2009-2011, 2014) decreased cattle milk production by a range of 39% to 66% while in other species the ranges of reduction were: 45% to 77% (goats) and 44% to 68% (camels). Drought related losses accounted for the highest production losses in all species (81% to 87%) followed by other abortions (12-17%) and RVF (infection and abortions) at 0.2-3% (Table 0-13) The high drought losses can be attributed to the fact that shocks occurred in 4 out of 8 years (2006, 2009, 2010, 2011), and are assumed to occur in 2014 while RVF occurred in late 2006 and early 2007 and over the same period in 2014 and 2015.

Table 0-13: Milk losses (Million litres) by cause during the years with RVF

	2006-2007			*2014-2015 Baseline (S1)*		
Cause of loss	Cattle	Goats	Camels	Cattle	Goats	Camels
Milk losses from RVF	30.9	1.6	1.6	47	2	2
Milk loss from drought	224.4	3.1	16.7	239	5	43
Milk loss from baseline abortions	36.1	8.8	6.5	27	5	7
Total loss	**291.4**	**13.5**	**24.8**	**313**	**12**	**52**
% of loss attributed to RVF	11%	12%	6%	15%	17%	4%

Source: study computations

During the two years with RVF epidemics (2006-2007 and 2014-2015) with S1 milk production losses from RVF was estimated about 46.5 and 62.2 million litres respectively, of which 83% -86% was cow milk.

Table 0-14: Proportionate of total milk losses from each species and cause disaggregated by production system for the period 2006-2007

Species /Cause of loss	*2006/2007*		
	PAP	MFM	MFHP
Cattle: RVF (infection and abortions)	32.4	21.8	45.9
Cattle: Drought	9.9	14.8	75.3
Cattle: Other abortions	8.5	9.8	81.7
Goat: RVF (infection and abortions)	69.0	18.3	12.6
Goat: Drought	45.9	30.2	24.0
Goat: Other abortions	26.8	36.6	36.6

Source: study computations

This accounted for 11-15%; 12-17%; and 4- 6% of the total milk losses in cattle, goats and camels respectively (Table 0-13). The 2006 and assumed 2014 drought accounted for: 76-77%; 23-44%; and 67-83% of the two year milk losses in cattle, goats and camels respectively.

Drought, RVF and other abortions show differential impacts in different farming systems influenced by the proportion of species milk originating from the system and sensitivity of the system to drought. Of the 2006/2007 RVF associated milk losses MFHP accounted for the highest at 46%, while MFM had the lowest accounting for 22% of the losses Table 0-14. In Goats 69% of the RVF milk losses were recorded in the PAP system.

Drought and other abortion related impacts in cattle were highest in the MFHP. Drought and RVF associated goat milk losses were heaviest in PAP while MFM and MFHP were impacted similarly in the case of other abortions. During the epidemic period, RVF accounted for 76% -86% of the milk losses while other abortions accounted for the rest (Table 0-15). In cattle and goats, the 2006/2007 RVF epidemic associated milk production losses were attributed more (96% and 77%) to reduced milk production in affected females and less to RVF abortions. In camels RVF abortions accounted for 50% of the milk losses associated to the disease.

Table 0-15: Estimated Milk losses (million litres) during the 2006/2007 RVF epidemic

Species/Cause				*2006 2007*				*2014 2015*
	PAP	MFM	MFHP	Total	PAP	MFM	MFHP	Total
Cattle: milk losses from RVF	9.59	6.51	13.61	29.72	6.60	6.38	33.37	46.35
Cattle: Milk loss from RVF abortion	0.40	0.21	0.56	1.17	0.26	0.31	0.88	1.44
Cattle: Milk loss from base abortions	0.66	0.77	6.42	7.85	0.52	0.69	4.58	5.79
Goat: milk losses from RVF	0.95	0.27	0.04	1.25	1.80	0.24	0.09	2.13
Goat: Milk loss from RVF abortion	0.18	0.03	0.17	0.37	0.24	0.11	0.32	0.67
Goat: Milk loss from base abortions	0.51	0.70	0.70	1.91	0.14	0.15	0.77	1.06
Camels: milk losses from RVF	1.40			1.40	1.60			1.60
Camels: Milk loss from RVF abortion	1.40			1.40	1.60			1.60
Camels: Milk loss from base abortions	1.41			1.41	1.58			1.58
Total				**46.48**				**62.23**

Source: study computations

In goats, RVF abortions caused less milk losses compared to other abortions. Rich and Wanyioke (2010) estimated higher RVF abortion cattle and camel milk losses in Garissa as 2.3 million litres of valued at KES 5 million compared to this study's 3 million litres for all species and in all high risk areas. The difference lies in assumptions made.

The impacts of the alternate 10 strategies (compared to base practice) on the 2014/2015RVF milk production losses reflect the proportionate reduction in the number of animals infected. Compared to base practice, S3 reduced milk production losses by 63% followed in decreasing order by S2 (60%), S6 (59%), S5 and S8 (57%) and S7 (48%) and others at 14-27%.

6.4.3.1 Estimated value of production and losses 2006-2015

Table 0-16 summarise the value of production and losses. As expected, years with drought recorded the lowest value of milk production (KES 11- 21.2 billion), which was 36-47% lower than the value of production in normal years. Estimates show that RVF high risk areas incur milk losses valued up to KES 11.3 billion due to drought. Baseline abortions milk losses are also significant (up to KES 1.46 billion). The milk losses associated with the 2006/2007 RVF epidemic were estimated at KES 0.84 billion which represents 11% of the value of the total milk losses for the 2 year period (2006-2007). Maintaining the current strategy (S1) would result in RVF milk losses estimated at KES 1.55 billion (in case of a next assumed 2014/2015 epidemic). Compared to the baseline, strategies with improved vaccination would avoid the RVF milk losses by 38% to 55% which is the equivalent of KES 0.59 to 0.86 billion.

During normal years, annual value of other mortality ranged from KES 3.3 to 5.6 billion. Drought shocks increased this loss by an average of 112% to between KES 10.5 to 16.4 billion. The higher value of other mortality in 2007 (non- drought year) compared to 2008 is attributed to additional mortality as a result of floods and unusually high rainfall. The value of total RVF mortality during the 2006/2007 epidemic was estimated as KES 3 billion of which cattle, sheep, goats and camels accounted for 52%, 34%, 11%, and 3% respectively. The total RVF mortality value during the next assumed epidemic under the baseline practice was estimated at KES 6.2 billion. The 8 year period (2006-2013), total value of the mortality was estimated at about KES 76.14 billion; cattle accounted for nearly three quarters (74%) of the loss while camels accounted for 7%. Sheep and goats accounted for the rest almost on equal basis.

Similar high drought impacts on the livestock sector (mortality loss valued at KES 56 billion and production losses of KES 643 billion) for the period 2009-2011 are reported in ROK (2012). Similar to our model results, analysis of ROK, 2012 raw data show that more animals died during the 2006 drought compared to that of 2009. It can therefore be said that the individual herd model provided more or less good estimates for drought mortality.

Table 0-16: Estimated value (Billion KES) of production and losses during the period 2006-2015 (all species combined).

	2006	2007	2008	2009	2010	2011	2012	2013	2014/2015 (S1)	Total
Milk production	16.2	33.7	35.6	14.6	10.8	21.2	43.3	48.4	93.4	317.0
RVF milk losses	0.4	0.5	-	-	-	-	-	-	1.6	2.4
Drought milk losses	5.4	-	-	11.3	8.3	9.2	-	-	10.4	44.6
Baseline abortions milk losses	0.4	1.1	1.3	0.6	0.4	0.4	1.3	1.5	1.6	8.4
Sub total milk losses	6.2	1.5	1.3	11.9	8.7	9.6	1.3	1.5	13.5	55.5
Other mortality	10.5	7	4.7	10.3	16.4	12.2	7.9	7.4	34.2	110.4
RVF mortality	1.5	1.5							6.2	9.2
Sub total mortality losses	12.0	8.5	4.7	10.3	16.4	12.2	7.9	7.4	40.3	119.6
Value of sold animals	8.0	4.3	4.8	9.0	9.7	8.0	6.2	6.4		56.4
Value of slaughtered animals	1.2	1.2	1.4	1.2	1.6	2.1	1.4	1.6		11.5
Sub total value of live animals	9.2	5.4	6.2	10.2	11.3	10.1	7.7	8.0	0	67.9
Total Production	25.3	39.2	41.8	24.7	22.1	31.2	50.9	56.4	93.3	384.9
Total losses	**18.3**	**10.0**	**6.0**	**22.2**	**25.2**	**21.7**	**9.2**	**8.8**	**53.8**	**175.1**

Source: Study computation

Over the 8 year period, the value of off take was KES 67.93 billion. This was lower than value of mortality (KES 79.16 billion). Cattle accounted for 73% of the total value of sold animals and 55% of the value of home slaughtered animals. Sheep and goats accounted for 20% and 18% of the total value of sales and 35.5% and 31.6% of the home slaughter respectively. Camels slaughter and sale value accounted for 9% each. Value of off takes was higher during drought years.

The estimated average (for all control options) value of other (non RVF) mortality for the period 2014-2015 was KES 34.5 billion. Cattle account for slightly more than a half of these losses followed in decreasing order by goats (44%), sheep (33%), and camels (12%). The decreased contribution of cattle compared to the 2006-2007 period is attributed to population trends where less drought sensitive goats and camels have increased in population compared to cattle that had decreased by end of year 2015. When the value of RVF mortality is compared across the strategies, as expected, those that incorporated improved vaccination demonstrate lower values. The RVF mortality value would be lowest for S3 at KES 3.48 Billion, which when compared to base practice S1 value of KES 6.17 billion represents a saving of KES 2.69 billion. The value of RVF mortality for other strategies that have incorporated improved vaccination (S2, S5, S6, S7 and S8) is higher than that of S3 but less than 4.13 billion. The even higher values of KES 5.7 to 6.2 billion for the other strategies are 77% higher than those of S3. The strategies without improved vaccination demonstrate minimal saving of between KES 0.11 to 0.5 billion.

6.4.4 Market chain value added losses associated with the two RVF epidemics.

Based on the simulation results presented in the previous sections, it is evident that none of the assumed alternate control strategies would stop an assumed 2014-2015 RVF epidemic and therefore similar to 2006/2007 outbreaks, downstream and upstream value addition losses or impacts would happen, those were therefore estimated. The 2014/2015 RVF outbreak was assumed to be as extensive as the one of 2006/2007, where nearly all RVF high risk areas were affected. Ban on live animal movement and marketing, sale of raw milk unless through processing firms, and home and commercial slaughter were assumed to be implemented for 3 months. The direct impacts would be reduction in volumes traded, incomes and revenues for all actors along the camel, cattle, and sheep and goats value chains.

6.4.4.1 Milk value added losses

During the 2006/2007 epidemic, forgone value addition revenues associated with both milk that was not produced due to RVF infections and could have been sold, and milk produced but could not be sold due to RVF sanitary bans were estimated at KES 1.8 billion. Cattle milk accounted for nearly all, 97% of the losses (Table 0-17). Similar estimates for the assumed 2014/2015 epidemic under baseline practice show that the losses would be KES 2.66 billion. Similar estimated losses under 10 alternate prevention and control were more or less the same, attributed to methodology of factoring both milk not produced but could have been produced were it not for RVF and the forgone milk sales for milk produced due to bans.

Table 0-17: Estimated milk value addition losses for the RVF epidemic of 2006/2006 and the 2014/2015 under different prevention and control scenarios.

	2006/2007	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
Cattle	1.74	2.50	2.45	2.44	2.48	2.45	2.45	2.46	2.45	2.49	2.49	2.50
Goats	0.01	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Camels	0.05	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Total	**1.80**	**2.66**	**2.62**	**2.61**	**2.64**	**2.61**	**2.61**	**2.62**	**2.61**	**2.65**	**2.65**	**2.66**

Source: Study computation

6.4.4.2 Live animal trade and red meat value added losses

Table 0-18 presents computed average proportionate reduction in number of animals sold or slaughtered as well total animals not sold during the two epidemics in the RVF high risk areas; for the latter, only base practice was considered in computations. About 177,239 and 124,780 animals could have been sold or slaughtered respectively during the 2006/2007 RVF outbreak but were not. This is because they died and could not enter the meat chain or just their sale was delayed until after the outbreak. In the next assumed 2014/2015 epidemic, 245,808 and 163,921 could have been sold or slaughtered and would not be. The modelling assumed that bans do not reduce sales and slaughter in infected areas by 100% due to delays in implementation and non-compliance by livestock keepers and traders. The market level losses were estimated for adults and immature males and females only, assuming calves are sold for further rearing.

The forgone cattle, sheep, goats and camel marketing chain revenues for various actor’s involved in both (live animal to meat) and hides trade during the 2006/2007 and

2014/2015 (under baseline strategy) were estimated as KES 2.3 billion and KES 5.0 billion respectively (Table 0-19). The losses represent reduced returns to capital and management on live animal markets, slaughter, wholesaling and retailing of meat, hides and skins. Market losses due to exports bans were not considered.

Table 0-18: Estimated reduction (%) in number sold and slaughtered during a with RVF outbreak compared to without RVF.

	Cattle	*Sheep*	*Goats*	*Camels*
2006/2007				
% reduction in number sold	50	42	32	74
% reduction in number slaughtered	99	80	64	45
Forgone number of animals sold	35,269	74,425	62,292	5,252
Forgone number of animals slaughtered	14,548	70,644	38,096	1,492
2014/2015 with S2				
% reduction in number sold	52	57	57	87
% reduction in number slaughtered	66	81	72	47
Forgone number of animals sold	37,453	105,238	92,182	10,935
Forgone number of animals slaughtered	13,159	79,084	68,661	3,017

Source: Study computation

The market level losses represented the difference between live animal off take value added losses represented the difference between final value of an animal at retail prices of meat, offal's, hides and skins, heads/legs and other organs and farm gate price. Based on Muthee (2003), margins to live animal traders, accounted for the 50% of the marketing chain revenues followed in decreasing order by margins to meat traders (35%), transport and trekking costs (8%), live animal markets and slaughter houses revenues (4%) and butcheries operating costs (3%) .

Table 0-19: Estimated value addition and losses (KES Billion) during the RVF epidemics

	Product	Cattle	Sheep	Goats	Camels	Total
2006/2007 without RVF	Live animal to Meat	1.18	0.41	0.45	1.01	3.05
	hides/skins	0.26	0.18	0.12	0.01	0.58
2006/2007 with RVF	Live animal to Meat	0.54	0.16	0.23	0.37	1.29
	hides/skins	0.00	0.01	0.02	0.00	0.03
2014/2015 without RVF	Live animal to Meat	2.14	0.88	0.84	1.80	5.65
	hides/skins	0.23	0.22	0.21	0.03	0.69
2014/2015 with RVF	Live animal to Meat	0.68	0.20	0.25	0.20	1.33
	hides/skins	0.00	0.01	0.01	0.00	0.03
Forgone revenues 2006/2007		0.90	0.42	0.32	0.66	2.30
Forgone revenues 2014/2015		1.69	0.89	0.78	1.62	4.98

Source: Study computation

6.4.4.3 Production and value addition (market chain) losses combined.

A summary of RVF associated production and marketing losses during the period 2006-2007 and 2014/2015 (under 11 different control strategies) are compared with two year (2006-2007 and 2014-2015), non RVF losses (baseline mortality and non RVF milk production losses). During the 2006/2007 RVF outbreak a KES 7.95 billion loss was attributed to production and marketing losses (

Figure 0-14). The 2014/2015 assumed RVF outbreak would result in RVF associated losses that range from KES 12 billion to 15.3 billion depending on the strategy; and which represents 25% to 35% of the total losses incurred during the two years that would experience RVF outbreak. The strategies that have incorporated improved vaccination would reduce the losses by 17 to 23% compared to the baseline while those that do not would reduce by 1-5%. Distribution of losses shows the production and marketing losses are nearly equal (Figure 0-15) and that producers bears the highest costs as a group followed by raw milk traders , live animal traders and meat sellers. The distribution of the production and market impacts shows that traders and meat sellers have also a big stake in RVF and should be engaged in control decisions.

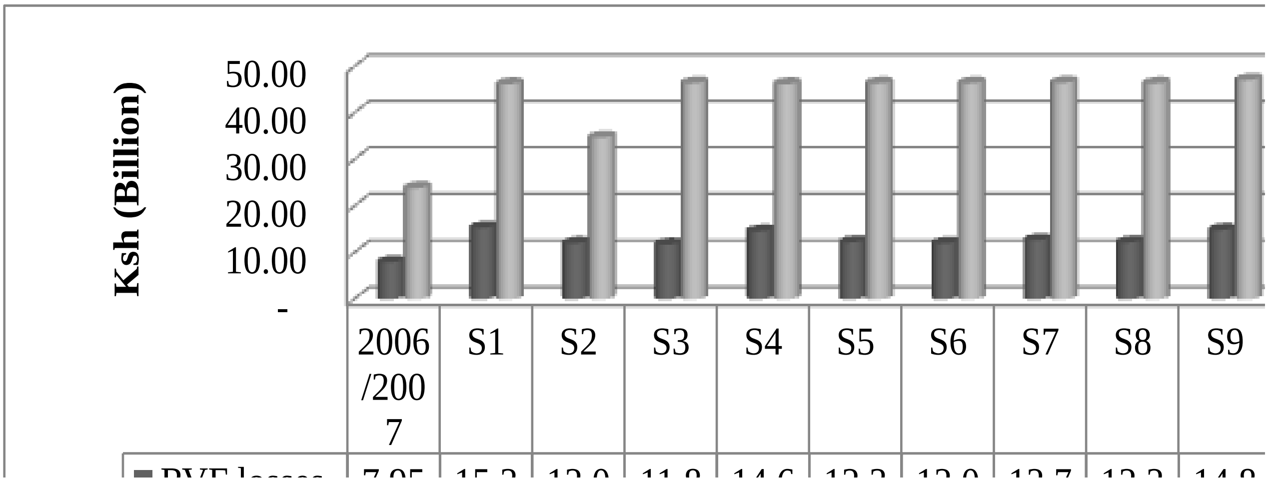

Figure 0-14: Summary of RVF and non RVF associated losses during the years with epidemics

Source: Study computation.

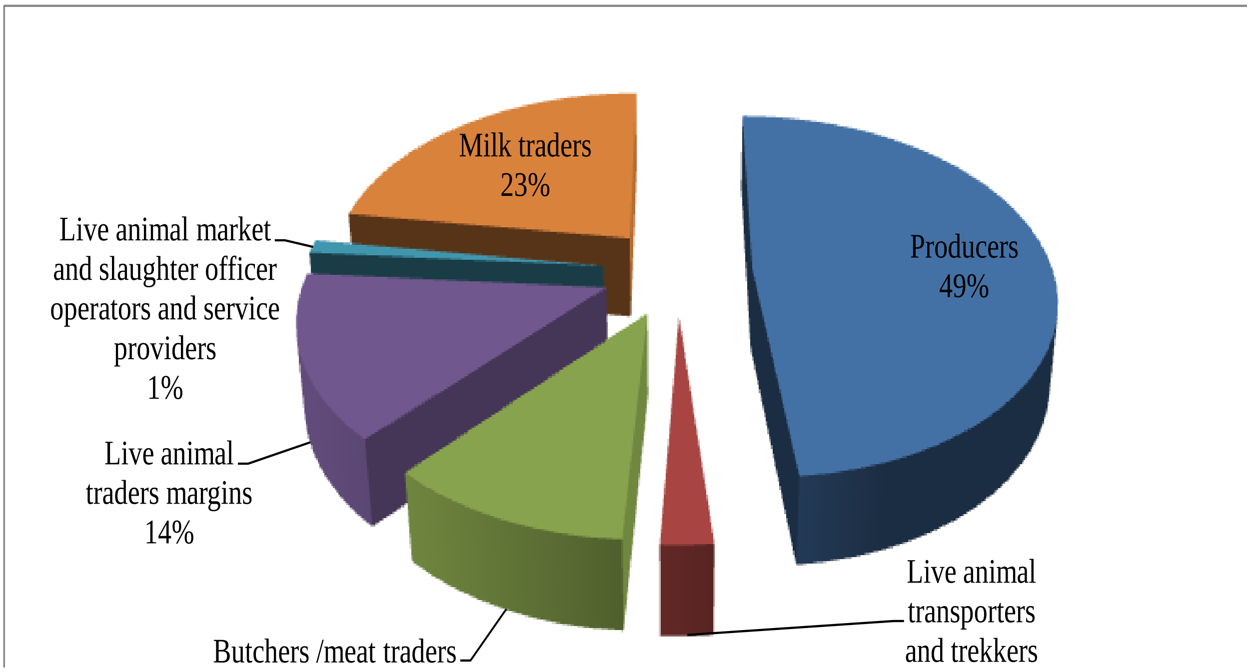

Figure 0-15: Distribution of RVF production and marketing losses associated with the 2006/2007 epidemic

Source: Study computation.

6.4.5 Economy wide impacts of the RVF outbreaks

The simulation model estimated normal year live animal off takes (sale and home slaughter) as 7.2%, 13.3%, 9.8% and 7.5% for cattle, sheep, goats and camels respectively. The model also estimated that during the three peak months of the 2006/2007 RVF outbreak, proportion of off takes reduced by a total of by 57% (sheep and cattle), 39% (goats) 77% (camels). Annually this translates to 1.7% (cattle), 1.9% (sheep), 1% (goats) and 1.4% in camels. The assumed 2014/2015 RVF outbreak would reduce off takes by more or less similar margins of 56%, 79%, 64% and 88% in cattle, sheep and goats and camels respectively which translates to annual reductions of 1.7%, 1.5%, 1.6 and 1.3%

The 2006/2007 value addition losses (assumed here to represent the meat commodity in the SAM) were estimated to represent 54%, 62%, 48% and 64% in cattle, sheep, goats and camels during the 3 months. The proportionate reduction in meat from sold animals was assumed to be same as for live animals. On the other hand, the 2014/2015, value addition losses (assumed here to represent the meat commodity in the SAM) in cattle, sheep, goats and camels was estimated to be 68%, 77%, 70% and 89% during the 3 months. The 2006/2007 value of milk sold reduced by 71% during the 3 months compared to 57% in 2014/2015. Value estimates showed that in 2007 and 2015, the reduction in value of marketed milk was 1.6 and 1.7 respectively, compared to without RVF. The proportionate annual reduction in value of milk off take during the 2014-2015 outbreak for the different control strategies ranges from 1.64 -1.4 for strategies without enhanced vaccination and ranges from 0.69 to 1.0 for strategies with enhanced vaccination (Table 0-20).

Table 0-20: Percentage reduction in annual milk off takes- sales only compared to years without RVF.

	2006/ 2007	*S1*	*S2*	*S3*	*S4*	*S5*	*S6*	*S7*	*S8*	*S9*	*S10*	*S11*
Reduction in dairy	1.66	1.63	0.77	0.70	1.4	0.85	0.80	1.0	0.85	1.55	1.49	1.62

Source: Study computations

Table 0-21 presents estimated economy wide impacts of the 2006/7 RVF outbreak and the next assumed 2014/2015 event under baseline strategy while Table 0-22 presents the income effects in different households. The 2006/2007 RVF outbreak reduced the value of total domestic supply by KES 3,740.4 million (US$43.5 million). This is much higher than the estimates of KES 2.1 billion reported in Rich and Wanyoike (2010) for the same outbreak. The difference lies in estimated proportion of reductions which are higher for this study as well as inclusion of camel's outputs in our analysis. As expected, the livestock sector bore most (50%) impacts.

The crop sector accounted for nearly 10% of the domestic supply losses. The sector has direct link to the livestock sector especially in mixed farming systems where crops are used as animal feed. Also in mixed systems sale of animal to purchase inputs for crop production. RVF outbreaks occurred or were assumed to occur during critical months when land preparation and planting is undertaken. The rest were faced by the non-agricultural sectors mainly trade, transportation, finance, chemicals, and petroleum. The SAM takes into account possible price/income effects on consumers. Simulated income effects, on rural and urban households by income docile show minimal income effects, at less than 0.19% of the total annual household income. Based on a percentage basis, the impact was slightly higher on better-off households in rural areas, while in urban areas, the impact was more pronounced amongst the middle-decile households. The SAM simulation results for the different strategies during the next assumed 2014/2015 outbreak shows that strategies with improved vaccination returned avoided losses of between KES 297 million to 436 million when compared with the base strategy (Table 0-23). The strategy that avoided the highest losses was S3 followed in decreasing order by S2, S6, S8, S5 and S7.

Table 0-21: SAM derived impacts/losses (KES millions) of the 200/6007 RVF outbreak and the next assumed 2014/2015 under base prevention and control strategy compared to without RVF.

Commodity/service	*2006/ 2007*	*% change*	*2014/ 2015*	*% change*	*Commodity/ service*	*2006/ 2007*	*% change*	*2014/ 2015*	*% change*
Meat & dairy	605.1	0.89	606.0	0.89	Poultry	41.4	0.79	41.7	0.8
Beef	482.1	2	482.5	2	Chemicals	39.6	0.04	39.84	0.04
Trade	349.1	0.25	352.0	0.25	Vegetables	38.6	0.14	38.96	0.14
Dairy	342.2	2.33	349.3	2.37	Pulses & oil seeds	37.2	0.16	37.57	0.16
Transport	219.3	0.1	221.4	0.1	Hotels	37.0	0.1	37.33	0.1
Other services	210.0	0.15	212.0	0.15	Petroleum	35.5	0.02	35.79	0.02
Finance	179.1	0.17	180.6	0.17	Sugar & bakery & confectionary	34.2	0.09	34.55	0.1
Grain milling	110.1	0.24	110.9	0.24	Printing and publishing	32.1	0.09	32.3	0.09
Real estate	91.0	0.12	91.8	0.12	Education	31.9	0.03	32.24	0.03
Maize & rice	95.4	0.24	93.3	0.3	Fruits	31.4	0.26	31.7	0.26
Others crops	83.1	0.52	83.7	0.52	Roots & tubers	30.7	0.28	30.98	0.28
Communication	80.3	0.16	81.1	0.16	Electricity	28.7	0.14	28.93	0.15
Other manufactures	72.9	0.07	73.5	0.07	Metals and machines	27.8	0.02	27.89	0.02
Sheep, goat and lamb for slaughter	72.4	2.46	76.2	2.58	Health	26.7	0.09	26.99	0.09
Beverages & tobacco	58.1	0.07	58.7	0.08	Leather & footwear	24.3	0.1	24.51	0.1
Construction	44.4	0.03	44.6	0.03	Fishing	8.7	0.16	8.72	0.16
Water	43.5	0.3	43.7	0.3	Other livestock	8.0	0.18	8.05	0.18
Others	88.9	0.1	89.6	0.1					
Total						**3740.4**		**3771.6**	

Source: Study computation.

Table 0-22: 2006/2007 RVF SAM analysis income effects compared to without RVF

Rural	*Income effects (KES Million)*		*Urban*	*Income effects (KES Million)*	
Rural Decile 0	13.82	0.12%	Urban Decile 0	0.01	0.14%
Rural Decile 1	24.81	0.16%	Urban Decile 1	0.29	0.12%
Rural Decile 2	35.52	0.16%	Urban Decile 2	0.89	0.14%
Rural Decile 3	41.25	0.15%	Urban Decile 3	0.8	0.18%
Rural Decile 4	50.59	0.17%	Urban Decile 4	3.56	0.19%
Rural Decile 5	59.7	0.17%	Urban Decile 5	17.77	0.16%
Rural Decile 6	66.2	0.17%	Urban Decile 6	48.9	0.14%
Rural Decile 7	79.55	0.17%	Urban Decile 7	73.98	0.14%
Rural Decile 8	93.03	0.17%	Urban Decile 8	148.71	0.17%
Rural Decile 9	128.6	0.17%	Urban Decile 9	543.96	0.16%
Total	**593.06**			**838.86**	

Source: Study computations

Table 0-23: SAM output derived saved losses (KES millions) and incremental benefits during the 2014/2015 outbreak.

	Impacts	*Saved losses*
S1	3,771.59	
S2	3,367.66	403.92
S3	3,335.17	436.42
S4	3,660.16	111.43
S5	3,404.81	366.78
S6	3,381.59	389.99
S7	3,474.45	297.14
S8	3,404.81	366.78
S9	3,729.80	41.78
S10	3,701.94	69.64
S11	3,762.30	9.29

Source: Study computations

6.4.6 Livestock sector cost benefit analysis of the RVF control strategies.

A cost benefits analysis that compares 7 year period (2008 to 2015) costs of control (reported in chapter five) and avoided losses during the next assumed epidemic under different control scenarios is summarized in Table 0-24 and Table 0-25 The period reflects a time when baseline measures were being implemented to minimize impacts of the next outbreak, while alternative strategies assumed improvement in years 2012-2014.

Table 0-24: The Present value (PV) of the costs (KES) of control for the 8 year period compared to RVF losses associated with the 2014/2015 RVF outbreak.

Scenario	*Losses*	*8 year period*	*Annualized*
Scenario 1	PV RVF losses	3,249,411,426	406,176,428
	PV RVF control costs	470,175,392	58,771,924
Scenario 2	PV RVF losses	2,411,143,120	301,392,890
	PV RVF control costs	708,631,990	88,578,999
Scenario 3	PV RVF losses	2,340,348,009	292,543,501
	PV RVF control costs	723,844,956	90,480,619
Scenario 4	PV RVF losses	3,065,598,104	383,199,763
	PV RVF control costs	571,985,529	71,498,191
Scenario 5	PV RVF losses	2,466,334,047	308,291,756
	PV RVF control costs	705,983,451	88,247,931
Scenario 6	PV RVF losses	2,400,207,859	300,025,982
	PV RVF control costs	721,316,981	90,164,623
Scenario 7	PV RVF losses	2,573,840,404	321,730,050
	PV RVF control costs	634,020,924	79,252,615
Scenario 8	PV RVF losses	2,456,231,487	307,028,936
	PV RVF control costs	629,836,900	78,729,613
Scenario 9	PV RVF losses	3,160,657,130	395,082,141
	PV RVF control costs	552,467,976	69,058,497
Scenario 10	PV RVF losses	3,160,657,130	395,082,141
	PV RVF control costs	574,634,067	71,829,258
Scenario 11	NPV RVF losses	3,226,265,870	403,283,234
	NPV RVF control costs	571,985,529	71,498,191

Source: Study computation

The annual control costs expressed as present value for the baseline strategy was KES 58,771,924. When control costs were increased by a range of between 18% and 54%, the incremental benefits remained higher (benefit cost ration of 1.1 to 5.0) to than incremental costs except for strategies S10 and S11. Among the strategies with improved vaccination, S8 returned the highest benefit cost ratio followed by S7, S3, S2, S6 and S5. However S3 offered the highest incremental benefits followed in decreasing order by S6, S2, S8, S5, and S7. When the costs of alternate strategies are increased by 20%, the BCR remains positive only in the case of improved vaccination strategies at between 2.0 to 2.28.

Table 0-25: Incremental benefits and costs and benefit cost analysis (in KES)

S	*Incremental benefits (avoided losses in 2014/2015)*	*7 year incremental costs*	*% increase in costs*	*BCR*
S2	838,268,306	238,456,598	51	3.52
S3	909,063,417	253,669,564	54	3.58
S4	183,813,322	101,810,137	22	1.81
S5	783,077,379	235,808,059	50	3.32
S6	849,203,567	251,141,589	53	3.38
S7	675,571,022	163,845,532	35	4.12
S8	793,179,938	159,661,508	34	4.97
S9	88,754,296	82,292,584	18	1.08
S10	88,754,296	104,458,675	22	0.85
S11	23,145,556	101,810,137	22	0.23

Source: Study computations S= Strategy

6.5 Discussions and conclusions

During the 2006/2007 epidemic, populations of all species declined and sheep recorded the highest negative rates followed in decreasing order by cattle, goats and camels. Maintaining the current base practice of control would result in nearly similar trends being observed during an assumed 2014/2015 epidemic. The simulation showed that adopting improved vaccination strategies two years before an epidemic can yield significant positive impacts on animal populations and production due to avoided infections, mortality and abortion rates. Simulation showed depending on farming system, during the 2006-2007 epidemic about 7-9 %, 10-21%, 9-14% and 1.3% cattle, sheep, goats and camels in high risk areas were infected which was equivalent to a total of 2.13 million animals, of which 1.2 million died. Also about 216,430 abortions occurred in all species following infection of pregnant females. In case an RVF epidemic occurred in 2014/2015, under the current base control practice of vaccinating about 1 million sheep and goats in RVF high risk areas, about 2.7 million animals would be infected, while 1.4 million would die. Adopting two mass vaccinations over two years and increasing coverage nearly fivefold above the current base practice or one year mass vaccination and two years of mass vaccination of young animals only would reduce infection rates by between 26-32%.

Estimates showed that RVF high areas, annually produce about 1.2 billion to 1.5 billion litres of milk (valued at KES 35.6 and 48.4 billion) during normal years which reflect about one third of national production. RVF epidemics, reduced this milk production by 1.7% and the value of losses were estimated at KES 0.84 billion and KES 1.55 billion during the 2006/2007 and 2014/2015 (under base practice) RVF epidemics respectively. Improving vaccination coverage 2 years before an outbreak would avoid the losses by between 38% and 55%. The total RVF mortality value during the 2006/2007 epidemic was estimated as KES 3 billion while the value during the hypothetical assumed 2014/2015 outbreak (under base practice) would be KES 6.17 billion. Improving vaccination avoids the mortality losses by as much as KES 2.69 billion.

Apart from milk production and mortality losses, RVF is associated with market level losses estimated at KES 4.1 billion during the 2006/2007 and KES 7.6 billion during the assumed 2014/2015 epidemic. Incorporating improved vaccination would reduce the losses by 17 to 23% compared to the baseline while those that do not would reduce by 1-5%. While producers bear the highest losses other value chain actors namely raw milk traders, live animal traders and meat sellers also bear significant losses and should be involved in policy decisions concerning the disease.

The SAM framework shows that the production and marketing losses spill to other sectors of the economy namely the crop sector and also have differential impacts among rural and urban households. As expected vaccination strategies with improved vaccination exhibited higher benefit cost ratios. Between the two improved vaccination strategies, two year mass vaccinations returned higher BCR compared to one mass vaccination of all ages followed by two years of vaccination of young animals.

However, while the focus of this study was RVF impacts, simulation of ten year herd dynamics covering two RVF epidemics and four drought years revealed significantly higher impacts of drought shocks compared to RVF. Also, over the ten year period, baseline abortions and mortality caused higher impacts than RVF. The findings have implications for livestock development programming.

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CHAPTER SEVEN

BURDEN OF HUMAN RVF AND COST-EFFECTIVENESS OF LIVESTOCK INTERVENTION FROM A PUBLIC HEALTH PERSPECTIVE

7.1 Introduction

Major animal and human Rift Valley fever (RVF) outbreaks have occurred in several countries in both Africa and Middle East (Bird *et al.,* 2009). Pepin, *et al.,* (2010); Swanepoel and Coetzer, (2004), and Bitek, 2013 have documented RVF impacts in the public health Sector. As mentioned in other chapters, the last two epidemics in Eastern Africa, occurred in 1997/1998 and 2006/2007. The long inter-epidemic period (IEP) is attributed to association between the epidemics and El Niño rains.

In managing human RVF, governments seek to optimise health gains by reducing: risk of occurrence; severity or duration of disability; and deaths. In the process, budgetary constraints force difficult decisions on allocation of limited resources. Health economists support evidence-based decisions by providing data on disease burdens (monetary and non-monetary) as well as cost-effectiveness of control options. Monetary costs include prevention/control costs and opportunity costs. On the other hand, disability adjusted live years (Daly's), a non-monetary measure that reflect premature death and reduced quality of human life (disability) in non-fatal cases has been recommended by World Health Organisation (WHO), (Murray, 1994). One DALY is equal to one lost year of "healthy life".

Cost-effectiveness assists in prioritising public health sector's engagements allowing decision makers to compare financial costs and gains made or likely to arise from different interventions. Expressed as cost of intervention per DALY averted, WHO sets thresholds based on per capital national incomes. An interventions that costs less than three times the national annual per capita GDP is considered cost–effective, whereas one that costs less than once the national annual per capita GDP is considered highly cost–effective. For zoonotic problems such as RVF, gains in human health arise from both animal and public health interventions and, therefore, examining costs and benefits at both levels and in particular benefits to public health sectors arising from animal interventions become important. Zoonotic transmission is mostly animal to human and not the reverse; this implies that the diseases need to tackle at source- animal level. Therefore, effectiveness of interventions for public health zoonotic problems lies mostly outside public health sector. Assessing costs and benefits of control from a multisectoral perspective facilitates identification of strategies that yield highest benefits to both sectors, while knowledge of distribution of benefits would inform animal control cost sharing between animal and public health sectors.

This cost-effectiveness analysis (CEA) examines impacts of 11 alternate livestock sector level RVF interventions on public health and identifies those that offer highest benefits to the public health sector.

7.2 Literature review

7.2.1 A review of human RVF epidemiological parameters

This literature review focuses on epidemiological parameters as they were important in supporting cost-effectiveness analysis

7.2.1.1 Human RVF incidences, prevalence and geographic spread in Kenya

Laboratory detection of human IgM and IgG antibodies in serum samples, confirm on-going or past RVFV infections respectively. Frequency and spatial extent of RVFV transmission to humans during outbreaks are not well defined (LaBeaud *et al.,* 2007) and therefore IgG antibodies (that last for decades after infection) are assumed to provide a reliable index or prevalence of prior exposure to outbreaks (LaBeaud *et al.,* 2011). In Kenya and contrary to limited geographic spread of clinical cases detected during past epidemics, antibody sero-surveys suggest otherwise. The surveys show that transmission (during epidemic and inter-epidemic) to human and primates have occurred across the country with varying sero-positivity rates (Johnson *et al.,* 1982, 1983a, 1983b; Morril *et al.,* 1991 and LaBeaud *et al.,* 2007 and 2008).

During the period 1994 to 2007, sero-positivity of 13%-18% (IgM) and 0-40% (IgG) are reported in 16 / 47 (34%) counties of Kenya including Garissa, Turkana, Kilifi, Kwale, Uasin Gishu, Baringo, Wajir, Tana River, Lamu, Malindi, Mombasa, Taita Taveta, Kajiado, Isiolo, Nakuru, Laikipia (Munyua *et al.*,2010; Woods *et al.*,2002; LaBeaud, *et al.*,2007). During the 1994 to 1997 inter-epidemic period (IEP), Turkana, Uasin Gishu and Kwale Counties had an overall IgG sero-prevalence of 10.8%, highest in Turkana (19.1% in 1994) and lowest 0% in Kwale in 1996 and 1998, (LaBeaud *et al.,* 2007).

LaBeaud *et al.,* (2007), report greater regional transmission of the 1997/1998 epidemic than previously thought. For the same epidemic Woods *et al.,* (2002) reports seropositivity rates of 18% (IgM age adjusted to 14%) and 13% (IgG) in North Eastern RVF hot spots in Garissa County. About 8.5 years after the 1997/1998 epidemic and seven months before the 2006/2007 epidemic similar IgG seropositivity rate of 13% (overall); 20% (rural village) and 6% (urban area) are reported in the same area (LaBeaud *et al.*, 2008). During the 2006/2007 epidemic period a higher IgG sero-prevalence (23%) and a 13 % (IgM) rate are reported in Garissa, Kilifi, Ijara and Baringo (Nguku *et al.,* 2010). After the 2006/2007 epidemic, IgG sero-positivity remained close to prior rates at 23% (LaBeaud *et al.,* 2011). The demonstrated high prevalence suggests endemic transmission patterns that may preclude accurate estimation of regional acute outbreak incidence and high risk of exposure (LaBeaud, *et al.,* 2007, 2011).

Reported morbidity and mortality incidence does not reflect the high sero-prevalence rates. During the last two epidemics, human RVF incidences are reported as 170 deaths and unknown cases (for 1997/98) and 700 cases and 90 deaths (for 2006/07). These are fewer than sero-prevalence derived cases of 27,500 and 185,000 for the two epidemics respectively (Woods *et al.,* 2002; Nguku *et al.,* 2010). Therefore, to reflect near real life situation, adjusting for underreporting is important when surveillance data is used for burden estimation. In addition to under-reporting, surveillance data has additional limitations of misclassification which can mislead burden estimation. For example, out of the 700 RVF line listed cases in 2006/2007, 150 were non-cases; 392 were confirmed and probable recovered cases (Nguku *et al.,* 2010). Under reporting could be attributed to high clinically symptomatic RVF cases (WHO, 2000 and 2010; Peters, 1997). In Kenya, another factor could be the location of RVF hotspots in remote underdeveloped regions. In 2007, the distance between health facilities in North Eastern Kenya was more than 40km and less than 95% of RVF human cases (mild and acute) may not have reached health facilities (Schelling and Kimani, 2008).

In other countries, similarly high RVFV (IgG, IgM) sero-prevalence of 3.3% to 42% has been reported. In Sudan IgG sero-prevalence of 42% is reported for the 2007/2008 RVF epidemic (Hassanain *et al.,* 2011) while 707 human confirmed cases and 230 deaths occurred (WHO, 2008). Anyamba *et al.*, (2010) estimated human cases of 75,000 implying 99% under reporting. RVFV IgG sero-prevalence in other countries is: 22.3% in Senegal, (Wilson *et al.*, 1994); 3.3% in Gabon (Pourrut *et al.*, 2010) and 6.7%, in Nigeria, (Olaleye, 1996).

7.2.1.2 **RVF morbidity /clinical symptoms; Sequeale and mortality**

Figure 0-1 and Appendix 32 summarise the wide range of RVF clinical manifestations and timelines associated with the two forms of human RVF. A self-limiting febrile illness occurs in the majority cases with or without clinical manifestations, while the severe form occurs in a small proportion of cases that develop one or more of three distinct signs of haemorrhagic fever/bleeding, meningo-encephalitis/ neurological disorders, or retinitis/ blindness after the febrile period with varying disability (Easterday, 1965; Peters and Meegan, 1981; Weiss 1957; Peters 1997; and WHO, 2000, 2010; and Ikegami and Makino, 2011).

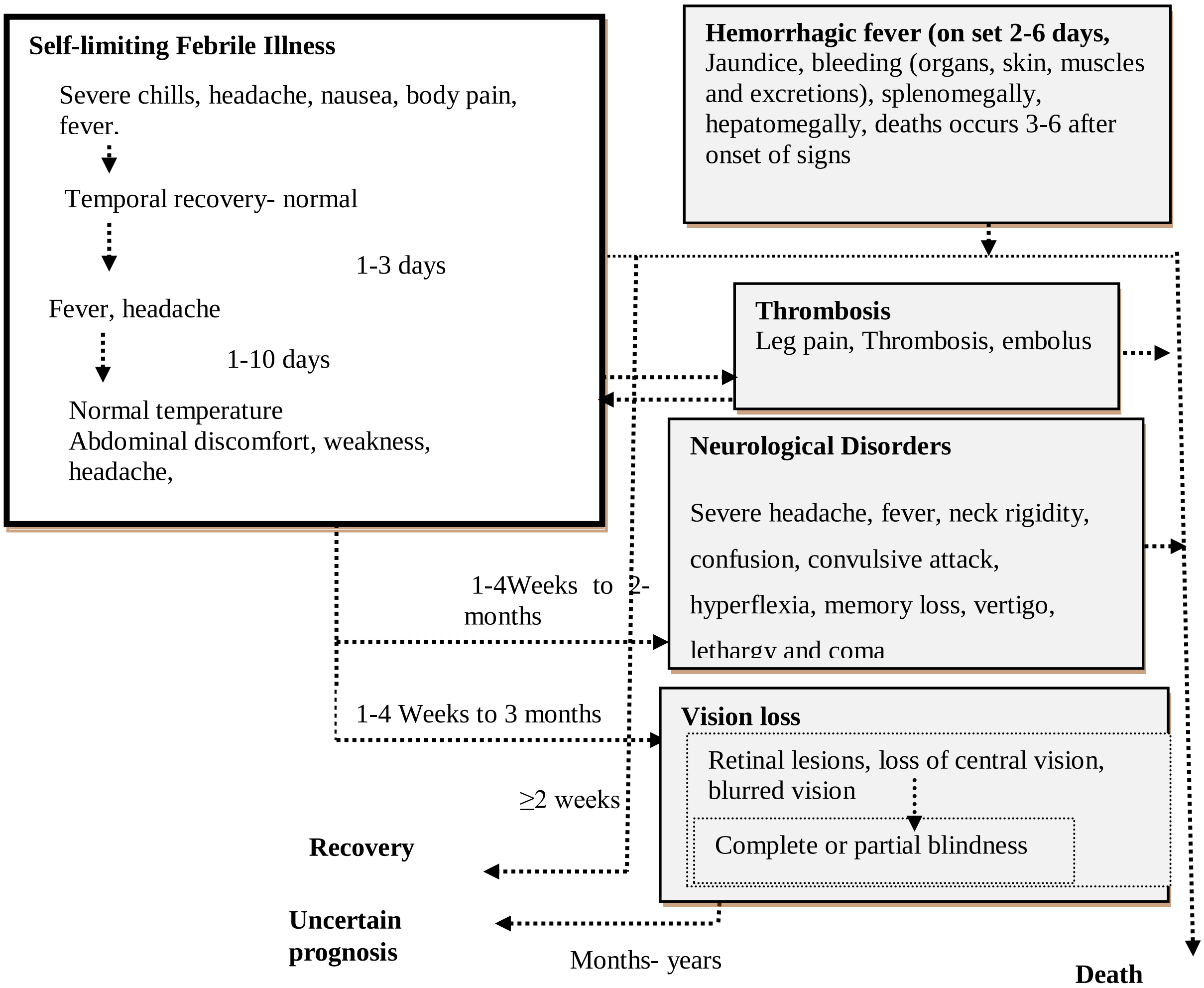

Figure 0-1: Pathological Form of RVF in humans.

Source: (Ikegami, T and Makino, S 2011; Nguku *et al.*, 2010; Kahlon *et al.*, 2010; WHO, 2010)

Clinical manifestations associated with symptomatic self-limiting febrile mild infections are often difficult to distinguish from other mild, self-limited illnesses or can mimic those of malaria. The length of hospitalization was 5 days (Kahlon *et al.*, (2010). During the 2006/2007 epidemic in Kenya, non-severe RVF illness was reported in 53% (95% CI = 41–64%) of cases that sought medical care while a post epidemic survey, showed a lower rate of 17% (Anyangu *et. al.*,2010). On the other hand, the severe cases accounted for 47% (95% CI = 35–59%) of the cases seeking medical care and 6% of the survey sample; the latter more or less agrees with cross-sectional survey derived rates of 7-8% reported in (Velden *et al.*,1977).

Haemorrhagic (bleeding) fever is seen in less than 1% of all cases (WHO, 2010), and in 50% (or higher) of severe cases (Kahlon *et al., 2010.*). During the 2006/2007 epidemic in Kenya, haemorrhagic form was detected in 11-15% (23%-32% of severe cases) (Nguku *et al.,* 2010). The neurological severe form is seen in less than 1% cases (WHO, 2010;), Ocular (retinitis) severe form occurs in 0.5 to 2.8% of the patients and about 50% of affected patients experience permanent loss of vision (WHO, 2010; LaBeaud *et al.*,2008) although higher rates of 1-20% have been reported (Madani *et al.,* 1979). In Kenya chronic uvieitis/retinitis complications or sequaelae is widely reported as an RVF complication where 71% of retinitis cases had visual impairment (LaBeaud *et al.*, 2011). Chronic retinal disease cases were 5 times more likely to be RVFV seropositive (LaBeaud *et al.*,2011) and accounted for 39% of the RVF severe cases of over 50 years old (LaBeaud, *et al.*,2008). Other severe forms reported include renal impairment in Sudan and in 60% of admissions of which 90% required dialysis (Imam *et al.,* 2009).

Overall the RVF mortality rate in humans is low - 0.5% to 2.0% and in 50% of patients suffering from haemorrhagic form and 25%-31% of renal complications (CDC, 2002; Laughlin *et al.,* 1979). Mortality is rarely associated with neurological and ocular forms. Higher mortality rates of 8% in South Africa (Archer *et al.,* 2013); 26.4% in Kenya (Nguku *et al.,* 2010); 40% in Sudan; 13.9% in Saudi Arabia (Madani *et al.,* 2003); 47.0% in Tanzania; 42.8% (Sudan,) and 6.3% (Kahlon *et al.,* 2010) are reported.

7.2.1.3 Risk factors for human RVF infection, severe illness, and death

Two transmission routes for human RVF include contact with infected animals or animal products and through mosquito bites (WHO, 2012; LaBeaud *et al.,* 2008). Between the two, higher rural sero-positivity is most likely associated more to contacts than mosquito bites (LaBeaud *et al.,* 2008; Anyangu *et al.,* 2010). In Kenya, risk factors associated with sero-positivity, identified through univariate, bivariate and multivariate analysis and summarised in Appendix 33 include: (i) demographics (sex and age); (ii) occupation; (iii) animal factors and (iv) geographical location and environmental factors as epidemics have repeatedly occurred in specific geographical locations which has enabled risk mapping into high, moderate and low risk areas.

Demographics factors include: household size of less than four persons (p = 0.001); being male; being herd boy; and being older (Woods *et al.*, 2002; LaBeaud, *et al.,* 2007, 2008 and 2011; Nguku *et al.,* 2010). Males were nearly 3 times more likely to be seropositive (20% vs. 9%; adjusted OR 2.78, (95% CI 1.18– 6.58)) and more likely to die from acute RVF. However, in Turkana, being female had a greater risk of infection p≤ 0.025 (LaBeaud *et al.,* 2008). Being < 15 years of age is associated with lower sero-positivity (p = 0.001). For each year of life, the odds of being RVFV sero-positive increased by 5%.

Animal related risk factors include: drinking raw milk; sheltering livestock; milking animals; disposal of aborted foetuses; assisting animal births; killing or skinning animals; cooking meat; slaughtering animals (Woods *et al.*,2002; Anyangu *et,al.*,2010; LaBeaud *et al.*,2008). Disposal of aborted foetuses increased the chance of getting RVF by nearly 3 times (OR, 2.78 (CI, 1.03-7.52) (LaBeaud *et al.,* 2011). Contact with a dead human body is also reported as a risk factor (Anyangu *et al.,* 2010). From multivariate analysis only contact with sheep blood, amniotic fluid, or milk (not including milk consumption); and sheltering domestic livestock in during floods are significant. Drinking raw sheep milk was independently associated with infection, but did not reach statistical significance (RR 1.6, 95% CI 0.9-2.9). However, other studies support that raw milk consumption is strongly associated with RVFV exposure (LaBeaud *et al.,* 2011).

Among the species, sero-positivity association was greatest with sheep-related activities (followed by goats, cattle and lastly camels. This is attributed to the fact that sheep are mostly affected (Jost *et al.*, 2010) and could contribute to high contact rate. Consuming or handling products from sick animals was associated with death (Anyangu *et al.,* 2010). Slaughtering as a risk factor is also reported in Egypt, where abattoirs workers that handled animal parts had the highest risk of being sero-positive (RR, 2.37, p= 0.05) followed by those that cut animal throats (RR, 2.23, p= 0.04) and skinned animals (RR, 2.06, p=0.07); as well as opening up the carcass and cleaning up.

Risk factors reported in studies outside Kenya report similar treads. Past infection (IgG) sero-positivity increased with age and varied among groups of household (0-37.5%); (Wilson *et.al*,1994) Occupation differences in sero-positivity has been reported in Gabon where hunters had the highest prevalence of 4.4% followed by farmers (3.5%), and the rest 2.4% (Pourrut *et al.*,2010).

7.3 Methodology

The cost-effectiveness analysis process involved: (i) estimation of monetary and non-monetary (Daly's) costs of two human RVF epidemics – the 2006/2007 and a next assumed and simulated outbreak in 2014/2015; (ii) cross –sectoral allocation of costs and; (iii) comparisons of allocated control costs of 11 control interventions implemented at the animal health level to Daly's averted. Seven steps of CEA described in Martins and Rushton (2014) guided this analysis and are summarised in Figure 0-2.

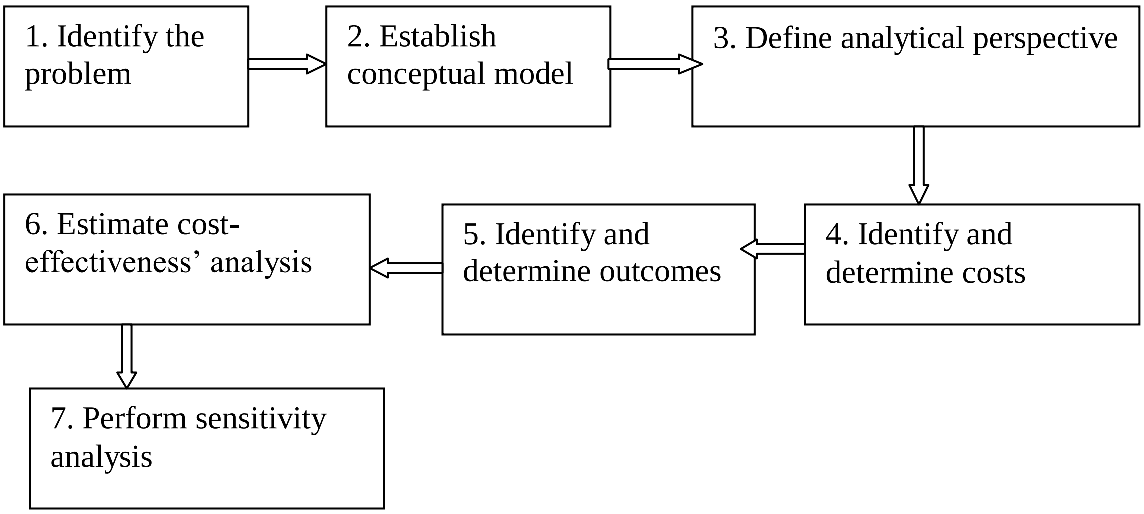

Figure 0-2: Steps involved in CEA.

Source: Martins and Rushton (2014); adapted from Petitti, 2000.

7.3.1 The problem, conceptual model and analytical perspective

The peak in human RVF incidences coincides with livestock epidemics (Archer *et al.*, 2013, Wood *et al.*, 2002). The problem was therefore described as human RVF epidemics transmitted from animals and therefore requiring efforts to address it at animal source. From a public health perspective the need for CEA based prioritisation of animal control measures was compelling. It is assumed that animal RVF control strategies reduce human epidemics by lowering the size of infected animal populations particularly those with a higher likelihood of transmitting infection through contact. Subsection 7.2.1.3 highlights the contact risk factors. A herd dynamics and RVF simulation model (described in chapter six) simulated the number of animals infected during the 2006/2007 RVF epidemic and the extent to which ten alternative animal RVF control strategies (described in chapter five) reduced the number of infected animals for a hypothetical epidemic in 2014/2015.

In modelling costs and benefits of animal RVF control to the public health sector, the CEA took a public health partial societal perspective and all significant costs and benefits are considered irrespective of who pays or benefits. The costs of control constitute the numerator in a cost-effectiveness analysis while outcomes or an effectiveness measure is the denominator (Gold, 1996).

7.3.2 Identification and estimation of costs

Three types of costs considered important to the CEA include:

(i) Expenditures on animal RVF control reported in chapter five. The costs would be incurred by the livestock sector and human health benefits would be produced without separable costs which presented a challenge for the CEA. To address this, the study adapted basic elements of a technique for joint cost allocation in multipurpose projects, known as the "separable costs–remaining benefits" method (Gittinger, *1982*) to allocate the animal health control costs to both sectors in proportion to the benefit gained.

(ii) household out of pocket costs

(iii) Direct expenditures by the government on diagnosis, treatment and hospitalization for inpatients and outpatients.

The latter two types of costs for the 2006/2007 RVF epidemic were obtained from Orinde, (2014)[16]) and Schelling and Kimani, (2008). Data from both studies were extrapolated for a 2014/2015 epidemic. Indirect recurrent public health sector expenditures and fixed costs for government (salaries, surveillance, deprecation of equipment and transport) could not be estimated due to data and time constraints.

7.3.3 Identification and determination of outcomes

Effectiveness of animal interventions from a public health perspective (reduced human cases) would depend on the extent to which measures reduce the number of animals that would be infected and infected animals that die or abort, or get slaughtered. Reduced human cases translate into lower mortality and disability (reduced or averted Daly's) and decreased case management costs both which were used as measures of effectiveness in this study.

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[16] This study was done in a larger collaboration between veterinary and public health sectors in Kenya and based on field data collected during and shortly after the outbreak in spring 2007 after the 2006/2007 RVF epidemic. In addition, we use data of an hypothesised and modelled outbreak in 2014/2015.

The 2006/2007 DALY calculations relied on best available evidence–based estimates of the registered incidence, IgM sero-prevalence, mortality, average age at death obtained from literature and outbreak reports. The incidence was adjusted for under reporting. To estimate the 2014/2015 human RVF incidence, the magnitude of animal risk factors during the epidemic were taken to be the total number of infected animals generated by the livestock RVF simulation model. The risk factors included the number of animals (cattle, sheep, goats and camels) infected and dead from RVF; pregnant animals that abort from the disease; infected animals that were slaughtered or sold.

To estimate human cases that would arise from the simulated 2014/2015 animal cases, a simple compartmental Susceptible-Exposed-Infectious-Recovered (SEIR) model constructed in R software (Dunn, 2007) was used to describe transmission of human RVF from infected animals. The model assumed that all human cases originated from infectious animals during the epidemic and categorised the population as either susceptible (S), incubating (E), infectious (I) and infected. The latter either died or recovered (R). The total human population (N) can be mathematically represented as:

N = S + E+I+ R

The empirical equations for human population for day 1 is given by

The empirical equations for human population for day 1 is given by

(a) $S = S_{DO} - \beta^{*}(\frac{IL}{TL})$ ……………………………………………….(i)

(b) $E = E_{DO} + (\beta * S_{DO} * \left(\frac{IL}{TL}\right) - E_{DO} * (\frac{1}{IP})$………………………(ii)

(c) $I = I_{DO} + \left(E_{DO} * \left(\frac{1}{IP}\right)\right) - \left(I_{DO} * \left(\frac{1}{RP}\right)\right) - (I_{DO} * mr)$………(iii)

(d) $R = R_{DO} + (I_{DO} * \left(\frac{1}{RP}\right))$……………………………………..(iv)

Where:

do = day Zero

β = daily transmission rate from animals to humans

IL = infected livestock population (cattle, sheep, goats and camels)

TL= Total livestock population (cattle, sheep, goats and camels)

IP= Incubation period

RP= Recovery period

mr = Mortality rate

Published RVF prevalence rates associated with four epidemics in Tanzania, Egypt and Mauritania (summarized in subsection 7.3.2.1) were applied to susceptible animal and human populations to obtain sero-prevalence derived total infected populations. Livestock population were obtained or extrapolated from literature. The total infected populations together with that of the 2006/2007 epidemic in Kenya were used to fit the model to estimate β- daily transmission coefficient of each epidemic. The data was obtained from literature. A single β value obtained through a uniform randomisation in Excel was applied and the model fitted with the 2014/2015 epidemic SEIR parameters for different strategies and animal RVF epidemiological data to generate total number of human cases and mortality.

The DALYs associated with two human RVF epidemics – the 2006/2007 and next assumed 2014/2015 (with 11 strategies), were estimated for the epidemic periods of November 2006 to June 2007 and November 2014 to June 2015. Inter-epidemic cases were not included as the animal RVF model assumed no animal inter-epidemic transmissions.

7.3.3.1 Estimation of DALYs associated with the 2006/2007 and 2014/2015 RVF epidemic

Narrod *et al.,(*2012); Murray, (1994; and Murray and Lopez (1996) describe how to estimate DALYs as the sum of: (i) years of healthy life lost (YLL) due to premature death from a standard expected years of life lost (SEYLL), and (ii) for non-lethal cases, years of productive life lived with disease specific disability (YLD). Similar to LaBeaud *et al.,* (2011), this study estimated DALYs for both chronic and acute cases as summarized in the formula below.

DALYs = YLL + YLD (for acute and chronic cases) ------------- (1)

YLL = (Incident deaths) × (standard expected years of life lost at median age of death) --- (2)

YLD_{acute} = (Incident cases with acute disease only) × Disability Weight $(DW)_{acute}$ × (duration acute disease) - (3)

$YLD_{chronic}$ = (Incident cases progressing to chronic disease) × $DW_{chronic}$ × (duration of chronic disease) ---- (4).

Data to support analysis of DALYs obtained from literature included; 2006/2007 RVF epidemic associated infected human cases and deaths disaggregated by age categories and sex; antibody (IgM) sero-prevalence derived total human cases; estimates of incidence of acute and chronic cases including sequalae; average age at death; duration of illness and disability weight. Year 2000 (representing 2006) and 2012 (representing 2014) global level highest life expectancy of birth values of 78 years and 82 for men and, 85 and 87 years for women respectively were obtained from model life table (WHO, 2013). Similar to LaBeaud *et al.,* (2011), this study used published proxies of disability weight of 0.22 and 0.62 for acute cases and chronic cases respectively. Based on LeBeuard *et al.,* (2008) and Riou *et al.,* (1989) the study assumed a chronic case rate of 10% which is the upper limit of 4% to 10% of survivors who develop prolonged ocular and neurological complications of ophthalmitis and meningoencephalitis.

The analysis was limited to a sub-national population of the high risk areas in the pastoral and agro pastoral systems (PAP) and disaggregated by nine age categories and sex Appendix 31. While discounting of DALYs and age weighting are recommended, this study estimated undiscounted and unweighted values. This was due to the fact that analysis was at sub-national population and mainly for the purposes of ranking control strategies. Also, there is increasing criticism of discounting and age-weighting because they are additive.

7.3.4 Cost-effectiveness analysis and sensitivity analysis

Cost-effectiveness of 10 alternate RVF strategies implemented at animal level was expressed as net present value of public health allocated costs of each control option per DALY averted. Also a benefit cost ratio is computed to compare public health monetary costs and allocated control costs. A discount rate of 20% is used, assuming base year for evaluating control strategies was 2007. The discount rate was varied by 10% for sensitivity analysis.

7.4 Results

This section is organised in such a way that a review of the epidemiological parameters (prevalence, total number of cases, clinical signs and risk factors) of human RVF are first presented as a basis of understanding the problem and identifying appropriate parameters for estimating the non-monetary burden of RVF which is presented in later subsections.

7.4.1 Estimated DALYs associated with the RVF epidemics

7.4.1.1 Estimated DALYs associated with 2006/2007 RVF outbreak and quantified animal –human transmission relationship

The 185,000 human cases in the RVF hotspots, derived from a 13% IgM sero-prevalence by Nguku *et al.,* (2010) were assumed to represent all RVF infections in high risk areas in PAP and Kilifi (in MFM). Based on reported (literature) proportions of underreported, acute, severe and asymptomatic, the 185,000 cases were disaggregated as shown in Figure 0-3. The desegregation was considered realistic as the 90 deaths reported represents1% of the estimated acute cases, which falls within the 0.5% to 2.0% reported in literature. The 175,750 asymptomatic cases were assumed to result in negligible disability and were excluded from DALY analysis. Since analysis focused on high risk areas in PAP systems, cases falling out of this system (estimated as 15 deaths and 9 chronic complicated and 824 acute cases) were removed. The demographic distribution of confirmed and probable cases reported in Nguku *et al.*, (2010) and summarised in Table 0-1, were extrapolated to all acute and chronic non-fatal cases. A disability weight of 0.22 and 0.62 was used for acute RVF cases that recovered without and with complications respectively and for duration of 0.1 years.

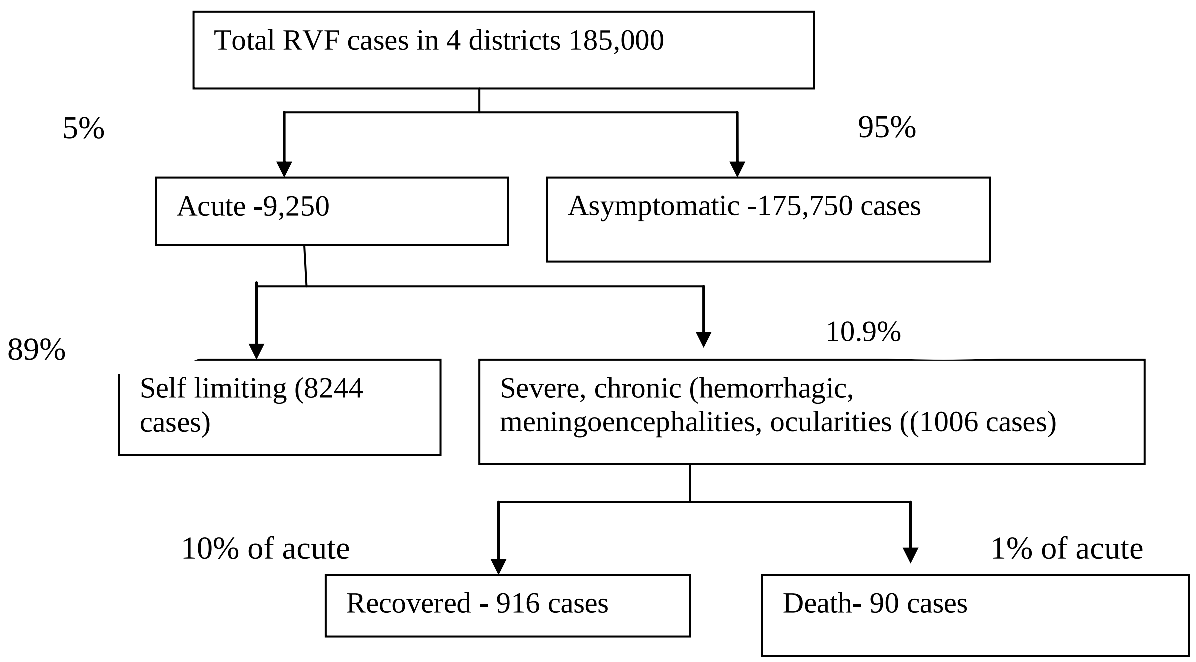

Figure 0-3: Disaggregated incidence of the RVF cases in RVF hot spots

Table 0-1: Number of 2006/2007 probable and confirmed human RVF cases, deaths and CFR, by age group and sex

Age group	# probable and confirmed cases			# Deaths and (CFR %)		
	Female	Male	Total	Female	Male	Total
less than 10 years	4	4	8	0	0	0
11 to 20 years	25	49	74	4 (16)	11(22)	15(20)
21-30	44	61	105	9(20)	35(57)	44(42)
31-40	38	33	71	10(26)	9 (27)	19(27)
41-50	23	20	43	3(13)	2(10)	5(12)
51-60	6	11	17	0	1(9)	1(6)
61-70	5	10	15	0	5(50)	5(33)
71-80	1	3	4	0	1(33)	1(25)
over 80	2	1	3	0	0	0
Total	148	192	34017	26(18)	64(33)	90 (26)

Source: Nguku *et al.*, (2010)

Table 0-2 to Table 0-4 summarize incidence, YLL, YLD and undiscounted, unweighted DALY estimates for 2006/2007 RVF epidemic in PAP high risk areas disaggregated by sex and nine age categories. The total DALY burden for 2006/2007 in PAP high risk areas was estimated as 3,974.05 or 1.50 DALYs per 1,000 population of which mortality contributed 94.6%. Orinde, (2014) estimated a higher value of 4,035.6 (3.4 DALYs per 1,000 population) for the same epidemic. This was attributed to the fact that Orinde (2014) used a disability weight of 0.652 for all cases (684 cases, 90 deaths) line listed and considered human populations in three Counties only.

As mentioned in the literature review, not all line listed cases were due to RVF. Also, this study considered human population in all RVF high risk areas in PAP areas and adjusted prevalence for under reporting. This study and Orinde, 2014 imply that the burden of RVF associated with 2006/2007 RVF outbreak might be higher than the estimates.

[17] Demographics data was not available for 52 cases

Table 0-2: Estimated YLL for the RVF high risk areas in PAP areas and for the 2006/2007 epidemic

Sex	*Population*	*Deaths*	*Deaths per 1,000*	*Av. Age at death*	*YLLs*	*YLL per1000*
Males						
less than 10 years	542,302	0	-	7.15	0	-
11 to 20 years	438,252	9	0.02	17.25	546.75	1
21-30	164,607	32	0.19	24.2	1721.6	10
31-40	109,567	7	0.06	34.5	304.5	3
41-50	80,689	1	0.01	41.45	36.55	0
51-60	48,455	1	0.02	48.4	29.6	1
61-70	24,353	5	0.21	63	75	3
71-80	8,040	1	0.12	72.5	5.5	1
over 80	9,242	0	-	80	0	-
Sub-total	1,425,507	56			2719.5	1.91
Females						
less than 10 years	485,061	0	-	5	0	-
11 to 20 years	320,577	3	0.01	31	153	0
21-30	175,934	7	0.04	21.7	422.1	2
31-40	128,036	8	0.06	34.8	377.6	3
41-50	64,008	2	0.03	38.25	87.5	1
51-60	28,028	0	-		0	-
61-70	14,823	0	-		0	-
71-80	6,208	0	-		0	-
over 80	8,955	0	-		0	-
Sub-total	1,231,630	20			1040.2	0.84
Total	**2,657,137**				**3759.7**	**1.41**

Source: Study Computation

Table 0-3: Estimated YLD for acute cases for the 2006/2007 RVF high risk areas in PAP

Sex /age category	*Acute cases*					*Chronic cases*			
	Population (X10,000)	Incidence (Inc)	Inc/1,000	YLD	YLD/1000	Incidence (Inc)	Inc/1000	YLD	YLD/1000
Males									
≤10	54.2	118.7	0.22	2.6	0	13.2	0.02	0.8	0
11 - 20	43.8	1,127.80	2.57	24.8	0.06	125.3	0.29	7.8	0.02
21-30	16.5	771.7	4.69	17	0.1	85.7	0.52	5.3	0.03
31-40	11.0	712.3	6.5	15.7	0.14	79.1	0.72	4.9	0.04
41-50	8.1	534.2	6.62	11.8	0.15	59.4	0.74	3.7	0.05
51-60	4.8	296.8	6.13	6.5	0.13	33	0.68	2	0.04
61-70	2.4	148.4	6.09	3.3	0.13	16.5	0.68	1	0.04
71-80	0.8	59.4	7.38	1.3	0.16	6.6	0.82	0.4	0.05
over 80	0.9	29.7	3.21	0.7	0.07	3.3	0.36	0.2	0.02
Total	142.6	3,799.00	2.67	83.6	0.06	422.1	0.3	26.2	0.02
Females									
≤10	48.5	118.7	0.24	2.6	0.01	13.2	0.03	0.8	0
11 -20	32.1	623.3	1.94	13.7	0.04	69.3	0.22	4.3	0.01
21-30	17.6	1,038.80	5.9	22.9	0.13	115.4	0.66	7.2	0.04
31-40	12.8	831	6.49	18.3	0.14	92.3	0.72	5.7	0.04
41-50	6.4	593.6	9.27	13.1	0.2	66	1.03	4.1	0.06
51-60	2.8	178.1	6.35	3.9	0.14	19.8	0.71	1.2	0.04
61-70	1.5	148.4	10.01	3.3	0.22	16.5	1.11	1	0.07
71-80	0.6	29.7	4.78	0.7	0.11	3.3	0.53	0.2	0.03
over 80	0.9	59.4	6.63	1.3	0.15	6.6	0.74	0.4	0.05
Total	**1,231,630**	**3,621.00**	**2.94**	**79.7**	**0.06**	**402.3**	**0.33**	**24.9**	**0.02**
Grand total	**2,657,137**	**7,420.00**	**2.79**	**163.2**	**0.06**	**824.4**	**0.31**	**51.1**	**0.02**

Source: Study Computation

Table 0-4: Total DALYS for the 2006/2007 RVF high risk areas in PAP

Sex **Sex/age category**	**Population**	*Population* DALYs	DALY per 1000
		Males	
less than 10 years	542302	3.43	0.01
11 to 20 years	438252	579.33	1.32
21-30	164607	1,743.89	10.59
31-40	109567	325.08	2.97
41-50	80689	51.98	0.64
51-60	48455	38.17	0.79
61-70	24353	79.29	3.26
71-80	8040	7.21	0.90
over 80	9242	0.86	0.09
Total	1425507	2,829.25	1.98
		Females	
less than 10 years	485061	3.43	0.01
11 to 20 years	320577	171.01	0.53
21-30	175934	452.11	2.57
31-40	128036	401.61	3.14
41-50	64008	104.65	1.63
51-60	28028	5.14	0.18
61-70	14823	4.29	0.29
71-80	6208	0.86	0.14
over 80	8955	1.71	0.19
Total	**1231630**	**1,144.80**	**0.93**
Grand total	**2657137**	**3,974.05**	**1.50**

Source: Study computation

7.4.1.2 Estimated number of animal risk factors for human RVF infection during the 2006/2007 and next assumed 2014/2015 epidemics.

The simulation model derived potential animal risk load for human transmission associated with the 2006/2007 and assumed next outbreak in 2014/2015 under different control strategies (S1-11) is summarised in **Table 0-5.** The base (current) practice (S1) involved vaccinating slightly less than 1 million or 7% of sheep and goats in high risk areas and with animal sentinel surveillance (with irregular sampling) and passive surveillance. Strategies with enhanced vaccination improved both coverage and also extended vaccination to cattle and camels as described in chapter five.

Table 0-5: Estimated number of animal risk factors for all species combined and by epidemic and control options

Strategy	Infected	Abortion	Mortality	Sold	Slaughtered	Lactating
2006/2007	1,575,472	157,866	902,324	1,171	231	538,442
S1	1,744,601	162,302	931,777	8,532	1,345	814,208
S2	1,338,020 (23)	115,899 (29)	719,897 (23)	4,435 (48)	679 (49)	589,112 (28)
S3	1,288,301(26)	95,303 (41)	690,588 (26)	3,260 (62)	631 (53)	572,653 (30)
S4	1,665,017 (5)	160,688 (1)	889,905 (5)	5,392 (37)	876 (35)	771,824 (5)
S5	1,348,598 (23)	129,377 (20)	726,375(22)	4,642 (46)	726(46)	594,117 (27)
S6	1,302,900 (25)	98,579 (40)	698,203 (25)	3,893 (54)	678 (50)	586,594 (28)
S7	1,344,711 (23)	107,203(34)	726,301 (22)	5,035 (41)	744 (45)	585,335 (28)
S8	1,320,711 (24)	98,977 (39)	707,958 (24)	5,856 (31)	830 (38)	589,543 (28)
S9	1,718,239 (5)	157,710 (3)	917,459 (2)	7,313 (14)	1,065 (21)	798,173(2)
S10	1,703,703 (5)	154,029 (5)	909,889 (2)	6,235 (27)	886 (34)	795,974 (2)
S11	1,743,345 (0)	162,302 (0)	930,535(0.1)	6,509 (24)	1,119 (17)	813,273 (0.1)

Source: Computed from the animal RVF transimission model**.**

Number in brackets **represent** the percentage by which alternative 10 strategies reduce risk load compared to baseline

Strategies with enhnaced vaccination strategies (S2, S3, S5, S6, S7 and S8), would reduce number of by a much higehr proprotion compared to those assuming baseline vaccination strategy. Strategies with both enhanced vaccination and surveillance strategies (S2,S3, S5, S6, S7) show higher reduction of number of infected animals compared to those with enhanced surveillance and baseline vaccination, e.g (S8). Over all, S3 would reduce the total risk load by 29% followed in decreasing order by S6, S8, S7, S2 and S5. Strategies without vaccination would reduce total risk load by less than 5%, making vaccination strategy adopted as the single most important strategy to reduce risk for human RVF.

7.4.1.3 Estimated human RVF incidence associated with 2014/2015 by control strategy

To quantify the RVF transmission coefficient between infected animals and humans, first the study had to obtain human and animal RVF secondary data on sero-prevalence, mortality and morbidity reported for concurrent epidemics from literature. Only four studies (1 in Tanzania, 1 in Egypt, 2 in Mauritania) simultaneously or separately report human and animal sero-prevalence during epidemics.

The 2006/2007 RVF epidemic in Tanzania, was widespread occurring in 10 (out of a total of 30) regions. Animal and human cases were reported in 45/120 and 28/120 Districts, respectively (Sindato *et al.,* 2011). In 7 (out of the 21) districts that concurrently reported humans and livestock cases, data from 74 households showed infection rates of 7.4% in cattle, 8.3% in goats and 4.9% in sheep (Chengula *et al.,* 2013). The rates are lower than the 62%- 66%, reported in Jost *et al.,* (2010) and higher than the 0.4% -1.0% reported by veterinary staff. Considering the shortcomings in rates obtained through surveillance, the household data was considered more appropriate and was used in modelling animal-human transmission rates. The corresponding public health data from the 21 districts were 309 human cases and 142 deaths; no sero-prevalence data was available. In absence of human sero-prevalence data reported alongside livestock rates, the study assumed that the reported 142 fatal human cases represent 1% of acute cases and 0.05% of total cases (acute and assymptomatic) and applied this to total human populations to estimate cases that could have arisen.

In Mauritania, RVF epidemics occurred in 2003 and 2010 in a total of five (5) out of 13 provinces. In 2003, human IgM and IgG sero-prevalence of 25.5% (25/98) and 10% respectively are reported (Ousmane *et al.,* 2007) yet surveillance data showed 25 human cases and 4 deaths. At the same time, evidence of recent infection (IgM) was detected in 46.3 % of livestock (25/54, 48 goats and 6 sheep). On the other hand, human IgM sero-prevalence associated with the 2010 RVF epidemic was 37.5% (30/80 patients; (Ousmane *et al.,* 2010) while rates in livestock were 27.7% (23/83 animals 70 goats and 13 sheep) animals. Also, 3/5 sick camels tested positive. The 2010 outbreak resulted in 63 human cases, and 13 deaths (El Mamy, *et al.*,2011) since human and animal sero-prevalence data from the two outbreaks was based on a small sample, this study working backwards estimated the human acute and non-acute cases as well as overall prevalence from mortality detected. For livestock, lower sero-prevalence associated with the 1993 RVF outbreak reported in Southern Mauritania as 16% (42/262) in goats, 14% (12/84) in sheep, 13% (8/62) in cattle, and 33% (19/58) in camels (Saluzzo *et al.,* 1987) was adopted.

In Egypt, during an epidemic in 2003, human prevalence of 7.7% (n= 375) and animal prevalence of 10.4% and 5% in cattle and sheep, respectively, were reported in Kafr el-Sheikh Governorate of Egypt (Kamal, 2011). A fifth epidemic also considered was the 2006/2007 RVF epidemic in Kenya. This study estimated in chapter six, the number of animal cases while literature review in section 7.2 highlights the sero-prevalence derived human cases.

Table 0-6: and Table 0-7 summarise information for the five epidemics in terms of the susceptible livestock populations, prevalence rates and estimated total infected animal and human populations which acted as inputs for the animal-human transmission model to estimate transmission coefficients. The animal-human modelling estimated transmission coefficients were estimated as: 0.016% (Mauritania 2003); 0.024% (Tanzania); 0.057% (Kenya); 0.068% (Egypt) and 0.1% (Mauritania 2010). A random value of 0.069% (obtained by applying a uniform distribution to these values) was applied in the model to generate numbers of human cases resulting from infected animals during the assumed hypothetical 2014/2015 RVF epizootic by each control strategy (Figure 0-4). As expected, strategies with improved vaccination options (S2, S3, and S5-S8) showed significant decline in cases compared to the baseline (S1). Strategy 3 (S3) shows the highest decline of 26%, followed in decreasing order by S6 (25%), S8 (24%) and S2, S5, and S7 (23%). Among strategies without enhanced vaccination, S11 offered minimal change at (0.01%), while S4, S9 and S10 showed slightly higher change of between 2-5%.

Table 0-6: Sero-prevalence derived animal cases during specific epidemics in selected countries

Country RVF epidemic	Livestock population in outbreak area (, 000)*				Sero-prevalence**				Sero-prevalence derived cases (,000)			
	cattle	sheep	goats	camels	cattle	sheep	goats	camel	cattle	sheep	goats	camels
Kenya 2006/2007	2840.9	3606.0	4123.5	651.5	0.09	0.21	0.14	0.01	244.3	753.6	569.0	8.5
Tanzania 2006/2008	8102.5	5733.0	1714.5		0.07	0.05	0.08		599.6	84.0	475.8	
Egypt, 2003	47.4	76.6	68.4		0.10	0.05			5.0	3.8	0	0
Mauritania, 2003	528.0	3872.0	2464.0	286.0	0.16	0.13	0.14	0.33	84.5	503.4	345.0	94.4
Mauritania, 2010	24.0	308.0	196.0	247.0	0.16	0.13	0.14	0.33	3.8	40.0	27.4	81.5

Source: * estimated from FAO STAT, ** (Kamal, 2011), Ousmane *et al.*, 2010, Saluzzo *et al.*, 1987

Table 0-7 Sero-prevalence derived human cases during specific epidemics in selected countries

Country	RVF epidemic	Human population in RVF area	Sero-prevalence	Estimated acute and non-acute cases	Acute	Non acute	Deaths
Kenya	2006/2007	1,280,769.23	0.13	166,500	8,325	158,175	90
Tanzania	2006/2008	10007159.5	0.029	291,889	14595	277295	146
Egypt	2003	655,052	0.077	50,439	2521.95	47917	25
Mauritania	2003	221,301	0.03615	8,000	400	7600	4
Mauritania	2010	82,297	0.00039	26,000	1300	24700	13

Source: Nguku *et al.*, (2010), human population census data,

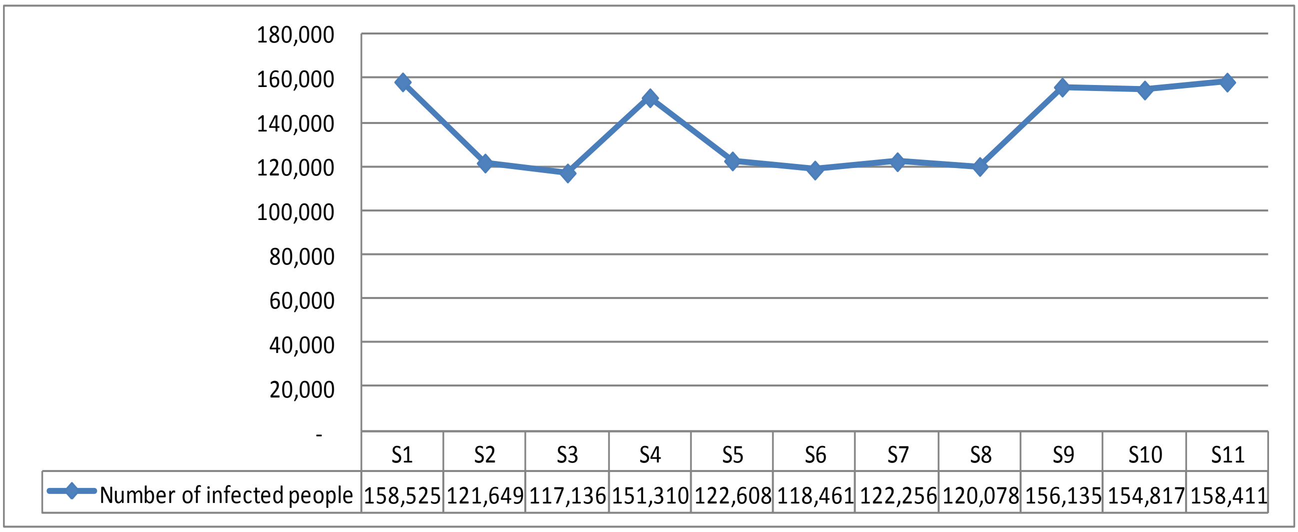

Figure 0-4: Estimated number of human cases associated with 2014/2015 hypothetical epidemic under eleven prevention and control strategies (S1-S11).

Source: Animal-human simulation model

Table 0-8: Estimated number of human RVF mortality during the 2014/2015 and disaggregated other case categories by prevention and control options

	# Cases	Asymptomatic Cases (95%)	Acute (5%)	Self-limiting acute cases	Chronic	Mortality
S1	158,525	150,598	7,926	7,062	864	78
S2	121,649	115,566	6,082	5,419	663	60
S3	117,136	111,279	5,857	5,218	638	57
S4	151,310	143,744	7,565	6,741	825	74
S5	122,608	116,478	6,130	5,462	668	60
S6	118,461	112,538	5,923	5,277	646	58
S7	122,256	116,143	6,113	5,446	666	60
S8	120,078	114,074	6,004	5,349	654	59
S9	156,135	148,328	7,807	6,956	851	76
S10	154,817	147,076	7,741	6,897	844	76
S11	158,411	150,490	7,921	7,057	863	78

Source: Study computation

7.4.1.4 Estimated of DALYs associated with hypothetical assumed 2014/2015 RVF outbreak

DALYs estimated from acute, chronic and dead cases are summarised in Table 0-9 as well as averted DALYs in the case of alternate strategies. Detailed age and sex disaggregated DALYs are presented in Appendix 35. If the current base practice (S1) is continued a next assumed outbreak would result in 4,548 DALYs (3.13 per 1,000 people) in high risk areas located in pastoral and pastoral systems which is 14% higher than the DALY burden associated with the 2006/2007 outbreak. Strategies with enhanced vaccination showed benefits of reducing or averting slightly more than 1000 DALYs. Strategies with the base vaccination strategy averted few DALYs.

Table 0-9; Estimated DALYs (and averted) for the hypothetical 2014/2015 by prevention and control options

Strategy	DALYs	DALYs averted
S1	4,548	
S2	3,490	1,058
S3	3,360	1,187
S4	4,341	207
S5	3,517	1,030
S6	3,398	1,149
S7	3,507	1,040
S8	3,445	1,103
S9	4,479	69
S10	4,441	106
S11	4,544	3

Source: Study computation.

7.4.2 Estimated public health costs and monetary benefits associated with alternative animal RVF control measures

7.4.2.1 Estimated household out of pocket and public sector expenditures on case management and benefits

During the 2006/2007 RVF outbreak, household out-of-pocket expenditures incurred following sick patients and hospitalization ranged from KES 8520 to 9,510 (Schelling and

Kimani 2008; Orinde, 2014; Table 0-10.). The government incurred an extra KES 5’500 per patient on diagnosis, drugs, and protective clothing (Schelling and Kimani, 2008). The study assumed that only the severe acute (that progress to chronic) associated with each control strategy would seek medical treatment and would be hospitalised. The baseline animal RVF practice would result in hospitalisation of about 864 cases, resulting in household out-of-pocket and government direct costs of case management amounting to about KES 13 million (

Table 0-11). Households out pocket costs would account for 63.4%. Compared to the baseline, strategies with enhanced vaccination would reduce this cost by between KES 3.8 to 4.3 million while the others would save less than KES 2 million.

Table 0-10: Estimates for out of pocket expenditures for Human RVF cases

Cost element	**Costs [a]** n= 127	**Costs [b]** **n= 20**
Transport	1460	1000
Care givers, accommodation	2000	2000
Food (care giver and patients)	500	500
Hospitalisation fee	2500	1000
Card/prescription	50	20
Material (Needles\syringes\gloves)	500	500
Diagnosis (including lab fee)	100	1000
Special tests (X-rays, liver function tests Kidney, liver function, malaria tests)	1200	1000
Drugs	1200	1500
Grand Total	9510	8520

Source: [a]Bitek (2013) and [b] Schelling and Kimani (2008)

Table 0-11; Estimated avoided monetary costs for the 2014/2015 by prevention and control strategy

Control strategy	*hospitalised cases*	*Estimated total monetary costs*	*Saved costs*
S1	864	12,968,035	
S2	602	9,038,426	3,929,609
S3	580	8,703,167	4,264,868
S4	749	11,242,246	1,725,789
S5	607	9,109,749	3,858,287
S6	586	8,801,614	4,166,421
S7	605	9,083,541	3,884,495
S8	594	8,921,716	4,046,320
S9	773	11,600,752	1,367,284
S10	766	11,502,842	1,465,194
S11	784	11,769,848	1,198,187

Source: Study computation

As explained in the methodology, these costs, though important for the CEA were not the only public health costs. Schelling and Kimani (2008), report additional public health costs (though not measured then due to data gaps) as costs of recruitment of additional staff (40 nurses and 10 nutritionists) and staff salary time spent on case management and surveillance (5% of staff time). Data obtained from Ministry of Health showed that about KES 100 million from government and an established amount from NGOs funded the following activities: case management; community education; preventive measures (e.g. vector control, mosquito nets); sampling and transportation of samples; laboratory diagnosis; and surveillance and referrals of suspect cases.

7.4.2.2 Animal RVF control costs allocated to public health.

Table 5.13 and Figure 5-4 in chapter five present a summary of the total 10 year costs associated with each of the eleven animal RVF control strategies, which range from KES 1.2 to 2.0 billion. The costs were considered as joint costs and allocated to livestock and public heath proportionally as benefits (avoided costs or losses). The benefits considered were those to: the livestock sector (avoided production losses, detailed in chapter six); households (from reduced out-of-pocket expense and avoidance of hospitalization and drugs); and government public health (avoided costs of treatment of sick and hospitalized cases). Saved public monetary costs (benefits) accounted for: 0.5-0.6% (S2, S3, S5, S6, S7 and S8); 1.5-1.6% (S9 and S10); and 4.9% (S11) of the total public and livestock sectors monetary benefit. Animal health costs allocated to public health ranged from KES 3.2 million (S8) to KES 9 million (S10) and KES 28 million in S11 (Table 0-12).

Table 0-12: Summary of benefits and cost-effectiveness by strategy (KES 00,000)

Srategy	Saved costs PH	LS	DALY averted	Total control costs	control costs allocated to PH	BCR-PH	CE (KES)/DALY Averted
S2	39	8,383	1,058	7,086	33	1	3,126
S3	43	9,091	1,187	7,238	34	1	2,847
S4	17	1,838	207	5,720	53	0	25,713
S5	39	7,831	1,030	7,060	35	1	3,360
S6	42	8,492	1,149	7,213	35	1	3,065
S7	39	6,756	1,040	6,340	36	1	3,485
S8	40	7,932	1,103	6,298	32	1	2,899
S9	14	888	69	5,525	84	0	122,301
S10	15	888	106	5,746	93	0	87,770
S11	12	231	3	5,720	282	0	8,622,231

Source: study computations; PH= public health; LS= livestock sector; CE = cost-effectiveness; BCR = benefit cost ratio. S= Strategy

The high cost allocated to public health in S11 is attributed to the fact that the strategy had almost similar impacts as the baseline. The benefit cost ratio that compared allocated costs to saved monetary costs shows that compared to baseline, strategies with enhanced vaccination had a BCR of slightly higher than one. Based on BCR the strategies can be ranked as: S8, S3, S2, S6, S9, S10, S5 and S7. Strategies with enhanced vaccination also had the lowest control cost per DALY averted; ranging from KES 2847 to KES 3,485 per DALY averted while the rest (excluding S11), ranged from KES 25713 to 122,301 per DALY averted. Based on costs per DALY averted, the strategies can be ranked as: S3, S8, S6, S2, S5, and S7. S2 and S3 exhibited control cost per DALY averted of US$62 and US$77 and US$43 and US$ 47 respectively with 20% and 10% discount rates. In 2007, per capital GNI was US$ 720 (World Bank, 2015). When a discount rate of 10% is used, S2 and S3 remain cost-effective while the BCR is less than one showing that saved monetary costs are lower than control costs allocated.

7.4.3 Discussions

This study's CEA sought to demonstrate public health sector benefits gained from controlling RVF at animal level. Due to unavailability of animal-human RVF transmission model at the time, we applied two separate models linked through data. The results showed significant public health sector monetary and non-monetary burden (DALYs) associated with the 2006/2007 RVF epidemic in high risk areas in PAP systems. Considering that the systems carry 53%, 66%, 73% and 99.7% of the cattle, sheep, goat and camels found in high risk areas and, that human transmission is mostly through animal contact the DALYs estimated are considered to constitute a large proportion of the national burden.

This study's estimates of 3,974.05 DALYs, are lower than estimates of 4,035.6 in Orinde, (2014) for the same epidemic. The difference lies in key parameters data used; Orinde used a disability weight of 0.652 for all cases and only considered line listed cases as well human populations in only three Counties. Nguku *et al.,* 2010 reports shows that not all line listed cases were due to RVF. Our study considered human population in all RVF high risk areas in PAP areas and used prevalence derived incidence to accommodate for under reporting. Both studies imply that the national burden of RVF associated with 2006/2007 RVF outbreak is likely to be higher than the estimates.

Total DALYs associated with the 2006/2007 and the hypothetical 2014/2015 outbreak (under base control scenario), translate to 852 annual un-weighted, undiscounted DALYs that represent 7% of the upper limit global RVF burden. Considering that RVF is a public health problem of 32 countries in Africa (LaBeaud, *et al.,* 2011) Kenya can be said to carry a significant burden of RVF. Inherent in DALY estimation process, it is the YLL from RVF mortality that account for the largest proportion of DALYs estimated. The animal-human RVF transmission modelling showed that under the animal control baseline practice, the magnitude of a next hypothetical epidemic would be nearly similar to that of 2006/2007.

Based on WHO thresholds for cost-effectiveness, improving animal vaccination coverage two or three years before an RVF epidemic can be considered to be highly cost–effective from a public health perspective in terms of reduction in DALYs and direct treatment costs for human cases. The strategies can significantly (23-26%) reduce DALYs. The base current practice of vaccinating a very low percentage of sheep and goats only in high risk areas is not cost-effective for the public health sector. Also, the benefit cost ratio comparing allocated costs to saved monetary costs shows that compared to baseline, some alternative strategies with enhanced vaccination had a BCR of slightly higher than 1 while others had less than 1.

Based on the model, enhancing surveillance in strategies that assume baseline vaccination options would yield only small benefits to the public health sector. However effective animal surveillance systems would allow public health sectors to implement public health communication earlier to minimise contact with infected animals, benefits which were not captured in our model. Enhanced animal surveillance also supports earlier implementation of sanitary bans and therefore limiting potential contacts through slaughter and marketing activities.

However the results must be interpreted from a perspective that in modelling animal-human transmission, this study faced challenges as no animal-human transmission model had been developed to support multi-sectoral analysis. At the same time few data sets on joint animal and public health outbreak investigations exist. This study relied on few data points from five epidemics in four countries. Similar difficulties were reported for other similar studies (LaBeaud *et al.,* 2011a, Randi, 2011), to an extent that Randi, 2011 assumed in case of a, human RVF outbreak in Southeast Texas, USA, it would achieve spread and infection rates similar to West Nile Virus. Similarly, LaBeaud *et al.,* (2011a) presented annual global burden of RVF as a wide range estimate of 353 to 11,958.

To overcome these challenges and particularly to strengthen One Health economic analysis of zoonotic diseases, there is need for future joint epidemiological investigations to generate data that could support animal-human RVF epidemiological modelling. Also, there is need for public health studies that estimate:

(i) the relative contribution of different public health measures such as surveillance and communication on the outcome of the epidemic;

(ii) Contact rates and transmission probabilities. Generating longitudinal data on human and animals cases during both the epidemics and inter –epidemic period and scale of measures applied would support modelling of livestock- human transmission as was the case of brucellosis modelling in Mongolia in Roth *et al.*, (2003).

Further, in modelling the magnitude of the hypothetical 2014/2015 RVF epidemic, we assumed that human behaviour prior to and during epidemics would not change and therefore, the force of infection is maintained as consistent. This was influenced by observations that the PAP areas are under developed and receive relatively lower quantity and quality of health services including community based communication for behaviour change. Consequently incidences of zoonosis are higher than in other farming systems as shown in the case of brucellosis (Regassa *et al.,* 2009; Racloz *et al.,* 2013) and anthrax (Nkedianye *et al.,* 2007). Some risk factors for human brucellosis and anthrax such as living in close proximity to livestock, handling livestock and consumption of raw products are similar to those of RVF. Owange *et al.,*(2015) highlights pastoralist's perception where mosquito bites are perceived as key risk factors compared to contact with infected livestock and livestock products which is contrary to other studies (Woods *et al.,*2002; Anyangu *et* *al.*,2010).). Finally, we note that errors could have resulted from the modelling process relying on two models to conduct this cost-effectiveness analysis. The errors could have made the model less sensitive to changes in some of the key processes being studied.

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CHAPTER EIGHT

GENERAL CONCLUSIONS AND RECOMMENDATIONS

The current study set out to answer four questions;

(i) Who are the stakeholders of Rift Valley fever (RVF) prevention and control and to what extent have they instutionalised a One Health (OH) approach to zoonoses control?

(ii) What are the annual costs associated with current (base practice) and alternative livestock level RVF prevention and control measures?

(iii) What are the impacts of the 2006/2007 and a hypothetical next assumed 2014/2015 RVF epidemic on the livestock sector and national economy as well as the benefits associated with the alternative measures?

(iv) What are the public health sector impacts of the 2006/2007 and a hypothetical next assumed 2014/2015 RVF epidemic as well as benefits of the livestock interventions to the sector?

7.5 Main conclusions

7.5.1 One Health stakeholder and institutional analysis findings and implications for RVF control.

1. Thirty two (32) and 21 public and private RVF and OH stakeholders were mapped at national and sub-national levels respectively. They were drawn from animal and public health sectors and climate prediction agencies
2. At national level,
    a. nearly half (47 %) of identified stakeholders were not involved in OH cooperation
    b. Each stakeholder played a unique role but DVS, WHO, ILRI, MOH and CDC were the critical stakeholders for cross-sectoral cooperation.
    c. The stakeholders at national level, led by line ministries with support from development and technical partners had mobilised for and institutionalized OH through formal structures.
3. At sub-national level (Garissa County),

a. Stakeholders had no mobilised for and neither had they institutionalized OH through informal or formal structures.
b. Public health stakeholders were more, better coordinated through formal intra-sector platforms and had a fairly strong link with communities
c. Animal health stakeholders were fewer, were poorly coordinated and had a weak interface with communities
d. The ratio of personnel capacity was 10:1 (public health sector to animal health sector). This would seriously undermine the rationale of stopping zoonotic outbreaks at animal level before they jump to human beings.

7.5.2 Annual costs associated with current (base practice) and alternative livestock level RVF prevention and control measures

1. The 2007 present value of annual control costs for the baseline strategy were estimated at KES 58,771,924.
    a. Surveillance, animal treatments with insecticides and animal vaccination accounted for 36%, 22% and 22% of the costs respectively
2. Annual average costs of integrated strategies with enhanced vaccination increased by 134% to 140% over the baseline strategy costs

7.5.3 Cost and benefits of RVF prevention and control from a livestock sector perspective.

3. The 2006/2007 RVF outbreak reduced the value of total domestic supply by KES 3,740.4 million (US$43.5 million).
4. Over a 10 year, period, the non RVF losses from drought, baseline mortality and abortions were more than twice that of RVF.
5. When vaccination coverage was increased 3-5 fold 2-3 years before a hypothetical outbreak, the benefit cost ratio was higher than 1 (BCR of 1 to 5)
6. Enhancing surveillance and adopting animal treatments with pour-on insecticides also yielded a BCR of more than 1. However, when the costs of alternate strategies are increased by 20%, enhanced surveillance and pour treatments show a BCR of less than 1
7. The annual baseline vaccination strategy of vaccinating less than 10% of sheep and goats only shows a benefit cost ratio of less than 1. if the practice is maintained, the

impacts of a next epidemic on the livestock sector would have a similar magnitude as the 2006/2007

7.5.4 Cost-effectiveness livestock RVF prevention and control to the public health sector

4. At 20% and 10% discount rate the cost per DALY averted for strategies with improved vaccination was ranging from KES 2,847 to KES 3,485.
    a. Based on WHO thresholds for cost-effectiveness, improving animal vaccination coverage two or three years before an RVF epidemic can be considered to be highly cost–effective from a public health perspective
5. Both the current baseline vaccination strategy and use of larvicidal chemicals were not cost-effective to the public health sector.

7.6 Main Recommendations

7.6.1 To improve future prevention and control the study recommends

(i) Shortening the OH institutionalisation process at sub-national by creating formal OH platforms that build on existing cross-sectoral coordination platforms,

(ii) Increasing capacity of the sub-national animal health sector to participate in OH

(iii) Extending the national OH network to include excluded stakeholders and organisations

(iv) Improving coverage of animal vaccination 2-3 years before an expected epidemic by 3 to 5 fold.

(v) Improving animal surveillance by incorporating vector surveillance and establishing community based surveillance systems.

(vi) Development of holistic livestock development plans that addresses all shocks especially impacts of drought, baseline mortality and abortions.

7.6.2 Contribution to livestock economics and areas of further research

7.6.2.1 New knowledge generated

The study

i. Has established baseline stataus of OH institionalisation in Kenya against which progress can be monitored in the future.
ii. developed a conceptual framework for societal costs associated with Rift Valley fever

iii. Estimated the costs and benefits associated with Rift Valley fever control from both livestock sector and public perspective.

The study can be constituted a near comprehensive analysis of RVF control from a OH perspective.

To improve future economic analysis of RVF and other zoonoses from an OH perspective, this study recommends further areas of research that include:

(i) Development of animal-human RVF transmission models that simulate magnitudes of RVF epidemics under different multisectoral control scenarios.

(ii) Design of epidemiological studies implemented jointly and which collect key data during joint outbreak investigations such as population of animals (by species) and people in outbreak areas, national prevalence and incidence rates, impacts of RVF outbreaks on animal production indices etc. without such data, models will be parametrised using proxies and expert opinions and values .

(iii) Generation of longitudinal data on human and animal's cases during inter –epidemic periods in addition to scale of measures applied.

(iv) Public health studies to estimate: the relative contribution of different public health RVF measures such as surveillance, sanitary bans and communication on the outcome of an epidemic; and animal- human contact rates and transmission probabilities.

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Appendix 1: Checklists and Questionnaire

Economic Analysis Of Rift Valley Fever Control Options From A Multisectoral Perspective In Kenya:

<u>Section One: Rift Valley Fever and other zoonoses stakeholder and institutional analysis checklist</u>

Introduction

I am --------- and I am conducting a study to explore the roles and responsibilities of organizations and individuals in RVF and other zoonoses control, OH activities implemented so far, stakeholders with whom you collaborate with, nature of relations and strength of relations. As an important actor in zoonoses control, it is crucial for us to obtain such information from your organization. The plan is to contact all critical stakeholders in this analysis and the information will be used to improve collaboration in RVF and other zoonoses control and inform policy decisions regarding One Health approach. Explain the One Health concept as "a framework, to address the risk of zoonoses and other emerging infectious diseases at the animal-human-ecosystems interface, which will see more coordinated collaboration between the animal and human health systems as well as wildlife and environment experts"

A) Background Information (all respondents)

Date of interview	Day ____month _____Year_____
District	
Location	
Village	
Type of interview, *tick as appropriate*	Key informant _____ Focus Group Discussion (FGD)____
<u>For key informant</u>	
Name of respondent	
Sex of respondent	☐ Male ☐ Female
Health sector of respondent	*1= Human health 2= Livestock health 3 =*

	*Wildlife Health 4= Others (specify)*_______
Designation/role of respondent	Designation--------
If involved in marketing of livestock and livestock products , mention all livestock products traded in	
No of years one has been working livestock business	
For focus group discussions	
No of males and females participants (*if FDG)*	Males ----------- Females----------
Village name *(if FDG)*	___________

B) Knowledge, roles, responsibilities, in RVF, zoonoses and One Health

Key informant respondents target (livestock producers, trader in livestock and livestock products, community animal and human health workers, technical officers working in different health sectors and at different levels, community leaders and any other respondent to whom may be relevant).

1. What do you consider as you're as your role in the control of diseases and in particular zoonoses?
2. Specifically, what has been your role and responsibilities in prevention and control of RVF and other zoonoses? Please elaborate?
3. Which sub-national, national, regional and international organizations or group of people have you collaborated with in the past in order to play your role and achieve your responsibilities specifically in RVF and other zoonoses control? Also, could you please mention other organizations working on RVF and other zoonoses that you know of and which you have not collaborated with? *Record information in the matrix below column 1,*

Organisation	Enter codes for collaboration linkage (see above, enter all that apply	Collaboration or linkage score

4. For each organization, mentioned, kindly mention the type of collaboration activities *(use the codes provided below to enter category of activities in column 2)*.

a) No linkage or collaboration
b) Provide financial support to;
c) receive financial support from,
d) technical support to;
e) technical support from;
f) information to
g) information flow from
h) hold joint meetings
i) Joint implementation of activities
j) 0thers specify________________________

5. How would you score the collaboration linkages for each relation, as in would you score them as none, (for no linkage), weak, medium, strong or very strong. *Insert information in column 3*,

C) Past and current activities in OH collaboration

Key informant respondents target (community animal and human health workers, technical officers working in different health sectors and at different levels, community leaders and any other respondent to whom may be relevant).

6. Have your organization or you as an individual been involved in any activities that can be described as having embraced, multisectoral and multidispinary collaborations or OH to address an animal or public health challenge? Please describe the activities in detail- timelines, individual or organizations worked with, collaboration structures, problem being solved, success of the approach, challenges and lessons learnt.

D) Capacity to undertake OH roles

Key informant respondents target (community animal and human health workers, technical officers working in different health sectors and at different levels, community and community leaders and any other respondent to whom may be relevant).

7. Regarding your roles mentioned above, what would you describe are the major challenges to you face and over can they be overcome?

8. And how would you describe the effectiveness of the roles played by communities, public veterinary services and medical services in North Eastern province and in your District, the challenges and solutions?

9. Describe the animal health and public health infrastructure in North Eastern province and in your District- staff, funding, offices, vehicles, motor cycles etc.

Section Two: Checklist to identify past and current RVF prevention and control options used

E) **Control measures implemented:** ***Focus group discussions and key informant traders***

Now, I would like to tell about available control measures for preventing and controlling RVF at animal level, some of which may be known to you. The measures include: disease reporting by farmers; surveillance activities by private and public animal health service providers including sampling; environmental spraying; spraying and dipping animals with pyrethroids; animal vaccination for RVF; communication and awareness; raw milk marketing bans, slaughter bans; movement restrictions and closure of livestock markets.

For each of the control measures ask:

10. Was it implemented during the 2006/2007 RVF epidemic?

11. If yes please explain the process briefly and who implemented it and who paid for it
12. If livestock keepers paid for the measures, ask how much money was paid?
13. What in your opinion was the efficiency of the measures used in the overall reduction of the disease in animals?
14. Of the measures implemented, which ones did you find very difficult to comply with and why?
15. Now to better respond to the future outbreak which measures in your opinion should be implemented during the epidemic and inter-epidemic phases of the disease and who should implement?
16. To improve animal disease surveillance for zoonoses, how can the livestock keeping community play a better role in gathering disease information and transmitting to the human and animal health officers?

F)* Control measures implemented: *Animal health service providers

17. Please describe the animal RVF prevention measures implemented during the following three periods: 1998- 2006 inter-epidemic; the 2006- 2007 epidemic and 2007- 2011 inter-epidemic period. The data should include: target areas, areas, target populations and number achieved; number and cadre of staff involved, allowances paid, number of days for planning and executing the implementation, types and quantities of materials and equipment's used and the associated costs.

G)* Control measures implemented: *Two workshop's with key RVF technical experts from animal and human health sectors

The outcome of Questions 10- 17 was shared with key technical experts for discussion and feedback on the following

18. What are the possible alternate RVF animal vaccination strategies that can be adopted in different farming systems, what are the realistic targets that can be achieved, and what in their opinion would be efficacy of such measures ***(A maximum of two alternative to be agreed on)***

19. What are the possible alternate RVF animal surveillance strategies that can be adopted in different farming systems, what are the realistic targets that can be achieved, and what in their opinion would be efficacy of such measures ***(A maximum of two alternative to be agreed on)***

20. What are the possible alternate RVF mosquito control strategies that can be adopted in different farming systems, what are the realistic targets that can be achieved, and what in their opinion would be efficacy of such measures ***(A maximum of two alternative to be agreed on)***

21. What are *"the must do"* RVF control strategies in different farming systems, what are the realistic targets that can be achieved, and what in their opinion would be efficacy of such measures ***(list all that apply)***

H) **Recurrent expenditures on control (Respondents- Field and Headquarter veterinary staff)**

Vaccination costs

22. Which RVF vaccine strains are available in the local and international market and what is the market unit (dose) cost for each?

23. What is the percent loss of vaccines during vaccination e.g. for every hundred animals vaccinated, what is the loss due to spillage or other reasons?

24. During vaccination campaigns, how many people constitute a delivery team and what are their designations e.g. veterinarian, animal health assistants etc.?

25. How many cattle, sheep, goats and camels can a team vaccinate in a day?

26. What logistics, materials, field and office equipment's are required by team to support vaccinations?

27. Do livestock keepers have any concern with animal vaccinations? If yes which ones,

28. Based on the different behaviour of livestock keepers towards vaccination what are the realistic RVF vaccination coverage that can be achieved in each farming system with and without goodies?

Surveillance costs for RVF during endemic and epidemic phases

29. How many sentinel herds have been established in the country and what are the cost elements and costs associated with sentinel surveillance?
30. What are the cost elements and actual costs associated with passive surveillance?
31. What is the cost elements and costs associated with active surveillance including pre and post vaccination monitoring?
32. How many officers are normally deployed in a team to undertake an active surveillance mission, their designations, and annual number missions in peace time and during outbreaks and number of mission days, distances covered, number of vehicles involved.

Personnel allowances

33. What are the meal and night allowances for various cadres of officers and by cities or towns?

Communication costs

34. what cost elements are involved in communication e.g. brochure, press releases etc. and what are the unit costs

Vector control costs

35. What are the control elements and costs involved in larvicidal and pour-on animal treatments? E.g. which chemicals are used, quantities, unit costs, personnel employed, their cadre, number of days, equipment's?
36. How many monthly treatments per animal are required during outbreaks?

Laboratory diagnosis

37. What are the cost elements for RVF diagnosis and what are the associated costs?

I) **Fixed costs on control (Respondents- Field and Headquarter veterinary staff)**

38. What laboratory equipment's are used for RVF Diagnosis? please list

39. complete list of equipment's, purchase unit cost, length of use (years) and salvage values for all equipment's used for RVF diagnosis and the proportion of annual time committed to RVF work
40. How many government officers are employed for the purposes of disease control and what proportion of their time is spent on RVF activities during peace time and in outbreaks?
41. How many vehicles are routinely used for disease control, their unit cost and proportion of time spent on RVF activities?

<u>Section Three: Checklist for herd dynamics and RVF epidemiological parameters</u>

J) Events during the 2005-2011 period (all respondents)

42. How would you describe the years since 2005 in terms of normal year, year with drought or year with disease outbreak and specify the disease in case of the latter (? ***Use table below to fill in the responses***

2005 ☐Peace time ☐Drought ☐Disease outbreak	2006 ☐Peace time ☐Drought ☐Disease outbreak	2007 ☐Peace time ☐Drought ☐Disease outbreak	2008 ☐Peace time ☐Drought ☐Disease outbreak	2009 ☐Peace time ☐Drought ☐Disease outbreak	2010 ☐Peace time ☐Drought ☐Disease outbreak	2011 ☐Peace time ☐Drought ☐Disease outbreak

K) Herd dynamics (Focus group discussion respondents)

43. Which are four major threats for livestock production in your district or village?
44. What are the most important **concerns that you relate to RVF**?
45. During a normal year, what proportion of the total community herd of sheep, goats, camels, cattle are_ males, females; adults, immature, young,

46. For each species, what proportion of adult females give birth, abort during drought and normal years
47. What proportion of each species and age and sex category die during normal and drought years
48. What proportion of each species and age and sex category are sold during normal and drought years
49. What proportion of each species and age and sex category are slaughtered at home during normal and drought years

_L)_ RVF parameters (Focus group discussion respondents and technical key informants)

50. How many RVF epidemic/ outbreak are you aware off that have occurred in your district since 20 years ago? Please state the date of the month (if known) and year of the outbreaks
51. What are the most important concerns that you have for a next RVF outbreak?
52. What clinical signs of animal RVF were observed during the outbreaks?
53. What livestock species were affected by RVF?

Section Four: Questionnaire for traders in livestock and livestock products.

54. How would you describe the years 2005 to 2011 in terms of good, normal and bad years with respect to sales and profits, demand and supply
55. For each livestock and livestock product traded in or processed, state weekly turnovers during normal, high and low supply and demand months?
56. For each livestock and livestock product traded in or processed, where do you source them (markets and locations), what are the intermediate and destination markets
57. For each livestock and livestock product traded in or processed, who are other actors involved in value chain before you, with you and after you.
58. How many employees- permanent and casual are employed by your business
59. What are the average operating costs of your business

60. Since the last 5 years, please explain how livestock market closures have affected your business?
61. Since the last 5 years, what has been the average annual wholesale and retail prices of meat livestock and livestock product traded in?
62. What is the value of monthly income loss to you as result on one month livestock trade ban? KES ----

Appendix 2: Number of Health facilities per persons, area and province.

	No. of Health facilities per 100,000 persons	No. of Health facilities per 1,000km2
Province	L2-L4	L2L3
North eastern (Wajir, Garissa and Mandera Counties)	14	1
Coast	22	8
Eastern	16	6
Central	25	91
Nairobi	12	56
Nyanza	13	44
Western	9	45
Rift Valley	17	10
National	16	11

Source: Ministry of Health data

Appendix 3: Health personnel capacity in NEP and at national level

Staff Category	National			NEP			National	NEP
	GOK	FBO/NGO	Total	GOK	FBO/NGO	Total	% in public	% in public
Consultant/Doctors/Dentists	1234	714	1948	24	4	28	63%	86%
Dental Technologists/COHOH/RCO	2382	649	3031	67	7	74	79%	91%
Nurses	17075	5832	22907	472	19	491	74.5	96.1
Phos/Phts	3304	231	3535	96	0	96	93%	100%
Pharmacists/Pharmaceutical Technologists	588	246	834	16	1	17	71%	94%
Lab Technologists/Lab Technicians/Orthopaedic Technologists/Plaster Technicians	2292	887	3179	52	6	58	72%	90%
Nutritionist	453	110	563	14	2	16	80.5	87.5
Radiographers	377	97	474	8	0	8	79.55	100
Physiotherapists	512	111	623	6	0	6	82.2	100
Occupational Therapists	279	52	331	3	0	3	84.3	100
Health Records And Information Officers/ Health Records And Information Technicians	752	195	947	8	1	9	79%	89%
Trained Community Health Workers	16649	1389	18038	334	75	409	92.3	81.7
Social Health Workers/CHEWS	1561	108	1669	11	0	11	94%	100%
Medical Engineering Technologists/ Medical Engineering Technicians	437	58	495	7	0	7	88%	100%
Total	**47895**	**10679**	**58574**	**1118**	**115**	**1233**		

Appendix 4: RVF specific stakeholder roles played during the RVF epidemics and inter-epidemic period.

Activity	Agencies involved in organizing, funding or implementing
Before the 2006/2007 RVF outbreak	
Production of Vaccines (Continuous)	KEVEVAPI
Issued early warning for the 2006/2007 RVF outbreak.	NASA
During the 2006/2007 outbreak	
Notification of outbreak to WHO and OIE and outbreak containment	MOH, DVS, WHO
Acted as source of technical information for the outbreak management & outbreak information	OIE, WHO, FAO, CDC,MOH, DVS
Technical assistance to the MOH and DVS	OIE, WHO, FAO, CDC.KEMRI, Water Reed Project, MSF
Financial support and coordination of the international response in public health	WHO
Outbreak investigations	KEMRI, the Walter Reed Project of the U.S. Army Medical Research Unit, CDC-Kenya Medicines Sans Frontiers (MSF), MOH,WHO, DVS
Capacity building of Central Vet Labs	CDC
Surveillance of RVF in wildlife	KWS
Provision of animal vaccines	USAID , FAO
After the 2006/2007 outbreak	
Rapid appraisal of the 2006/2007 RVF outbreak in Kenya, and national Worksop on lessons learnt from the 2006/2007 outbreak and development of RVF decision support tool	ILRI and DVS, FAO, CDC, MOH
Development of the country RVF contingency plan and establishment of	DVS with technical and financial support from FAO and CDC

sentinel herds and RVF risk mapping	
Implementation of inter epidemic animal vaccination	DVS, NGOs with financial and vaccine supply from FAO and DVS.
Implementation of RVF research projects	ILRI, CDC,ICIPE, KEMRI, DVS, KWS, KARI, University of NAIROBI (up to 10 projects between 2007 to 2012)
Warning of excessive rainfall and potential RVF outbreaks	IGAD-IPAC, KMD
Workshop on RVF – global, regional, national	OIE, FAO, AU-IBAR, DVS , CDC, ILRI, United States Army Medical Research Unit and USAID , KEMRI,
Scientific documentation of RVF outbreak	CDC and Am. J. Trop. Med. Hyg., 83(2_Suppl), 2010,
RVF (Clone 13 and others) Vaccine trails	CDC, DVS, GALMED, KARI
Human surveillance and diagnosis	CDC,MOH
Animal RVF surveillance	DVS

Appendix 5:2010 drought mitigation animal health interventions with RVF alert.

Livestock disease	Number vaccinated	As proportion (%) of the District livestock population
Foot and mouth disease (FMD)	100	0.04
Anthrax (camels)	5,769	5.24
Anthrax (Bovines)	4,490	1.66
Rift Valley fever	55,224	4.41
Contagious bovine pleuropneumonia (CBPP)	5,201	1.92
Sheep and goat pox	8,891	1.02
Contagious caprine pleuropneumonia (CCPP)	69,695	7.99
Peste des petits ruminants (PPR)	34,084	3.91

Source: computed from 2010, Annual report DVO Garissa.

Appendix 6: List of data sourced from literature and expert opinions

Variables	Values used/assumptions			
Duration of outbreak (days)	160			
	Cattles	sheep	goats	camels
Carcass weight of in Kg				
male young	15	5	5	50
male immature	80	10	10	100
male adult	150	15	15	250
female young	15	5	5	45
female immature	70	9	9	100
female adult	130	12	12	200
off takes rates normal years	0.05	0.08	0.06	0.05
reduced in off takes during RVF outbreaks	0.87	0.65	0.65	0.9
proportion of annual off take sold during Jan to APRIL	0.36	0.36	0.36	0.36
Period of market shut downs	3	3	3	3
live animal price reduction during RVF	0.27	0.27	0.27	0.27
Length of Lactation		305 (MFHP); 235(MFM,MFHP)	180	365
Milk off take (kg) per Lactation		1733(MFHP); 465(MFM); 250(PAP)	24 (PAP,MFM); 281 (Dairy goats)	600
proportion of goats milked			0.05 (MFHP); 0.5(MFM);0.1(PAP)	
proportion of goat milk sold			0.33	
Percent reduction of milk due to RVF		0.5 (PAP and MFM); 0.25(MFHP)		
Percent reduction of milk s due to base abortion		0.23 (PAP and MFM); 0.37(MFHP)		

Percent reduction of milk due RVF abortion	0.5 (PAP); 0.3 (MFM); 0.15(MFHP)			
Percent reduction of milk due to drought	0.5 (PAP); 0.5 (MFM); 0.4(MFHP)			
Estimation of average farm gate of milk and live animals price-50% of market	Milk -50% less of market price; live animals, 30% less of national average market price			
cost of slaughter	675	285	285	700
proportion of home slaughter skins and hides sundried	0.81			
proportion of home slaughter skins and hides wet cured	0.12			
proportion of home slaughter skins and hides sold raw	0.072			
proportion of slaughter house slaughtered animals with usable skins	0.7			
proportion of hides and skins sold from home slaughter	0.5			
proportion of home slaughter hides sold as sundried	0.405			
proportion of home slaughter hides sold as raw hide	0.06			
proportion of home slaughter hides sold as salted	0.036			
Price (KES) Sundried (producer; trader primary; trader secondary	300;500;700	25;50 ;100		100;225;300
Price (KES)Raw skins(producer; trader primary; trader secondary	400	35		225
Price (KES)Wet salted(producer; trader primary; trader secondary	500;1150;1600	60;65 ;70		450;550;450
county council levy on hides and skins (KES)	10	5	5	10

proportion of milk sold without RVF	0.05(PAP); 0.3(MFM);0.55(MFHP)	0.1(PAP)	0.1(PAP)
proportion of milk sold with RVF	0.015(PAP); 0.09(MFM);0.165(MFHP)	0.03(PAP)	0.03(PAP)
Value addition-milk (KES) 2006/2007	10.33333333	10.33333	10.33333
Value addition-milk (KES) 2014/2015	15.5	15.5	15.5

Appendix 7: **National Average Live Animal Market prices**

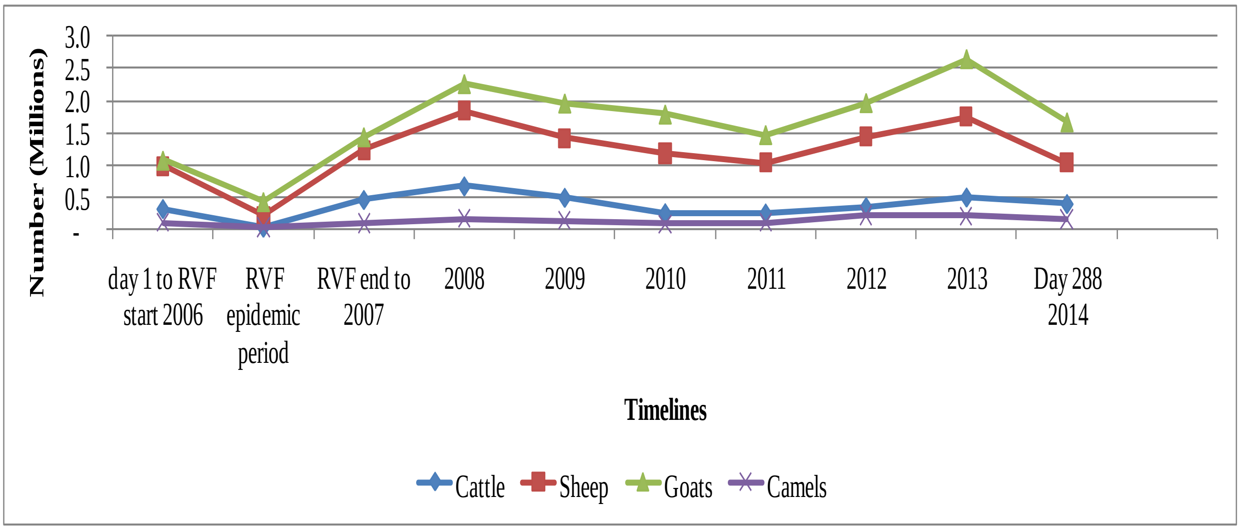
		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Cattle	male young	6,708	10,658	11,433	7,570	10,352	14,455	14,455	14,455	14,455	14,455
	male immature	7,338	12,136	13,446	9,496	16,834	17,384	17,384	17,384	17,384	17,384
	male adult	13,843	18,062	20,318	17,510	24,490	30,342	30,342	30,342	30,342	30,342
	female young	6,114	10,161	8,570	6,836	10,893	11,534	11,534	11,534	11,534	11,534
	female immature	6,594	10,619	13,768	9,763	11,666	18,697	18,697	18,697	18,697	18,697
	female adult	10,104	12,688	14,297	12,830	21,441	24,351	24,351	24,351	24,351	24,351
Sheep	male young	1,116	1,984	1,346	1,174	1,451	1,671	1,671	1,671	1,671	1,671
	male immature	2,012	2,085	1,611	1,695	1,885	2,296	2,296	2,296	2,296	2,296
	male adult	2,708	2,754	2,717	2,186	2,888	4,149	4,149	4,149	4,149	4,149
	female young	1,024	1,126	1,329	1,147	1,461	1,260	1,260	1,260	1,260	1,260
	female immature	1,124	1,216	1,389	1,815	1,563	2,029	2,029	2,029	2,029	2,029
	female adult	2,604	2,047	2,763	1,881	2,587	2,838	2,838	2,838	2,838	2,838
Goats	male young	944	1,910	1,491	1,539	1,561	1,492	1,492	1,492	1,492	1,492
	male immature	1,235	2,142	1,732	2,272	1,953	1,866	1,866	1,866	1,866	1,866
	male adult	2,066	2,304	2,573	3,254	3,577	3,653	3,653	3,653	3,653	3,653
	female young	783	1,147	1,411	1,776	1,464	1,526	1,526	1,526	1,526	1,526
	female immature	1,088	1,493	1,538	2,659	1,772	1,938	1,938	1,938	1,938	1,938
	female adult	1,242	1,898	2,538	2,036	3,022	3,081	3,081	3,081	3,081	3,081
Camels	male young	12,622	11,802	12,622	11,802	15,297	17,215	17,215	17,215	17,215	17,215

male immature	12,622	12,472	12,622	12,472	16,757	18,810	18,810	18,810	18,810	18,810
male adult	23,266	27,507	23,266	27,507	37,959	36,927	36,927	36,927	36,927	36,927
female young	15,714	12,472	15,714	12,472	20,779	21,510	21,510	21,510	21,510	21,510
female immature	15,714	16,653	15,714	16,653	27,075	25,312	25,312	25,312	25,312	25,312
female adult	18,118	24,247	18,118	24,247	29,941	30,224	30,224	30,224	30,224	30,224

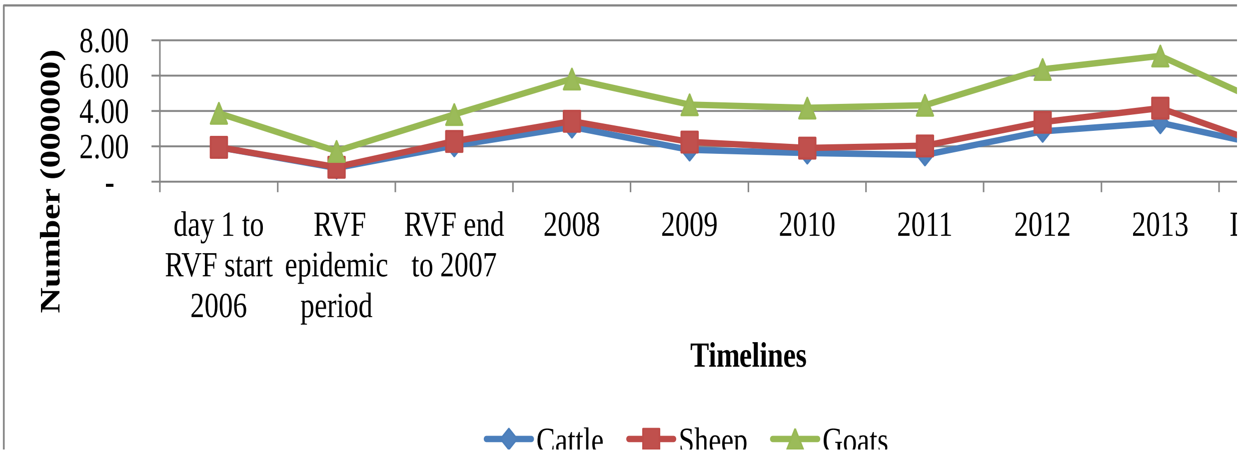
Appendix 8: Red meat and raw milk value chain sample

Actors category	Garissa	Thika	Nairobi	Nakuru	Total
Live animal traders	15	10	10	10	45
Petty trader around livestock markets/slaughter houses	10	10	10	10	40
Animal trekkers	15	0	0	0	15
Live animal motorized transport	8	4	9	4	25
Slaughter house	1	1	4	1	7
Retail meat sellers	10	10	10	10	40
Hides and skins	2	2	3	3	10
Offal's sellers	10	10	10	10	40
Raw milk vendors	10	0	0	0	10
Total	81	47	56	48	232

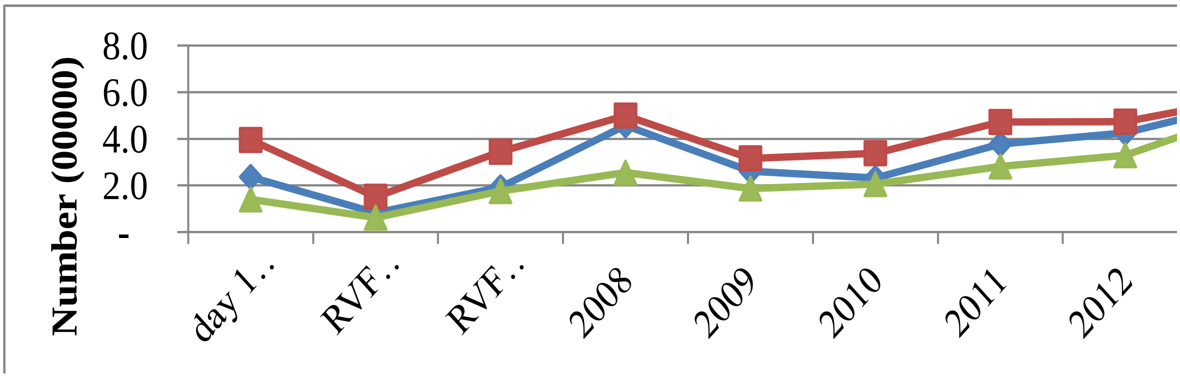
Appendix 9: **Number of births by species in the PAP.**



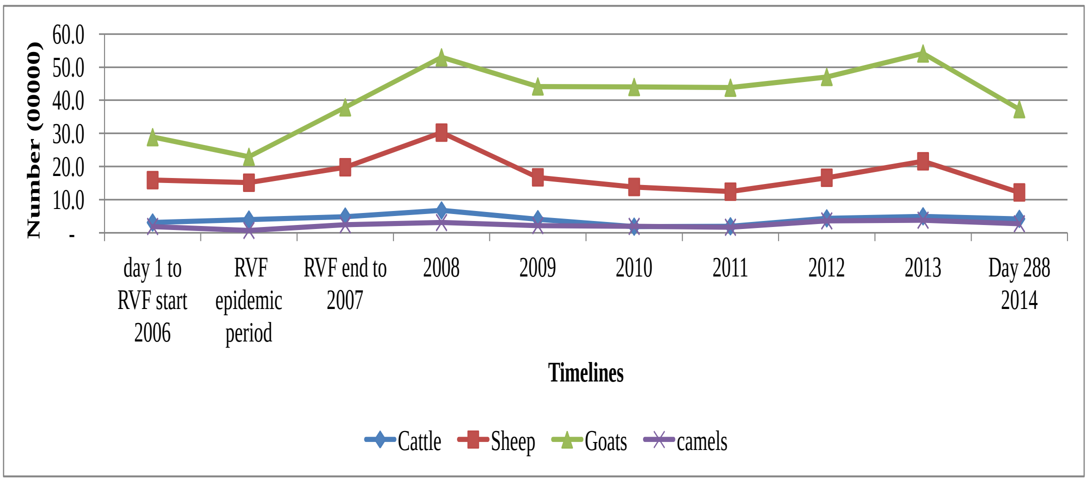
Appendix 10: **Number of births by species in the MFM.**



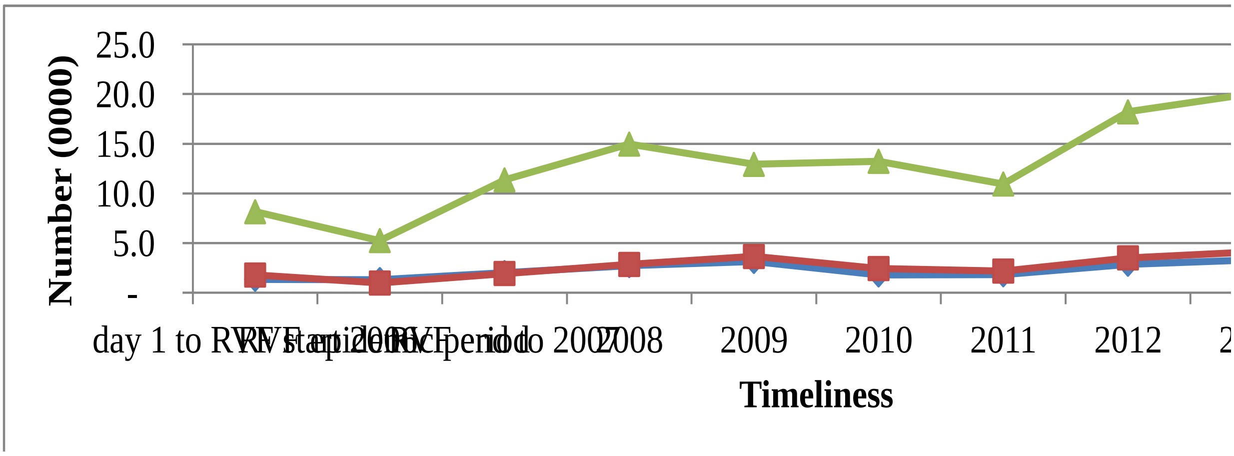
Appendix 11: **Number of births by species in the MFHP.**



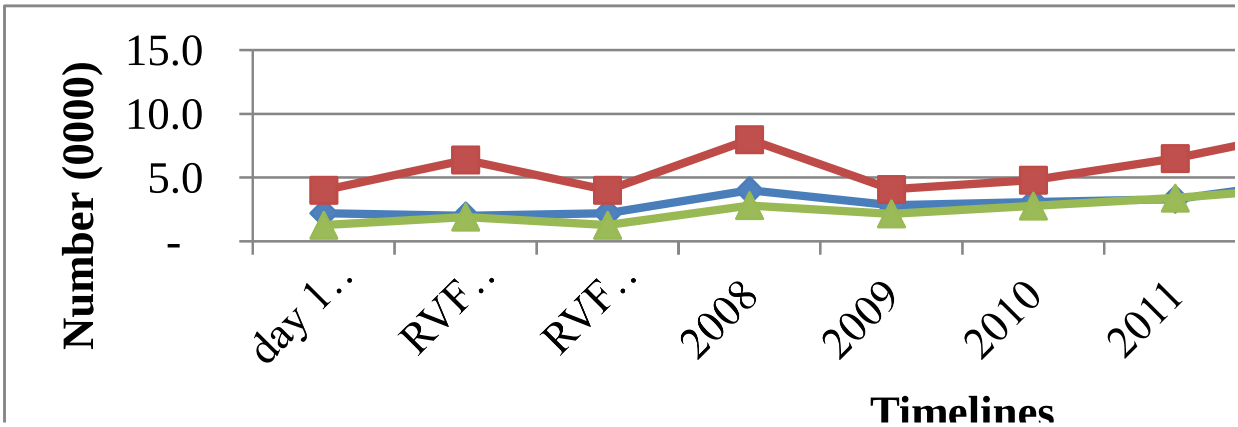
Appendix 12: Number of abortions by species in PAP



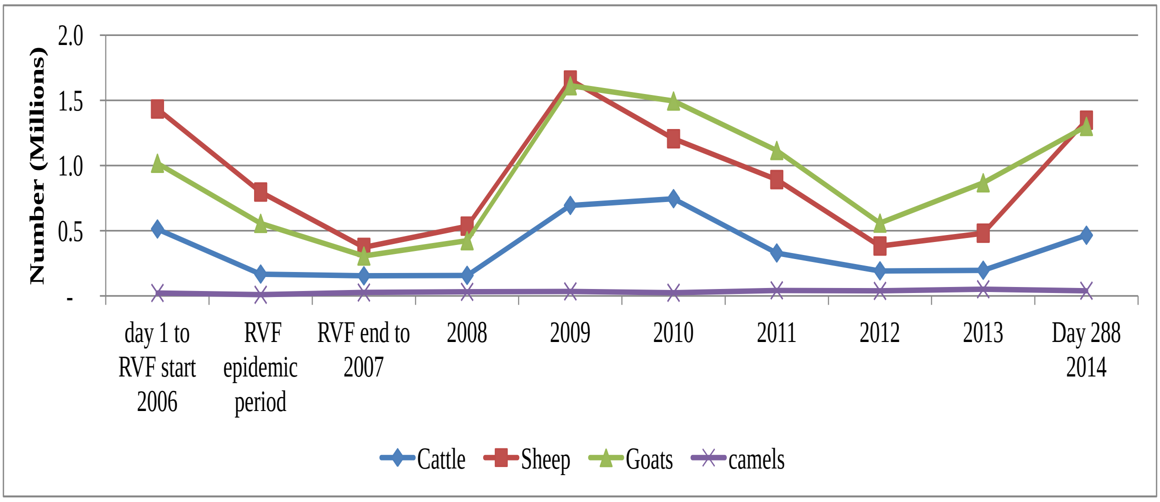
Appendix 13: Number of abortions by species in MFM



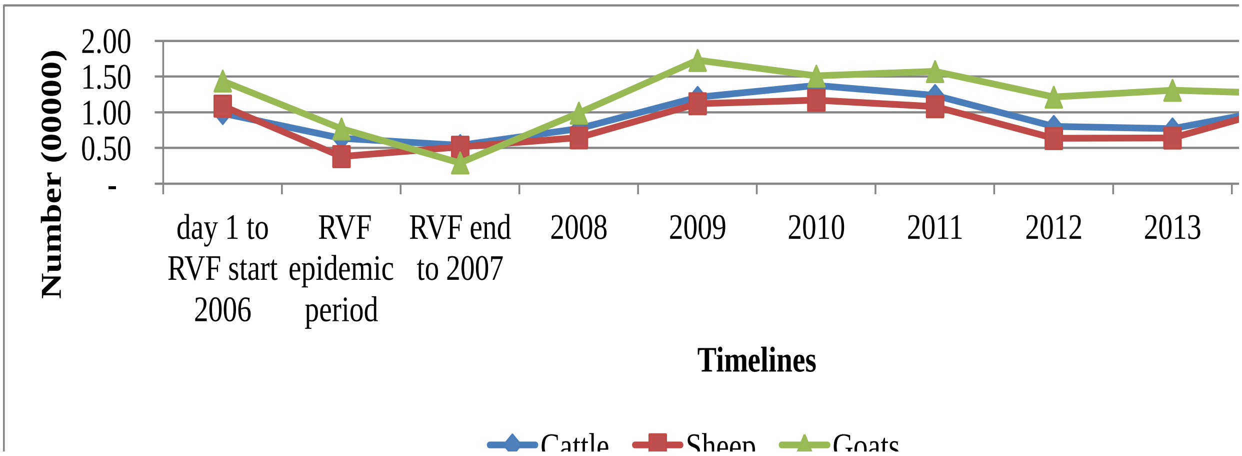
Appendix 14: Number of abortions by species in MFHP



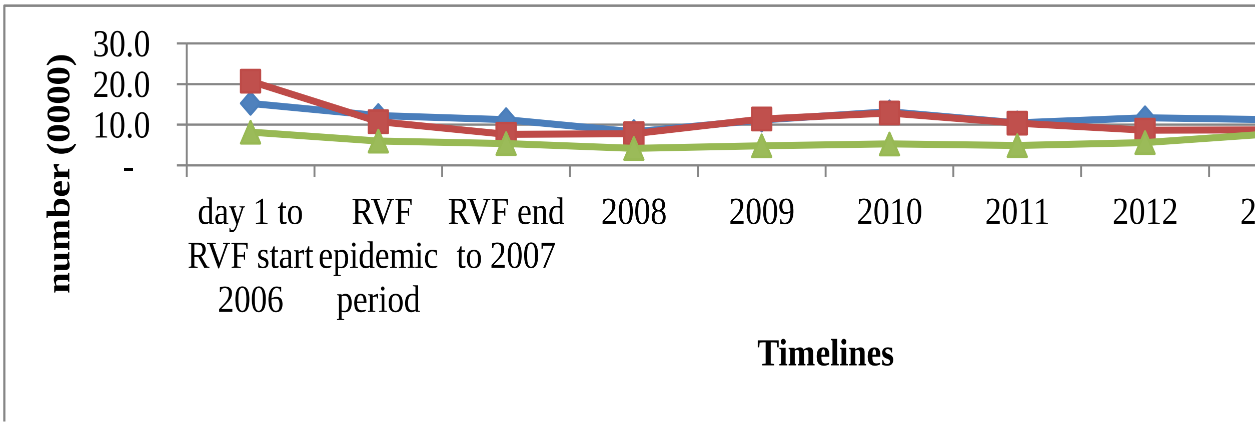
Appendix 15: Number of dead by species in PAP



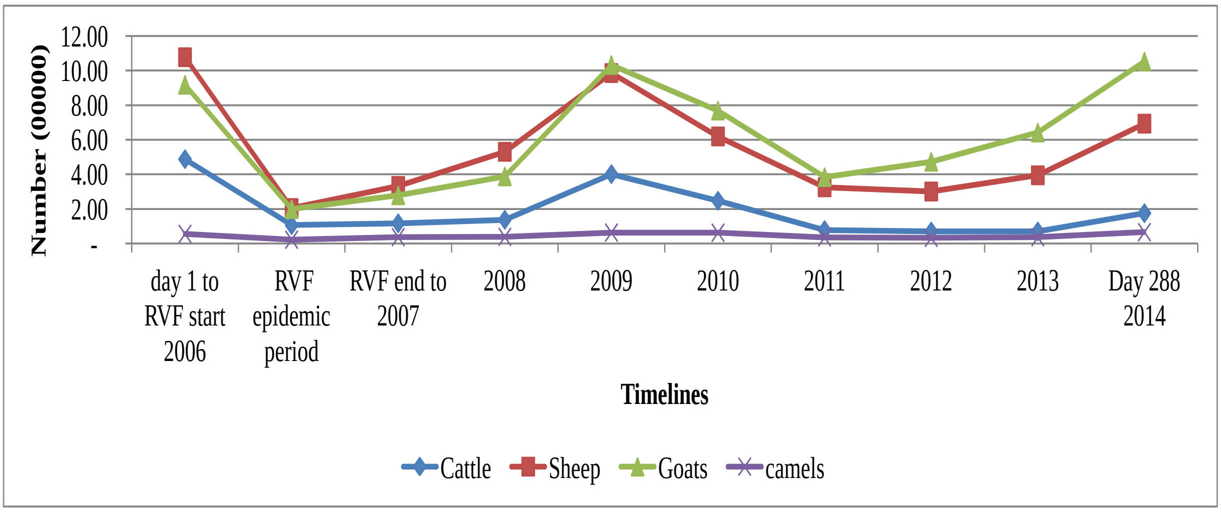
Appendix 16: Number of dead by species in MFM



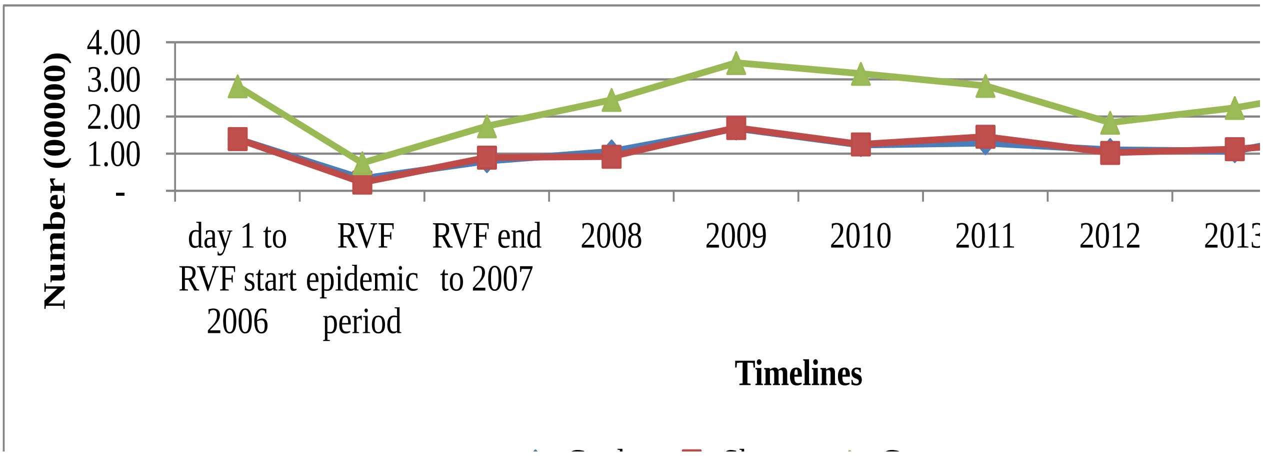
Appendix 17: Number of dead by species in MFHP



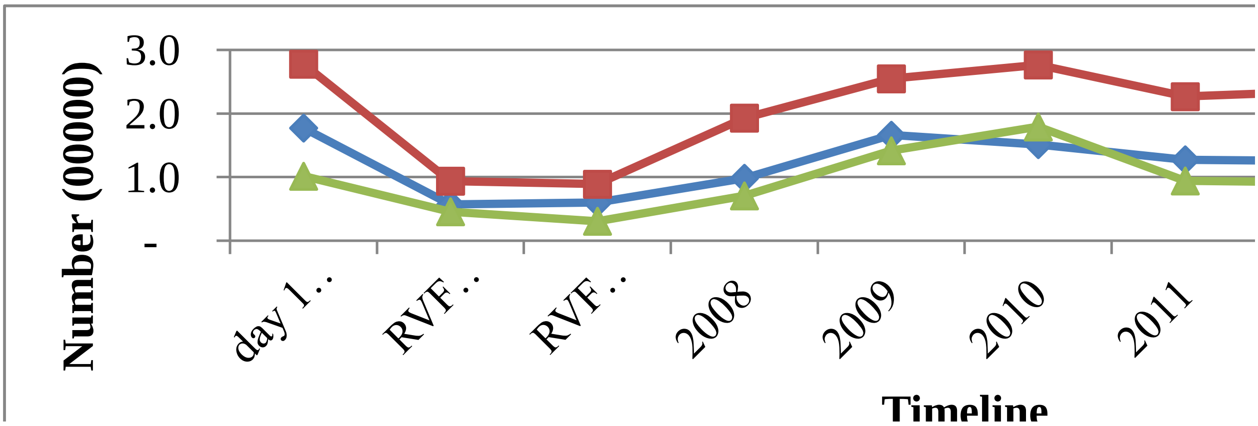
Appendix 18: Number of sold and home slaughtered animals by species and year in PAP



Appendix 19: Number of sold and home slaughtered animals by species and year in MFM



Appendix 20: Number of sold and home slaughtered animals by species and year in MFHP



Appendix 21: Number of animals that die from baseline mortality in each farming system by strategy.

	PAP				*MFM*			*MFHP*			*Total*
	cattle	**sheep**	**goats**	**camels**	**cattle**	**sheep**	**goats**	**cattle**	**sheep**	**goats**	
2006/2007	115,667	292,421	295,062	17,253	32,342	40,697	44,933	45,542	60,595	27,849	972,361
S1	128,995	265,070	432,207	22,626	35,798	45,616	53,398	58,484	59,229	41,365	1,142,787
S2	134,966	315,643	473,862	26,301	37,786	54,320	57,580	62,785	58,734	52,292	1,274,269
S3	140,514	290,025	445,217	22,377	37,633	53,997	56,487	60,202	30,065	67,979	1,204,496
S4	124,368	267,890	435,401	23,628	36,409	46,381	53,270	61,925	58,938	52,292	1,160,502
S5	135,782	282,141	437,186	23,993	36,868	54,239	56,873	61,926	58,718	51,811	1,199,537
S6	135,408	275,627	449,678	22,654	36,715	53,836	56,100	62,815	59,235	50,475	1,202,545
S7	140,514	290,025	445,217	22,377	35,798	49,363	53,591	60,234	31,969	68,789	1,197,877
S8	132,524	273,248	445,217	22,691	35,186	48,114	54,106	60,391	32,490	71,333	1,175,300
S9	127,937	278,706	462,574	26,301	36,409	46,019	52,884	59,281	57,410	50,016	1,197,537
S10	130,626	268,893	439,863	21,659	37,939	51,459	56,165	58,406	34,735	48,351	1,148,096
S11	128,995	265,070	426,478	22,626	35,798	45,616	53,398	58,406	5,996	12,622	1,055,004

Source: Computed from study.

Appendix 22: Number of births, base and RVF abortions by species and control options during the RVF epidemics in PAP.

		S1	*S2*	*S3*	*S4*	*S5*	*S6*	*S7*	*S8*	*S9*	*S10*	*S11*
Cattle	Birth	74,357	76,707	77,860	74,932	76,709	77,845	77,860	77,841	74,975	74,416	74,357
	Abortion	4,642	4,583	6,829	4,647	4,578	6,920	6,829	4,631	4,598	4,583	4,642
	Abortion RVF	4,642	2,289	1,138	4,066	2,291	1,153	2,338	1,158	4,023	4,583	4,642
sheep	Birth	348,400	363,709	371,561	348,901	362,189	370,717	371,561	370,531	350,709	351,521	348,400
	Abortion	41,293	51,736	55,154	44,406	49,640	52,848	55,154	49,281	40,750	45,967	41,293
	Abortion RVF	64,889	49,581	41,728	64,388	51,100	42,572	51,728	42,759	62,580	61,768	64,889
Goats	Birth	987,941	1,015,652	1,026,854	988,492	1,003,952	1,024,236	1,026,854	1,024,441	989,465	992,910	987,941
	Abortion	184,866	190,837	198,814	181,551	189,283	197,685	198,814	193,819	184,240	184,721	184,866
	Abortion RVF	90,966	63,255	52,053	90,415	74,955	54,466	75,053	54,671	89,442	85,997	90,966
Camels	Birth	68,103	68,878	69,526	68,091	69,135	69,522	69,526	69,520	68,245	68,229	68,103
	Abortion	9,290	10,054	10,234	9,095	9,296	9,810	10,234	9,359	9,218	9,566	9,290
	Abortion RVF	1,806	775	384	1,819	1031	387	1084	390	1,664	1,680	1,806

Appendix 23: Number of births, base and RVF abortions by species and control options during the RVF epidemics in MFM.

		S1	*S2*	*S3*	*S4*	*S5*	*S6*	*S7*	*S8*	*S9*	*S10*	*S11*
Cattle	Birth	40,711	45,706	45,642	40,988	45,661	45,589	45,322	45,407	41,049	41,851	40,711
	Abortion	7,847	8,264	8,526	7,843	8,718	8,506	8,574	8,744	7,774	7,976	7,847
	Abortion RVF	6,561	1,682	1,565	6,284	1,865	1,611	1,950	1,630	6,222	5,421	6,561
sheep	Birth	146,987	153,896	152,093	147,047	153,812	152,045	153,601	151,646	148,290	147,669	146,987
	Abortion	15,202	16,632	15,971	13,707	16,616	16,048	16,295	15,532	16,128	14,141	13,470
	Abortion RVF	15,551	10,445	8,642	15,491	10,493	8,726	10,892	8,938	14,248	14,869	15,551
Goats	Birth	347,814	365,484	364,337	348,837	364,963	363,855	363,095	361,894	346,242	351,985	347,814
	Abortion	80,998	90,284	91,131	82,230	89,961	89,814	88,573	88,418	59,512	83,970	80,998
	Abortion RVF	38,238	22,197	20,568	37,215	22,957	21,089	24,158	21,715	39,810	34,067	38,238
	Total other abortions	**104,047**	**115,180**	**115,628**	**103,780**	**115,295**	**114,368**	**113,442**	**112,694**	**83,414**	**106,087**	**102,315**
	Total RVF abortions	**60,350**	**34,324**	**30,775**	**58,990**	**35,315**	**31,426**	**37,000**	**32,283**	**60,280**	**54,357**	**60,350**

Appendix 24: Number of births, base and RVF abortions by species and control options during the RVF epidemics in MFHP.

		S1	*S2*	*S3*	*S4*	*S5*	*S6*	*S7*	*S8*	*S9*	*S10*	*S11*
Cattle	Birth	124,855	129,523	129,859	125,548	129,195	129,419	128,470	129,216	125,509	125,643	125,124
	Abortion	13,216	13,693	13,698	13,209	13,321	13,479	13,572	13,899	12,977	13,877	13,216
	Abortion RVF	7,668	3,000	2,664	6,975	3,328	3,104	4,053	3,307	7,014	6,880	7,399
sheep	Birth	219,861	238,266	238,732	223,454	237,367	237,272	230,302	230,499	221,973	223,161	219,861
	Abortion	31,153	30,857	30,990	30,771	31,224	31,165	30,905	30,545	30,528	30,768	31,153
	Abortion RVF	32,303	13,898	13,432	28,711	14,893	14,798	21,862	21,665	30,191	29,004	32,303
Goats	Birth	171,114	176,404	180,875	172,686	175,779	176,074	174,692	174,802	171,616	172,191	171,114
	Abortion	18,630	18,290	18,720	18,530	18,330	18,713	19,194	19,136	19,162	19,160	20,819
	Abortion RVF	17,323	12,033	7,562	15,751	12,658	12,363	13,745	13,636	16,821	16,246	17,323
	Total other abortions	**62999**	**62840**	**63408**	**62510**	**62875**	**63357**	**63671**	**63580**	**62667**	**63805**	**65188**
	Total RVF abortions	**57294**	**28931**	**23658**	**51437**	**30879**	**30265**	**39660**	**38608**	**54026**	**52130**	**57,025**

Appendix 25 : Number of animals sold and slaughtered –PAP during the RVF epidemics

Species	State	2006/2007	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
Cattle	Sold base	50,357	33,926	15,720	16,136	15,569	17,258	16,368	16,136	33,085	30,172	15,286	15,281
	Sold RVF	118	141	36	34	66	55	45	60	88	122	129	134
	Slaughtered base	5,661	3,462	1,489	1,532	1,600	1,473	1,183	2,332	2,151	3,488	1,578	1,906
Sheep	Sold base	160,596	112,666	40,035	55,747	48,900	52,530	56,078	55,747	72,700	82,572	49,330	44,059
	Sold RVF	707	4,061	2,304	1,593	2,743	2,594	1,862	2,793	3,285	4,044	2,930	2,993
	Slaughtered base	43,391	15,942	10,374	9,988	10,694	11,994	12,060	11,988	14,143	15,907	10,235	9,061
	Slaughtered RVF	118	205	133	113	158	156	148	161	180	160	168	199
Goats	Sold base	165,166	138,745	100,226	101,655	101,258	104,037	101,655	101,655	100,066	178,285	102,449	108,041
	Sold RVF	346	4,330	2,095	1,633	2,583	1,993	1,985	2,183	2,483	3,146	3,177	3,383
	Slaughtered base	33,195	39,959	25,558	21,114	20,655	22,950	22,950	21,114	22,032	36,743	21,114	15,736
	Slaughtered RVF	113	1,140	546	518	718	570	531	583	650	905	718	919
Camels	Sold base	18,516	12,057	5,994	7,739	7,626	7,828	7,834	7,739	12,371	12,904	7,573	5,363
	Slaughtered base	3,367	4,509	2,718	3,157	2,938	3,194	2,797	3,157	4,602	4,526	2,918	2,229

Appendix 26: Number of animals sold and slaughtered MFM

		2006/2007	*S1*	*S2*	*S3*	*S4*	*S5*	*S6*	*S7*	*S8*	*S9*	*S10*	*S11*
Cattle	sold base	38,478	20,007	16,789	16,455	17,094	16,485	16,424	16,606	21,007	22,549	16,975	17,059
	sold RVF	652	451	142	70	395	142	140	145	480	508	301	398
	slaughtered base	4,891	2,622	2,275	2,247	2,222	2,190	2,153	2,139	2,806	2,949	2,244	2,236
Sheep	sold base	19,394	14,831	14,157	13,396	14,418	13,231	13,348	13,208	17,626	18,986	14,201	14,419
	sold RVF	1,255	921	566	518	944	586	495	531	942	1,207	799	925
	slaughtered base	20,877	15,966	15,224	14,288	15,427	14,168	14,371	14,154	19,056	20,296	15,138	15,523
	slaughtered RVF	1,312	1,040	541	508	1,003	531	486	561	985	1,299	903	1,044
Goats	sold base	88,527	50,737	41,867	37,622	39,204	37,698	37,759	37,772	52,507	52,013	38,764	39,118
	sold RVF	2,677	1,801	959	935	1,391	960	880	978	1,676	1,823	1,236	1,434
	slaughtered base	30,593	15,420	12,760	11,490	11,872	11,488	11,600	11,552	15,108	15,326	11,759	11,889
	slaughtered RVF	765	480	243	222	382	252	220	257	539	606	309	382

Appendix 27: Number of animals sold and slaughtered MFHP

		2006/2007	*S1*	*S2*	*S3*	*S4*	*S5*	*S6*	*S7*	*S8*	*S9*	*S10*	*S11*
Cattle	sold base	42,144	29,088	23,795	25,200	23,854	24,921	24,436	24,100	23,874	24,524	23,569	25,318
	sold RVF	655	479	118	39	502	259	52	270	371	419	399	460
	slaughtered base	9,390	6,729	5,275	5,628	5,444	5,268	5,144	5,148	5,383	5,557	5,174	5,571
Sheep	sold base	66,916	44,270	27,450	31,200	26,756	27,767	27,303	28,800	28,271	28,403	26,592	30,350
	sold RVF	1,898	896	400	118	1,686	638	121	491	852	1,283	1,859	1,889
	slaughtered base	54,261	45,209	22,180	26,023	22,294	24,209	22,414	24,280	24,402	23,075	22,432	29,895
	slaughtered RVF	1,898	740	325	83	1,141	439	84	519	690	1,015	534	809
Goats	sold base	19,850	16,982	16,003	16,373	16,006	19,673	15,969	15,923	15,552	16,752	15,195	14,059
	sold RVF	1,263	574	138	103	402	146	133	271	433	578	499	569
	slaughtered base	20,752	18,279	17,735	17,659	17,423	21,894	17,560	17,271	17,203	18,304	17,042	16,152
	slaughtered RVF	1,444	779	126	109	375	344	116	448	606	760	727	782

Appendix 28: Total Annual milk production output and losses (million litres) by species and livestock systems

	2006	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*Total*
PAP									
Cattle off take	64.7	153.1	183.7	32.6	10.7	18.8	147.3	157.1	768.0
Cattle: loss	28.6	6.7	4.2	33.8	11.3	10.0	3.0	3.4	100.9
Goats off take	4.8	10.7	9.7	1.3	1.5	1.5	6.7	7.7	43.9
Goats: loss	2.8	2.2	1.6	1.9	2.1	1.4	1.3	1.4	14.6
Camels off take	16.7	128.2	161.0	32.0	32.9	67.1	218.3	217.1	873.3
Camels: loss	19.4	5.3	4.4	33.5	34.3	34.7	5.0	5.1	141.7
MFM									
Cattle off take	80.4	142.8	163.4	53.4	45.3	62.1	135.4	158.2	841.1
Cattle: loss	37.4	6.0	2.9	55.0	46.3	32.0	3.1	3.5	186.2
Goats off take	2.4	4.0	4.1	1.3	1.3	1.2	4.2	4.2	22.7
Goats: loss	1.2	0.5	0.4	1.5	1.5	1.4	0.5	0.6	7.6
MFHP									
Cattle off take	478.1	786.3	711.4	278.7	270.4	577.8	790.6	908.4	4,801.8
Cattle: loss	230.0	27.3	25.6	291.4	280.3	298.5	18.5	21.0	1,192.6
Goats off take	2.2	3.6	3.1	1.3	1.4	1.3	3.8	4.3	20.9
Goats: loss	2.4	2.4	2.9	2.7	2.8	2.9	4.4	5.3	25.9
All systems									
Cattle off take	623.3	1,082.2	1,058.5	364.7	326.5	658.7	1,073.3	1,223.8	6,411.0
Cattle: loss	296.0	40.0	32.7	380.2	337.9	340.5	24.5	27.9	1,479.7
Goats off take	9.3	18.4	16.8	3.9	4.1	4.0	14.7	16.2	87.5
Goats: loss	6.4	5.1	4.9	6.2	6.4	5.6	6.2	7.3	48.1
Camels off take	49.7	128.2	161.0	32.0	32.9	67.1	218.3	217.1	906.3
Camels: loss	19.4	5.3	4.4	33.5	34.3	34.7	5.0	5.1	141.7

Appendix 29: Milk production and losses (million litres) during 2014-2015 under different control strategies

		S1	*S2*	*S3*	*S4*	*S5*	*S6*	*S7*	*S8*	*S9*	*S10*	*S11*
PAP	Cattle total milk off take	181.6	215.1	218	188.6	195.8	200	191.9	194.4	181.7	185.4	171.6
	Cattle: milk loss	27	23.8	23.5	26.5	24	23.9	24.2	23.7	26.8	26.6	27
	Goats total milk off take	36.8	47.1	48.7	42.5	43.4	43.4	43.1	43.3	41	42.9	42.4
	Goats: milk loss	6.1	5.6	5.6	6.1	5.7	5.6	5.7	5.6	6.1	6.1	6.1
	Camels total milk off take	337.9	348.1	348.8	340.5	343.5	343.5	340.8	341.5	335.2	338.1	334.3
	Camels: milk loss	52.3	51.5	51.3	52	51.4	51.3	51.5	51.2	52.2	52.2	52.2
MFM	Cattle total milk off take	273.5	274.3	272.6	271.5	278.7	279.3	277.3	278.7	271.9	273.5	270.1
	Cattle: milk loss	39.1	35.3	35.1	38.9	35.3	35.2	35.8	35.6	39.1	38.2	39.1
	Goats total milk off take	5.1	5.2	5.2	5.3	5.3	5.3	5.3	5.2	5.2	5.2	5.2
	Goats: milk loss	2.3	2.2	2.1	2.3	2.2	2.2	2.2	2.2	2.3	2.3	2.3
MFHP	Cattle total milk off take	2,068.2	2,097.4	2,131.2	2,089.4	2,094.5	2,091.9	2,094.0	2,085.9	2,085.7	2,114.9	2,159.3
	Cattle: milk loss	278.6	259.7	258.7	272.4	261.5	260.8	266.2	262	276.4	276.2	279.6
	Goats total milk off take	9.4	9.1	9.3	9.1	9.1	9.2	8.9	8.9	9.2	9.2	8.7
	Goats: milk loss	5.6	5.5	5.4	5.6	5.5	5.5	5.6	5.6	5.6	5.6	5.7
All systems, all species	**Total off take**	**2912.6**	**2996.2**	**3033.8**	**2946.9**	**2970.3**	**2972.6**	**2961.3**	**2957.8**	**2929.9**	**2969.3**	**2991.7**
	Total loss	**411.1**	**383.6**	**381.7**	**403.7**	**385.6**	**384.5**	**391**	**385.9**	**408.5**	**407.3**	**412.1**

Source: study computations

Appendix 30: Estimate value (Billion KES) of milk production and losses during the period 2014 -2015 by systems

Species	*Production/loss*	*Control Strategy*										
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
Cattle	**Produced Milk**	68.13	69.84	70.79	68.84	69.36	69.42	69.21	69.09	68.56	69.49	70.23
	RVF milk losses	1.29	0.59	0.55	1.10	0.64	0.62	0.78	0.65	1.23	1.19	1.32
	Drought milk losses	7.24	7.24	7.24	7.24	7.24	7.24	7.24	7.24	7.24	7.24	7.24
	Baseline abortions milk losses	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.77	0.78	0.78
	Sub-total milk losses	10.01	8.35	8.29	9.12	8.43	8.39	8.65	8.45	9.30	9.25	9.44
Goats	**Produced Milk**	2.57	3.07	3.16	2.84	2.89	2.89	2.86	2.87	2.77	2.87	2.82
	RVF milk losses	0.14	0.10	0.09	0.13	0.10	0.10	0.11	0.10	0.14	0.13	0.14
	Drought milk losses	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
	Baseline abortions milk losses	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.27	0.28	0.28
	Sub-total milk losses	0.94	0.70	0.68	0.74	0.70	0.70	0.71	0.70	0.75	0.75	0.76
Camels	**Produced Milk**	22.64	23.32	23.37	22.81	23.02	23.01	22.83	22.88	22.46	22.65	22.40
	RVF milk losses	0.12	0.06	0.05	0.11	0.07	0.05	0.07	0.05	0.12	0.11	0.12
	Drought milk losses	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87
	Baseline abortions milk losses	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
	Sub-total milk losses	3.50	3.08	3.07	3.12	3.08	3.06	3.08	3.06	3.12	3.12	3.12

Source: Study computations

Appendix 31: Human Population in rural and urban high risk areas by farming systems.

	Age category	*MFHP*		*MFMP*		*PAP*	
		Male	Female	Male	Female	Male	Female
Urban	0 to 5	483113	476730	110229	108437	28774	26814
	6 to 10	318202	323899	77558	77156	25343	23231
	11 to 15	257001	274054	66166	67367	22195	19123
	16 to 20	281602	362975	66253	73319	21752	20343
	21 to 25	419831	489623	78096	87169	13514	14590
	26 to 30	424225	403251	79607	76041	12260	13372
	31 to 35	306057	238216	59184	46608	7570	7161
	36 to 40	232497	179214	46561	36213	7395	7162
	41 to 45	146627	105382	29093	21555	4316	3437
	46 to 50	118187	85271	25396	20143	5112	4030
	51 to 55	67774	45803	16268	12376	2532	1761
	56 to 60	48282	37144	12539	10866	2852	2386
	61 to 65	27320	21547	7247	6322	1181	1022
	66 to 70	16861	17386	5186	5930	1555	1577
	71 to 75	9595	9590	3374	3630	694	616
	76 to 79	4729	5372	1812	2150	356	351
	80+	10306	16737	4385	6783	1400	1717
Rural	0 to 5	365364	353043	173702	170829	219758	206354
	6 to 10	297260	290109	138057	134964	268427	228662
	11 to 15	259420	251775	115794	110390	217468	160249
	16 to 20	218383	202443	88579	88645	176837	120862
	21 to 25	168955	178122	51680	68995	74438	67928
	26 to 30	144429	158755	44018	60414	64395	80044
	31 to 35	122993	125786	36777	46960	39491	53050
	36 to 40	103269	111526	31568	40214	55111	60663
	41 to 45	76043	82898	22682	26190	31847	28564
	46 to 50	72334	81678	23540	30918	39414	27977
	51 to 55	48600	51864	18666	22789	19178	11310
	56 to 60	49474	52679	18122	20949	23893	12571
	61 to 65	34991	35392	12268	13635	10233	5521
	66 to 70	28881	35521	10287	12041	11384	6703
	71 to 75	18766	19727	6352	6743	4634	3361
	76 to 79	10433	12391	3310	3950	2356	1880
	80+	24330	35363	9516	13447	7842	7238

Source: computed from 2009 population census figures.

Appendix 32: Clinical symptoms associated with RVFV sero-positivity.

Clinical symptoms	Sources
Fever (100% cases)	(Summerpal *et al.*, 2010, LaBeaud *et al.*, 2008 and 2011 Nguku *et al.*, 2010, WHO, 2010) Kahlon *et al.*, (2010)
Muscle pain	(Summerpal *et al.*, 2010, LaBeaud *et al.*, 2008 and 2011 Nguku *et al.*, 2010, WHO, 2010)
Joint pain	(Summerpal *et al.*, 2010, LaBeaud *et al.*, 2008 and 2011 Nguku *et al.*, 2010, WHO, 2010) Kahlon *et al.*, (2010)
Headache	(Summerpal *et al.*, 2010, LaBeaud *et al.*,, 2008 and 2011 Nguku *et al.*, 2010, WHO, 2010)
Malaise,	(Summerpal *et al.*, 2010, LaBeaud *et al.*, 2008 and 2011 Nguku *et al.*, 2010, WHO, 2010)
Back ache	LaBeaud *et al.*, 2008 and 2011
Rash	LaBeaud *et al.*, 2008 and 2011
Neck stiffness,	Nguku *et al.*, (2010),
Eyes: sensitivity to light/blurred vision/ red eyes and eye pain/ poor vision	Nguku *et al.*, (2010), LaBeaud *et al.*, 2008 and 2011
Retinitis (17 to 20%	McIntosh *et al.*, (1980 Woods *et al.*, et al (2002)
Loss of appetite	(Summerpal *et al.*, (2010)
Comma	(LaBeaud *et al.*, (2008)
Vomiting coma and epigastric discomfort	(Summerpal *et al.*,., (2010) Nguku *et al.*, (2010), Kahlon *et al.*, 2010)
Subjective weight loss	(Summerpal *et al.*, (2010) Nguku *et al.*, (2010),
Diarrhoea	Nguku et a *et al.*, l (2010),
Meningmus	LaBeaud *et al.*, 2008 and 2011
Stupor/confusion	LaBeaud *et al.*, 2008 and 2011
Bloody stool	LaBeaud *et al.*, 2008 and 2011 Kahlon *et al.*, (2010)

Myalgia’s,	LaBeaud *et al.*, 2008 and 2011
Hepatic signs	Kahlon *et al.*, (2010)
Bleeding	Kahlon *et al.*, (2010)
Renal impairment	Imam *et al.,* (2009)
Right upper-quadrant pain	Kahlon *et al.*, (2010)
Delirium	Kahlon *et al.*, (2010)
Encephalitis (17%)	Woods *et al.*, (2002)
Haemorrhagic (26%)	Amwayi *et al.*, (2010)

Source: compiled from literature.

Appendix 33: Risk factors for RVF sero-postivity, acute, severe and dead cases in three districts (Garissa, 1997-98, 2006-2007; Baringo and Kilifi (2006-2007) in Kenya

Risk factor	Relative risk for sero-positivity in 1978/79 (95% CI), Woods *et al.*,(2002),	ODDs ratio for acute/severe/death RVF in 2006/2007 Amwayi *et al.*, (2010)
	Univariate analysis	
Animal exposures		
Sheltered livestock in home	5.3 (2.3-12.6)	
slaughtering and skinning an animal	2.4 (1.3-4.3)	
Butchered an animal	2 (1.1-3.6)	
Skinned an animal	2.4 (1.6-3.5)	
Cooked meat/animal products	2.3 (1.1-4.9)	
Milking animals	3.8 (1.9-7.7)	
Drank raw animal milk	8.6 (2.0-36.0)	
Care of animal during birth	2.6 (1.4-4.9)	2.80 (1.30–6.03),[a]
Disposal of aborted fetes	2.8 (1.5-5.5)	3.83 (1.68–9.07) [a, d,]
Consuming/ handling products/sick		2.53 (1.78-3.61) [a, d]
animals		3.67 (1.07–12.64) [c]
Contact/herding animals		2.04 (1.06-3.92) [a]
Sheep contact[b] with sheep blood or body fluids	6.3 (2.9-14.0)	
Goat contact[b]	3. (11.6-6.4)	
Cow contact[b]	2.4 (1.3-4.5)	
Camel contact[b]	1.3 (0.5-3.8)	
Non-animal exposures		
Home flooded	1.3 (0.8-2.1)	
Ill family member	1.6 (0.8-3.1)	
Contact with a dead human body	2.2 (1.0-4.6)	
Use mosquito nets	0.7 (0.3-1.4)	

Age associated with lower risk of infection	< 15 years (p=0.05)	
Being herdsman		1.77 (1.20–2.63) [b,d]
		2.22 (1.12–4.37) [a,e]
All exposures	Bivariate analysis	
Contact with sheep blood and body fluids	3.0 (1.3-6.7)	
Sheltering animals in the home	3.5 (1.3-9.1)	
Male gender	1.6 (1.0-2.8)	
Age <15Years	0.3 (0.06-1.0)	
Drinking raw sheep milk	1.6 (0.9-2.9)	

Source: reconstructed from Woods *et al.*, (2002) and Amwayi *et al.*, (2010). [a] = severe RVF, [b]= acute RVF, [c] = death, [d] = Bivariate analysis [e] = multivariate analysis

Appendix 34: Estimated risk factors for human RVF.

		RVF abortion	RVF mortality	sold RVF	slaughtered RVF	infected lactating females
Cattle	2006/2007	7,188	128,847	118	-	174,450
	S1	4,642	89,052	141	-	119,924
	S2	2,289	48,374	36	-	64,730
	S3	1,138	43,977	34	-	58,732
	S4	4,066	83,555	66	-	111,180
	S5	2,291	50,573	55	-	68,296
	S6	1,153	46,175	45	-	66,135
	S7	2,338	52,772	60	-	70,479
	S8	1,158	48,374	88	-	64,539
	S9	4,023	86,508	122	-	116,489
	S10	4,583	84,655	129	-	113,660
	S11	4,642	89,052	134	-	119,924
Sheep	2006/2007	82,926	503,981	707	118	
	S1	64,889	374,438	4,061	205	
	S2	49,581	318,807	2,304	133	
	S3	41,728	301,690	1,593	113	
	S4	64,388	363,740	2,743	158	

	S5	51,100	323,087	2,594	156	
	S6	42,572	303,830	1,862	148	
	S7	51,728	327,366	2,793	161	
	S8	42,759	308,109	3,285	180	
	S9	62,580	369,804	4,044	160	
	S10	61,768	368,019	2,930	168	
	S11	64,889	374,438	2,993	199	
Goats	2006/2007	66,993	261,290	346	113	358,104
	S1	90,966	452,149	4,330	1,140	682,134
	S2	63,255	344,026	2,095	546	517,834
	S3	52,053	337,473	1,633	518	508,308
	S4	90,415	429,214	2,583	718	650,369
	S5	74,955	344,026	1,993	570	519,250
	S6	54,466	340,750	1,985	531	514,857
	S7	52,053	337,473	2,183	583	508,308
	S8	54,671	344,026	2,483	650	519,394
	S9	89,442	445,980	3,146	905	670,262
	S10	85,997	442,320	3,177	718	671,107
	S11	90,966	452,149	3,383	919	682,134
Camels	2006/2007	759.3	8,205.93	-	-	5888
	S1	1,806	16,137.2	-	-	12149.94846

S2	775	8,689.3	-	-	6547.636403
S3	384	7,448.0	-	-	5613.355469
S4	1,819	13,396.3	-	-	10275.63158
S5	1,031	8,689.3	-	-	6570.234373
S6	387	7,448.0	-	-	5602.147389
S7	1,084	8,689.3	-	-	6548.914713
S8	390	7,448.0	-	-	5610.149491
S9	1,664	15,167.3	-	-	11421.93312
S10	1,680	14,895.9	-	-	11207.29914
S11	1,806	14,895.9	-	-	11215.33704

Source: Study computation

Appendix 35: Summary of calculated DALYs by age and sex categories for each respective control strategy for the 22014/2015 RVF epidemic

Sex/age category	Strategy										
Males	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
< 10	3	3	2	3	3	2	3	2	3	3	3
11 -20	654	502	483	624	506	489	504	495	644	639	653
21-30	2,009	1,542	1,485	1,918	1,554	1,501	1,549	1,522	1,979	1,962	2,008
31-40	381	292	281	363	294	285	294	288	375	372	380
41-50	59	45	44	56	46	44	46	45	58	58	59
51-60	46	35	34	43	35	34	35	34	45	44	46
61-70	116	89	86	111	90	87	90	88	115	114	116
71-80	14	11	11	14	11	11	11	11	14	14	14
> 80	1	1	1	1	1	1	1	1	1	1	1
Total	3,283	2,520	2,426	3,134	2,540	2,454	2,532	2,487	3,234	3,206	3,281
Females											
< 10	3	3	2	3	3	2	3	2	3	3	3
11 - 20	189	145	139	180	146	141	146	143	186	184	189
21-30	496	380	366	473	383	370	382	375	488	484	495
31-40	449	345	332	429	348	336	347	340	443	439	449
41-50	116	89	86	111	90	87	89	88	114	113	116
51-60	5	4	4	5	4	4	4	4	5	5	5

61-70	4	3	3	4	3	3	3	3	4	4	4
71-80	1	1	1	1	1	1	1	1	1	1	1
> 80	2	1	1	2	1	1	1	1	2	2	2
Total	1,264	970	934	1,207	978	945	975	958	1,245	1,235	1,263
Grand total	4,548	3,490	3,360	4,341	3,517	3,398	3,507	3,445	4,479	4,441	4,544

Source: Study computation

Appendix 36: Publication 1- One Health Satekholder and Institutional analysis in Kenya.

INFECTION ECOLOGY & EPIDEMIOLOGY
THE ONE HEALTH JOURNAL

ORIGINAL RESEARCH ARTICLE

One Health stakeholder and institutional analysis in Kenya

Tabitha Kimani, MSc[1,2]*, Margaret Ngigi, PhD[1], Esther Schelling, PhD[3,4] and Tom Randolph, PhD[2]

[1]Department of Agricultural Economics and Agribusiness, Egerton University, Njoro, Kenya; [2]International Livestock Research Institute, Nairobi, Kenya; [3]Department of Epidemiology and Public Health, Swiss Tropical and Public Health Institute, Basel, Switzerland; [4]University of Basel, Basel, Switzerland

Introduction: One Health (OH) can be considered a complex emerging policy to resolve health issues at the animal–human and environmental interface. It is expected to drive system changes in terms of new formal and informal institutional and organisational arrangements. This study, using Rift Valley fever (RVF) as a zoonotic problem requiring an OH approach, sought to understand the institutionalisation process at national and subnational levels in an early adopting country, Kenya.

Materials and methods: Social network analysis methodologies were used. Stakeholder roles and relational data were collected at national and subnational levels in 2012. Key informants from stakeholder organisations were interviewed, guided by a checklist. Public sector animal and public health organisations were interviewed first to identify other stakeholders with whom they had financial, information sharing and joint cooperation relationships. Visualisation of the OH social network and relationships were shown in sociograms and mathematical (degree and centrality) characteristics of the network summarised.

Results and discussion: Thirty-two and 20 stakeholders relevant to OH were identified at national and subnational levels, respectively. Their roles spanned wildlife, livestock, and public health sectors as well as weather prediction. About 50% of national-level stakeholders had made significant progress on OH institutionalisation to an extent that formal coordination structures (zoonoses disease unit and a technical working group) had been created. However, the process had not trickled down to subnational levels although cross-sectoral and sectoral collaborations were identified. The overall binary social network density for the stakeholders showed that 35 and 21% of the possible ties between the RVF and OH stakeholders existed at national and subnational levels, respectively, while public health actors' collaborations were identified at community/grassroots level. We recommend extending the OH network to include the other 50% stakeholders and fostering of the process at subnational-level building on available cross-sectoral platforms.

Keywords: *One Health; stakeholder; institutionalisation; Kenya*

Responsible Editor: Barbara Haesler, The Royal Veterinary College, United Kingdom.

*Correspondence to: Tabitha Kimani, PO Box 1510-00200 Nairobi, Kenya, Email: mugethikimani@yahoo.com

Appendix 37: Publication 2- Public Health Benefits from Livestock Rift Valley Fever Control: A Simulation of Two Epidemics in Kenya

EcoHealth 13, 729–742, 2016
DOI: 10.1007/s10393-016-1192-y

ECOHEALTH

Original Contribution

Public Health Benefits from Livestock Rift Valley Feve Control: A Simulation of Two Epidemics in Kenya

Tabitha Kimani,[1,2] Esther Schelling,[3,4] Bernard Bett,[2] Margaret Ngigi,[1] Tom Randolph,[2] and Samuel Fuhrimann[3,4]

[1]*Department of Agricultural Economics & Agribusiness, Egerton University, Njoro, Kenya*
[2]*International Livestock Research Institute, Nairobi, Kenya*
[3]*Swiss Tropical and Public Health Institute, Basel, Switzerland*
[4]*University of Basel, Basel, Switzerland*

Abstract: In controlling Rift Valley fever, public health sector optimises health benefits by considering cost-effective control options. We modelled cost-effectiveness of livestock RVF control from a public health perspective in Kenya. Analysis was limited to pastoral and agro-pastoral system high-risk areas, for a 10-year period incorporating two epidemics: 2006/2007 and a hypothetical one in 2014/2015. Four integrated strategies (baseline and alternatives), combined from three vaccination and two surveillance options, were compared. Baseline strategy included annual vaccination of 1.2–11% animals plus passive surveillance and monitoring of nine sentinel herds. Compared to the baseline, two alternatives assumed improved vaccination coverage. A herd dynamic RVF animal simulation model produced number of animals infected under each strategy. A second mathematical model implemented in R estimated number people who would be infected by the infected animals. The 2006/2007 RVF epidemic resulted in 3974 undiscounted, unweighted disability adjusted life years (DALYs). Improving vaccination coverage to 41–51% (2012) and 27–33% (2014) 3 years before the hypothetical 2014/2015 outbreak can avert close to 1200 DALYs. Improved vaccinations showed cost-effectiveness (CE) values of US$ 43–53 per DALY averted. The baseline practice is not cost-effective to the public health sector.

Keywords: public health, benefits, Rift Valley fever, livestock