SPATIAL ANALYSIS OF RISK FACTORS AND THEIR EFFECTS ON *PESTE DES PETITS RUMINANTS* CONTROL STRATEGIES IN KAJIADO AND MARSABIT PASTORAL SYSTEMS OF KENYA

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Thesis submitted in partial fulfilment of the requirements for the degree of

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DECLARATION

This thesis is my original work and has not been presented for a degree award in any other University

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To

Maithya, Kito, Sudi and Grace for your unwavering support.

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LIST OF ACRONYMS

AU-IBAR	African Union – InterAfrican Bureau for Animal Resources
ASAL	Arid and Semi- Arid Lands
CCPP	Contagious Caprine Pleuropneumoniae
CAHWs	Community Animal Health Workers
CIDP	County Integrated Development Plan
DIVA	Differentiation of Infected from Vaccinated Animals
DVS	Director of Veterinary Services
FAOSTAT	FAO-UN statistical division
FAO-UN	Food and Agriculture Organisation of the United Nations
FMD	Foot and Mouth Disease
GDP	Gross Domestic Product
GIS	Geographic Information System
GOK	Government of Kenya
GPS	Global Positioning System
IGAD	Inter-Governmental Authority on Development
KNBS	Kenya National Bureau of Statistics
Kshs.	Kenya Shillings
NGO	Non-Governmental Organisation
PPR	Peste des Petits Ruminants
PPRV	Peste des Petits Ruminants Virus
PVE	Post Vaccination Evaluation
RVF	Rift Valley Fever
SGP	Sheep and Goat Pox

OIE	Office international des épizooties (World organization for animal health)
TADs	Transboundary Animal Diseases
UON	University of Nairobi
USD	United States Dollar
VS	Veterinary Services
WAHIS	World Animal Health Information System
WAHID	World Animal Health Information Database

ABSTRACT

The contribution of sheep and goats to pastoralist livelihoods and economies is limited by the frequent occurrence of small ruminant diseases such as *Peste des Petits Ruminants* (PPR). PPR, also known as 'goat plague', is a highly contagious viral disease of sheep and goats characterised by sudden onset of depression, bilateral eye and nasal discharges, mouth sores , pneumonia, foul-smelling diarrhoea and death. In susceptible small ruminant herds, PPR virus infections result in high morbidity rates of 90 percent (%) and mortality rates of 70%. The disease is endemic across 70 countries in Africa, the Middle East and Southern Asia. Current global estimates indicate that PPR outbreaks in endemic countries results in an annual loss of close to 2 billion United State Dollar (USD). PPR was first introduced into Kenya in 2006, but despite vaccination control measures being in place, the disease has continued to spread and is now endemic throughout Northern Kenya. The underlying risk factors triggering outbreaks in Kenya are not well understood. A risk based cross-sectional study was therefore undertaken with an overall aim of improving the management of PPR disease in small ruminant pastoral production systems in Kenya. The study was carried out between January 2014 and March 2015 in Kajiado county which is a high risk PPR zone and Marsabit county which is an endemic PPR zone.

The study used integrated approaches of questionnaire survey, laboratory and spatial statistical analysis to address three specific objectives, the first objective, characterised small ruminant disease control practices amongst Kajiado and Marsabit pastoral communities. The second, determined the seroprevalence of antibodies against PPR virus as well as the prevalence of intestinal parasites of sheep and goat herds in the study areas. The third, identified risk factors and their effects on PPR control strategies using spatial statistical techniques of a geographical information system (GIS).

Sixty three livestock owners were surveyed across 28 sites in Marsabit and 35 sites in Kajiado. Information concerning the small ruminant husbandry and disease control practices was gathered from livestock owners whose herds were sampled. A total of 535 animals consisting of 245 sheep and 290 goats were randomly sampled. In total, 1,070 blood and faecal samples were collected from 213 small ruminants in Kajiado and 322 in Marsabit. Prevalence of PPR antibodies was determined using the competitive Enzyme Linked Immunosorbent Assay (c-ELISA) laboratory procedure. Clinical indicators of intestinal parasitism were evaluated using Body Condition Score (BCS) chart, FAMACHA© anaemia score chart and Packed Cell Volume (PCV) determination. Prevalence of intestinal parasitism was then confirmed using McMaster and pooled faecal culture laboratory techniques.

The study found that only 57% of livestock owners in Kajiado relied entirely on livestock keeping compared to 75% of livestock owners in Marsabit. All (100%) Kajiado livestock owners regularly purchased anthelmintic, antibiotic and tick control products for their small ruminant herds, while only 57% of invested in preventive vaccines. In contrast, all (100%) Marsabit livestock owners did not purchase tick control products or preventive vaccines. However, when available, 42.9% of Marsabit livestock owners occasionally purchased anthelmintic products while only 28.6% purchased antibiotic drugs for use in their small ruminant herds. An important finding with regard to PPR, was that all (100%) livestock owners in Kajiado and Marsabit study sites ranked Contagious Caprine Pleuropneumoniae (CCPP) disease in goats and helminthiasis infections in sheep as the most important small ruminant diseases associated with the highest production and mortality losses throughout the year. The three main constraints hindering livestock keepers' disease control efforts in Marsabit were lack of veterinary services (52.4%), lack of veterinary drug outlets (35.7%) and lack of inclusion when planning livestock disease control programmes (7.1%).

In Kajiado, 60% of livestock owners felt that lack of quality veterinary drugs especially anthelmintics was the main hindrance this was followed by lack of veterinary services (31.4%) and lack of early warning information about disease outbreaks in their area (8.6%). The main policy interventions recommended by majority of Kajiado (90.5%) and Marsabit (84.5%) livestock owners was the provision of regular and timely veterinary services. Veterinary services were defined by the livestock owners as the provision of free vaccination services, extension services and rapid response to disease outbreaks.

The overall PPR seroprevalence for Marsabit small ruminant herds was 22.4% (95% Confidence Interval (CI): 19.5 – 25.4) when compared to 37.1% (95% CI: 31.3 – 42.9) for Kajiado herds. PPR seropositivity in Kajiado was associated with geographical location of sheep and goat herds, animals from Lenkisem ward were 64.0 times ($p< 0.0001$) more likely to be seropositive when compared to animals from Bisil ward. Herd size of goats in Kajiado was also a significant predictor, goats sampled from large herds consisting of more than 100 goats were more likely to be seropositive when compared to medium sized herds composed of between 51 to 100 animals (β-estimate = - 2.19, O.R. = 0.112, $p= 0.001$). In addition, small ruminants herds in Kajiado that received regular doses of combined oral (Levamisole or Albendazole) and injectable (Ivermectin) anthelmintic products had a significantly ($p=0.001$) higher likelihood of being PPR seropositive when compared to animals receiving only oral Levamisole products (β-estimate = -1.623, O.R. = 0.197, $p=0.001$). Prevalence of intestinal parasites and age of animals in Kajiado were not significant predictors of PPR seropositivity. Geographical location of small ruminant herds was also significantly ($p< 0.0001$) associated with PPR seropositivity of animals in Marsabit, sheep and goat herds sampled from Loiyangalani ward had a 36.6 times ($p<0.0001$) probability of being PPR seropositive when compared to animals sampled from Dukana ward.

Animals sampled from herds that had reported past PPR outbreaks in Marsabit were 96.2 times ($p<0.0001$) more likely to be PPR seropositive when compared to those from herds that had not reported outbreaks. Further, Marsabit sheep and goat herds that had access to PPR vaccines had a 5.5 times ($p= 0.002$) probability of being seropositive when compared to herds that had no access to PPR vaccine. Age of animal was also significant ($p<0.0001$), adult animals that were above 3 years of age were 11.9 times more likely to be seropositive when compared to young animals between 6 and 12 months of age. Prevalence of intestinal parasites in Marsabit was not a significant predictor of PPR seropositivity. The average prevalence of intestinal parasites in Kajiado small ruminant herds was 54.5% (95% CI: 47.9 - 61.0) for coccidia parasite and 82.2% (95% CI: 77.0 – 86.9) for helminth parasites. In Marsabit, the average prevalence of intestinal parasites was 48% (95% CI 42.2- 54.0) for coccidia and 30.7% (95% CI: 25.8 – 36.0) for helminths. *Haemonchus* nematode specie was the most common larvae identified after faecal culture. Co-infection prevalence for both helminth and coccidia intestinal parasite was 51.2% (95% CI: 44.6 -57.7) for Kajiado herds and 21.7% (95% CI: 17.1 -26.4) for Marsabit herds.

The utility of GIS as a decision support tool when planning PPR control programmes was demonstrated using spatial statistical techniques of Boolean and overlay analysis, choropleth mapping, Euclidean distance calculation and Voronoi polygon development. GIS analysis found that access to veterinary services varied across Kajiado and Marsabit study areas with Marsabit herds being more disadvantaged due to terrain and long distances that needed to be covered. In conclusion, study findings indicate that small ruminant husbandry practices in Kajiado and Marsabit differed and the differences were due to the access levels to veterinary services, animal health inputs and livestock markets. The overall PPR seroprevalence in the study herds was lower than the recommended 70% that prevents PPR virus circulation in

endemic and high risk areas. This means that majority of Kajiado and Marsabit small ruminant herds were not protected from future PPR outbreaks. Serosurveillance was found to be an important tool that can be used to monitor the effectiveness of existing vaccination control programmes as well as evaluate veterinary service delivery. The Five risk factors significantly associated with PPR seropositivity in the study were (1) Age of animal in Marsabit, adult animals were more likely to be PPR seropositive when compared to animals between 6 and 12 months of age. (2) Geographical location of herds in both study areas, that determined accessibility to veterinary services (3) herd size of goats in Kajiado, animals from large herds were more likely to be PPR seropositive due to the likelihood of their owners investing in PPR preventive vaccines (4) Past PPR outbreak incidences in Marsabit and (5) PPR vaccination status in Marsabit. GIS spatial analysis techniques were found to be useful tools that can support decision making when planning, implementing and monitoring PPR control strategies in endemic and high risk areas.

The following recommendations should be considered, PPR control strategies in pastoral areas of Kenya should be tailored to specific geographical regions taking into consideration the prevalent small ruminant diseases, existing disease control practices, socioeconomic status of communities and access to veterinary services. Annual PPR vaccination activities should include CCPP vaccination for goats as well as target animals between 6 and 12 months of age. Policy makers should adopt the use of GIS and post vaccination serosurveys to monitor the effectiveness and coverage of PPR vaccination campaigns in pastoral areas in Kenya.

CHAPTER 1

1.0 GENERAL INTRODUCTION

1.1 Introduction

Kenya's Arid and Semi-Arid Lands (ASALs) constitute more than 80% of the country's total land mass and are inhabited by close to 10 million pastoral and agro pastoral communities (Kenya National Bureau of Statistics (KNBS) 2009). More than 85% of the national small ruminant population is reared in the ASALs (Government of Kenya (GoK) 2012). The contribution of sheep and goats to pastoral livelihoods is limited by the frequent occurrence of trade sensitive diseases such as *Peste des Petits Ruminants* (PPR). PPR, also known as sheep and goat plague, is a highly contagious viral disease of small ruminants that results in high morbidity rates of 90 % and depending on the immunity of herds a mortality rate of between 30 and 70% (Barret et al., 2006; Office international des épizooties (OIE) 2013). PPR virus does not infect humans but causes significant livelihood disruption for livestock keepers in Africa, the Middle East and Southern Asian countries (Food and agriculture organisation of the United Nations (FAO-UN/OIE 2015).

In endemic countries, direct annual losses due to PPR outbreaks are estimated to be between 1.2 and 1.7 billion USD. Additionally, it is also estimated that annual PPR vaccination expenditure ranges from 270 to 380 million USD (Elsawalhy et al., 2010; African Union – Inter-African Bureau for Animal Resources (AU-IBAR) 2014; FAO-UN/OIE 2015). The first PPR outbreak in Kenya was confirmed in August 2006 in Turkana, which is an arid county located in the remote north-western part of the country GoK 2008; Kihu et al., 2012). The disease gradually spread to neighbouring counties and by 2008 the whole of the Northern parts of Kenya had reported outbreaks (GoK 2008).

It is estimated that the Kenya government incurs an annual cost of close to 1 billion Kenya shillings (Kshs) due to expenditure spent on PPR vaccination and revenue foregone during quarantine and trade bans (GoK 2008). However, a recent socio economic study in Turkana found that losses due to the 2006 to 2008 PPR outbreak were previously undervalued and are now estimated at 19.1 million USD, with mortality of kids and lambs constituting the greatest economic losses valued at 16.8 million USD (Kihu et al., 2015a). The government response to the 2006 outbreak was slow and took 2 years with the launch of a 5 year vaccination campaign in 2008 (GoK 2008). The vaccination activities targeted both sheep and goat herds in all counties located in the Northern parts of Kenya. The campaign aimed at creating buffer zones that would prevent the southern spread of the disease to the rest of the country (GoK 2009; GoK 2015a). However, vaccination control measures have had limited impact and have failed to prevent the periodic outbreaks of PPR in Northern Kenya (Kihu et al., 2015b).

Risk factors that contribute to the persistent outbreaks of PPR in Kenyan ASALs are not fully understood and this is hindering the design of effective PPR surveillance and control programmes (Elsawalhy et al., 2010, Kihu et al., 2015b; FAO-UN/OIE 2015). A risk based cross-sectional study was therefore carried with an overall aim of improving the management of PPR disease in pastoral systems of Kenya. The study used integrated approaches of questionnaire survey, laboratory and spatial statistical analysis to identify risk factors associated with PPR and their effect on existing control strategies. The study was carried out between January 2014 and March 2015 in Kajiado county which is a high risk PPR zone and Marsabit county which is an endemic PPR zone.

1.2 Statement of the Problem

Outbreaks of PPR have continued to occur in Kenyan ASAL areas despite a 5 year vaccination control strategy being in place (Kihu et al 2015b). Several studies in Kenya have reported on clinical manifestation of PPR (Kihu et al., 2012; Gitao et al., 2014; Maina et al., 2015) as well as demonstrated the presence of PPR virus through seroprevalence antibody analysis (Ithinji 2011; Gitao et al., 2014; Maina et al., 2015; Kihu et al., 2015b) and viral genome identification (Gitao et al., 2014; Dundon et al., 2014). Studies have also determined through participatory epidemiological techniques risk factors causing PPR spread in endemic areas of Turkana, Baringo and Samburu counties of Kenya (Kihu et al 2012; Gitao et al., 2014). However, studies estimating the post vaccination seroprevalence of PPR antibodies in sheep and goat herds in endemic and high risk areas are limited (GoK 2009). Further, few studies have determined if pastoralist heterogeneous small ruminant disease control practices result in increased of reduced risk to PPR infections in their small ruminant herds (Gitao et al., 2014). There are no studies that have tried to determine the role played by intestinal parasitism in causing susceptibility of small ruminants to PPR infections. Furthermore, information is lacking on which tools can be used to plan, implement and monitor the effectiveness of existing PPR control strategies in endemic and high risk areas of Kenya.

1.3 Justification of the Study

It is estimated that over 70% of all livestock in Kenya are found in the ASALs and 90% of the ASAL human population rely on livestock for their livelihood (GoK 2012). In addition, the livestock sub-sector contributes 10% to Kenya's Gross Domestic Product (GDP) and approximately 42% to the agricultural GDP (KNBS 2009). However, a new study conducted jointly by the Inter-Governmental Authority on Development (IGAD) Livestock Policy Initiative (LPI) and KNBS in 2011 found that livestock contribution to Kenya's agricultural

GDP was grossly undervalued (Behnke and Muthama 2011), the commodity flow approach was used to estimate the ruminant livestock contribution to agricultural GDP, it was found that livestock contribution to the Kenya economy was close to 345.448 billion Kshs. this was 2 and a half times more than the 2009 official estimate of 127.723 billion Kshs. (Behnke and Muthama 2011). The Kenya vision 2030, is the policy blueprint guiding the economic growth plan of Kenya. Vision 2030 has identified the agricultural sector as one of the key areas that will transform Kenya into a middle income country by the year 2030. However, it will be difficult for Kenya to use livestock as a pathway to economic growth unless the numerous livestock diseases such as PPR are contained (GoK 2012). The first PPR outbreak in Kenya was reported in Turkana County in 2006 and by 2008, PPR virus had resulted in severe disease of more than 5 million small ruminants and mortality of more than 2 million animals (GoK 2008). The continued outbreaks of PPR are putting an estimated 28 million goats and 17 million sheep in Kenya at risk of infection (KNBS 2009). Exposure to PPR virus through natural infection or vaccination should confer a lifelong immunity (Diallo et al., 1989; OIE 2013; AU-IBAR 2014).

It is generally recommended that in endemic countries, PPR vaccination strategies should aim at achieving a 70% herd immunity as this breaks the virus transmission cycle resulting in a significant reduction of PPR incidences (FAO-UN/OIE 2015). PPR vaccinations in Kenya have been going on in endemic and high risk areas since 2008 but they have had limited impacts in preventing the frequent PPR out breaks especially in Northern Kenya (GoK 2015a). The underlying risk factors that trigger outbreaks are not well understood and this is hindering the effective management of PPR in Kenya (Kihu et al., 2015b). The probability of disease transmission is not uniform across animal populations, often, there are a number of risk factors that contribute to the overall risk of disease transmission in a particular livestock

sub-population (Elsawalhy et al., 2010; Dhama et al., 2013). These risk factors are often simple attributes of the sub-population such as transhumance activities in pastoralists systems or access to veterinary services or animal health inputs (FAO-UN 2013). The rationale for this particular study was therefore twofold. First, pastoral communities are differentiated by their geographical location and cultural ethnic backgrounds (Fratkin and Roth 2005). However, factors such as aridity, access to markets and population pressure play a key role in shaping the human societies residing in the dry lands (Kocheki and Gliessman 2005; Rutto et al., 2013). This concept of differentiation emphasizes that although pastoral communities may experience similar socioeconomic disruption due to drought or livestock disease there exists different application of their coping and adaptive strategies (Little 2002). This means that livestock disease control policies should not be applied as blanket interventions but should be informed by the ecological, social- cultural and economic setting of the target communities (Fratkin 2001). The study therefore aimed at identifying key small ruminant husbandry practices that can be recommended for policy action so as to achieve long-term control of PPR and other small ruminant diseases. Secondly, the study aimed at identifying tools that can be used to monitor the effectiveness of existing PPR vaccination control programmes. The applicability of post vaccination serosurveys and GIS techniques were investigated as possible tools that can be used in the planning, implementation and monitoring of PPR vaccination control programmes in endemic and high risk PPR zones in Kenya.

1.4 Broad objective

To improve the management of Peste *des Petits Ruminants* (PPR) disease in small ruminant pastoral production systems of Kenya.

1.5 Specific objectives

1. To characterize small ruminant disease control and husbandry practices amongst Kajiado and Marsabit pastoral communities.
2. To determine seroprevalence of antibodies against PPR virus as well as prevalence of intestinal parasites in sheep and goat herds of Kajiado and Marsabit counties of Kenya.
3. To identify risk factors and their effects on PPR control strategies using spatial statistical techniques of a geographical information system (GIS).

1.6. Research questions

1. Do the heterogeneous small ruminant disease control practices play a role in determining PPR incidences?
2. Does the prevalence of antibodies against PPR virus and intestinal parasites determine the susceptibility of small ruminant herds to PPR infections?
3. Can GIS techniques be used as tools that can support the planning, implementation and monitoring of PPR vaccination control programmes in endemic and high risk areas?

1.7 Limitation of the Study

The first challenge faced was due to under reporting of PPR disease outbreak at County level. This had an implication on the PPR information available at the Director of Veterinary Service (DVS) offices. PPR incidence reports were only available from August 2006 to December 2008. In addition, information after 2008 from suspected PPR outbreaks through serum samples submitted to DVS laboratories did not have information on the vaccination status of animals sampled. It was therefore difficult to differentiate seropositivity due to vaccination or natural disease outbreaks as the samples were sourced from areas that had the

ongoing PPR vaccination activities. Due to these limitations the spatial and temporal distribution maps of PPR outbreaks in Kenya from 2006 to 2015 could not be generated. The other challenge was to identify areas to be included in the study, without official outbreak reports. To address this challenge, the researcher sourced PPR serosurveillance reports from the DVS staff at the veterinary epidemiology unit and browsed the internet for literature on PPR incidences in Kenya. The reports were used to identify potential study areas that represented PPR high risk and endemic areas. Endemic areas identified were all Northern located counties while high risk counties included Narok, Kajiado and Tana-River located in the Southern parts of Kenya. However, limited time, security concerns and financial constrains necessitated the narrowing of the study to 2 counties, these were Kajiado and Marsabit to represent a high risk and endemic area respectively.

1.8 Organization of thesis

This thesis is in manuscript format and is divided into seven (7) chapters that do not include the reference and appendices section. **Chapter 1** titled General Introduction gives a brief overview of the socio-economic impact of PPR in Kenya and putative risk factors associated with PPR outbreaks in Kenya. The chapter concludes by justifying why the study was carried out and demonstrating the knowledge gap the study will address. **Chapter 2** is the General literature review section that provides a detailed analysis of pastoralism in Kenya with focus on historical and current policies that have shaped its development. The chapter also describes the contribution of small ruminants to the global, Kenyan and pastoral economies. This section also gives a detailed description of PPR disease its origin, aetiology, epidemiology, diagnosis and control strategies. The chapter then reviews the putative risk factors that may be causing PPR outbreaks in pastoral regions of Kenya. A historical background on provision of veterinary services in pastoral areas of Kenya is also given.

The chapter concludes by outlining the utility of GIS technology in livestock disease management. **Chapter 3** is the General Methodology section. The chapter describes how study sites were selected and gives an in-depth review of the study sites ecology, social and political setting. **Chapter 4** is the first chapter where findings of this study are presented. The chapter describes pastoralist small ruminant husbandry practices and their effect on PPR control strategies. **Chapter 5** applies statistical analysis to determine if risk factors have a causal relationship with the observed PPR seroprevalence in the study areas. **Chapter 6** presents the utility of GIS technology as a risk mapping tool that can be used to support decisions during the planning, implementation and monitoring of PPR control and surveillance programmes in Kajiado and Marsabit counties of Kenya. **Chapter 7** is the general discussion section that summarises key findings of the study. The chapter concludes by highlighting key recommendations and future areas for research.

CHAPTER 2

2.0 GENERAL LITERATURE REVIEW

2.1 Back ground on Pastoralism

Dry lands also known as rangelands cover more than 40% of the earth's land surface and are defined as arid and semi-arid lands (ASALs) due to their limited potential for crop cultivation (FAO-UN 2000). Dry lands are characterised by low and highly variable rainfall, steep terrain and extreme temperatures (FAO-UN 2000). The world dry lands support the livelihoods of more than 300 million people (Millennium Ecosystem Assessment (MEA) 2005). Pastoralism is an extensive livestock production systems that relies on strategic mobility which is well-adapted to the spatial and temporal distribution of water resources and grazing pastures (Ellis and Swift 1988). More than two decades of research has provided evidence that pastoralism is an economical, rational and viable system that has conserved rangeland biodiversity and maintained its ecosystem services (MEA 2005; Galvin 2009).

Livestock reared under pastoral production systems are able to convert large amounts of natural resources that cannot be utilised by humans into high value protein rich human foods (FAO-UN 2000). These products have been shown to have a lower environmental impact when compared to similar products from intensive livestock production systems (Perry et al., 2013; Intergovernmental panel on climate change (IPCC) 2014). Pastoralism is therefore an economic and social system well adapted to dry land conditions through a complex set of practices and knowledge (Galvin 2009). Pastoralism allows a sustainable equilibrium to be maintained between pastures, livestock and people (Kocheki and Gliessman 2005; Kaye-Zwiebel and King 2014.). The complex set of strategies ensures pastoral societies have a continuous food supply to minimize risks to people and livestock, it also allows avoidance of

disease outbreaks and maintains social and political stability (Ellis and Swift 1988; Notenbaert et al., 2012). These complex strategies include;

i. **Diversification of livestock species and breeds**. Pastoralists rear a wide range of indigenous livestock species and breeds that are selected on the basis of drought resilience and productivity (Ellis and Swift 1988). The rangelands also have plant species diversity that allows the livestock species to utilize the range resources with minimal competition (Ellis and Swift 1988). In addition, rearing more than one livestock specie ensures pastoralists can generate a wider variety of livestock products that will ensure food and economic security throughout the year (Notenbaert et al., 2012).

ii. **Mobility**. This is a rational and necessary strategy that allows sustainable use of rangeland resources (Little 2002). Mobility enables pastoralists to take advantage of pasture resources that are only seasonally available as well as allow access to salt patches that are critical for the livestock health (Galvin 2009; Hobbs et al., 2008).

iii. **Reserve of rich-patch vegetation areas**. Pastoralists set aside communally managed and governed grazing areas to use during the dry season or drought periods (Ellis and Swift 1988; Schiling et al., 2012).

iv. **Maximization of stock numbers**. Maintaining large livestock herds ensure survival of herds despite losses incurred during droughts or disease outbreaks (McCabe 1990). It also represents a method to accumulate food stock and marketable assets (Fratkin 2001). Sheep and goats are often sold during drought stress to generate income that is used to buy household grain feed as well as buy inputs (feeds or drugs) that are used to sustain the more valuable large ruminants such as camels and cattle (Onono et al., 2013)

v. **Splitting of herds**- This strategy aims at optimizing pasture use as well as reducing competition amongst the herds (Ellis and Swift 1988; Fratkin and Roth 2005).

vi. **Redistribution of assets**. These are mutually supportive social networks that ensure harmonious relationships amongst pastoral communities (International Institute of Rural Reconstruction (IIRR) 2013).

Historically, Kenya's ASALs have received low priority in the allocation of development resources (GoK 2012). This is partly due to policy directives taken immediately after independence, the sessional Paper No. 10 of 1965 titled 'Provincial Balance and Social Inertia', stated that the ASAL provinces natural resources could not be utilised for economic growth as the ASAL inhabitants were not receptive to development. The paper therefore advocated for all government investment be directed to high rainfall highlands areas and argued that the resultant production would drive the country's economic growth which would allow development to "trickle down" to the ASALs (GoK 2012). This policy approach did not work and it eventually led to the marginalization of ASAL areas seen today (AU-IBAR 2010; GoK 2012; Shilling et al., 2012). However in 2003, the Kenyan government made a policy shift through the economic recovery strategy which recognized that ASAL inclusion was key to the future economic growth of the country (GoK 2012). The government in 2008, launched Kenya Vision 2030 which is the country's economic development road map. Under this programme a new government ministry was created whose sole mandate was to fast-track investment and sustainable development of Northern Kenya (GoK 2012). This policy shift was further strengthened when the new constitution was enacted in 2010 (GoK 2012). The new constitution made provisions for an equalization fund that will be in effect for 20 years and that will allow fast tracking of infrastructure development in the ASALs (GoK 2012).

2.1.1 Role of Sheep and Goats in pastoral livelihoods

The world food economy has seen a shift to increased consumption of animal based protein food (FAO-UN 2014). This demand has been driven by human population growth and increasing incomes especially in urban areas (FAO-UN 2014). Livestock production is therefore, one of the fastest-growing sectors in agriculture especially in the developing countries (FAO-UN 2014). It is estimated that over 70% of all livestock in Kenya are found in the ASALs and 90% of the ASAL human population rely on livestock for their livelihood (KNBS 2009). The livestock sub-sector contributes to 10% to Kenya's GDP and approximately 42% to the agricultural GDP (KNBS 2009). However, a new study conducted jointly by the IGAD/ LPI and KNBS in 2011 found that livestock contribution to Kenya's agricultural GDP was two and a half times more than the official estimates of 2009. The study used the commodity flow approach and found that ruminant livestock contribution to agricultural GDP was close to 345.448 billion Kshs. this was 2 and a half times more than the 2009 official estimate of 127.723 billion Kshs. (Behnke and Muthama 2011).

The disparity was due to several factors, but the 2 main ones were that Kenya's livestock population size especially in the ASALs is largely unknown and estimates used in 2009 under represented its population size (Behnke and Muthama 2011). Secondly, previous calculations were based on official sales records, which missed production that was traded informally or directly consumed by livestock owning households (Behnke and Muthami 2011). Pastoralists derive more than 50% of their incomes from livestock and livestock products. In addition, more than 80% of the beef consumed in Kenya is produced by pastoralists from Kenya or from neighbouring countries (Muthee 2006; Akililu 2008). It is estimated that pastoral communities, traders and intermediaries exchange between 2 to 3.5 million heads of ruminant livestock a year with clan-based networks being the major support system that drives this

complex trade operations (Behnke and Muthami 2011). Current projections indicate that, between 2000 and 2030, the global mutton consumption will increase annually by 7 million tonnes with consumption in Sub-Saharan Africa projected to increase to 1.8 million tonnes (FAO-UN 2014).

Drought episodes in the ASALs have continued to increase in intensity and frequency (Steinfeld et al., 2006; Thornton 2010; Moenga et al., 2013; IPCC 2014). The frequent drought episodes means that pastoral households are in a constant state of recovery and rarely get the chance to re-stock their large ruminants herds before the next drought incidence (Peacock 2005; GoK 2012). This has seen pastoralists opting to keep larger herds of small ruminants and camels as they are more drought tolerant when compared to cattle (Peacock 2005; Rutto et al., 2013). Furthermore, sheep and goats offer a relatively cheaper pathway to acquiring and accumulating wealth as they have a shorter reproduction and maturity rate when compared to cattle and are therefore a more resilient pathway to recovery after drought or disease outbreak (Rutto et al., 2013). In addition, income generated from their sale supports the household basic needs for grain feed, medical and education expenses (Peacock 2005; Thornton et al., 2006). Small ruminants are also particularly important for providing household milk needs when cattle and camels have migrated away from households during dry season or drought episodes (Degen 2007).

2.2 PPR definition and Global distribution

Peste des petits ruminants (PPR) also known as sheep and goat plague, is a highly infectious viral disease that affects goats and sheep with goats reported to be more susceptible (OIE 2013). Some wild ruminants such as gemsbok, gazelles, springbuck, impala and wild goats are also susceptible (Barret et al., 2006; OIE 2013).

The disease epidemiology indicates that there is no known reservoir and no carrier state (OIE 2013). PPR virus (PPRV) does not infect humans but causes significant livelihood disruption for livestock keepers in Africa, the Middle East and Asia countries, where it is considered to be endemic (FAO-UN/OIE 2015). Once introduced in a herd, the PPRV causes clinical disease characterized by high fever, oral lesions, pneumonia and diarrhoea. This results in severe dehydration that often leads to death (OIE 2013). In naïve populations, that is animals with no previous natural or vaccination exposure, the mortality rate may approach 90% with deaths occurring within 5 to 10 days after infection. However, in endemic areas mortality rates vary from 30 to 70% and are restricted to young and juvenile animas (Barret et al., 2006; OIE 2013). The wide range of mortality rates in PPR infections is due to the varying levels of immunity development. Studies have shown that body condition of animal, species (Sheep or Goat), breed and age of animal as well as occurrence of concurrent bacterial or parasitic infections plays a role in PPR susceptibility (Barret et al., 2006).

PPR was first seen in Ivory Coast in 1942 by Gargadennec and Lalanne, who described PPR as a disease in goats and sheep that had similar clinical signs to rinderpest but was not transmitted to in contact cattle (Barret et al., 2006). The disease was for many years confined to West African countries but in 1972 a disease affecting goats and resembling rinderpest was reported in Sudan and was later confirmed to be PPR (Banyard et al., 2010). Current reports (Figure 1) indicate that PPR is now occurring in Central Africa (Ashley et al., 2010; Banyard et al., 2010), Eastern Africa (Muse et al., 2011; Luka et al., 2011; Kabaka et al., 2012; Kihu et al., 2012; Kihu et al., 2013), the Middle East (Ashley et al., 2010; Banyard et al., 2010) and in Asian countries of India, Nepal, Bangladesh, Pakistan and Afghanistan (Banyard et al., 2010).

The presence of PPR in the Middle East has resulted in European countries allocating resources to set up PPR surveillance systems as they cannot carry out preventive PPR vaccinations due to their PPR disease free status (FAO-UN/OIE 2015).

2.2.1 PPR epidemiology in Kenya

The first case of PPR in Kenya was reported in 2006 in Oropoi and Lokichogio areas of Turkana County. The disease then spread to neighbouring counties of Samburu, Pokot, Marakwet, Baringo and Keiyo. By September 2008, PPR had spread to most of the northern Kenya counties with current reports (Figure 2) indicating that it has spread to all arid and semi-arid pastoral areas in Kenya (GoK 2008; Nyamweya 2010; Kihu et al., 2012). Northern Kenya infected Counties are classified as endemic zones while the Southern Kenya counties are classified as high risk zones that experience sporadic PPR outbreaks (GoK 2015a). In response to the 2006 PPR outbreak, the Kenyan government imposed a strict quarantine and in collaboration with development partners and non-governmental organisations (NGOs) pooled resources to support PPR vaccination activities (GoK 2008). However, the response was slow and took 2 years to launch (GoK 2008). The 5 year vaccination campaign launched in 2008 targeted both sheep and goat herds in all counties located in the Northern parts of Kenya. The main aim was to create buffer zones so as to prevent the Southern spread of the disease to the rest of the country (GoK 2008). However, a number of challenges were encountered the main being an under estimation of small ruminant numbers that resulted in low vaccine coverage (GoK 2009). There was also lack of adequate human resource to carry out the vaccination activities as well as lengthy vaccine procurement procedures that resulted in unnecessary delays these resulted in the eventual spread of PPR to all (Figure 2) arid and semi-arid counties in Kenya (Kihu et al., 2012).

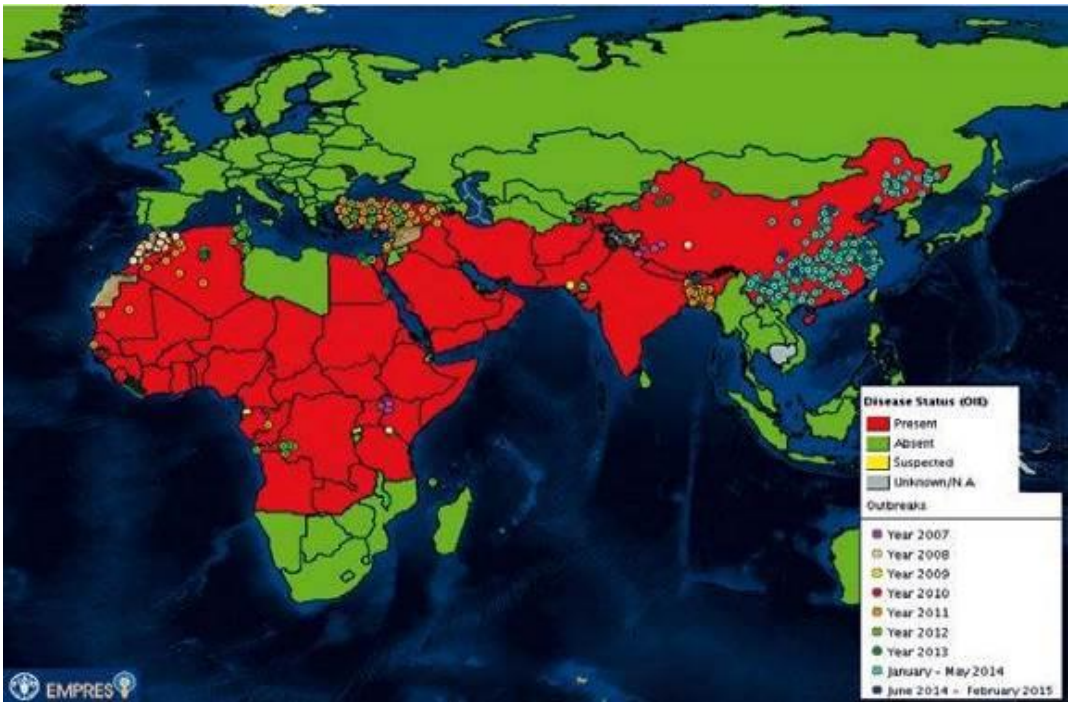

Figure 1: Global PPR distribution as at February 2015.
(Source OIE World Animal Health Information Database (WAHID)

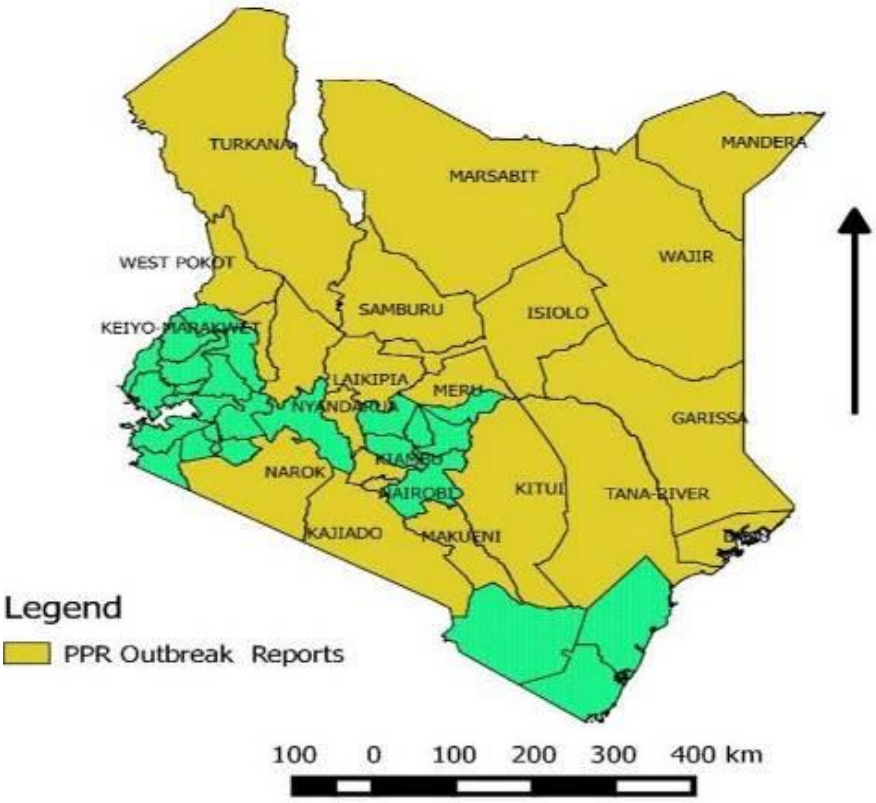

Figure 2: Map showing PPR spatial distribution in Kenya (Source GOK 2015a)

2.3 PPR causative agent

Peste des petits ruminants virus (PPRV) belongs to the genus *Morbillivirus* of the family Paramyxoviridae. Other viruses in the *Morbillivirus* genus include the rinderpest virus, human measles virus, canine distemper virus, phocine distemper virus and dolphin and porpoise distemper viruses. The PPRV has a lipoprotein membrane enveloping a ribonucleic acid (RNA) genome core. The genome is a negative polarity single stranded-RNA that is approximately 16 Kilo bases (kb) long. The PPRV genes are divided into six transcriptional units encoding two non-structural proteins (V, C) and six structural proteins: the surface glycoproteins which include fusion (F) and Haemagglutinin (H) proteins, the matrix protein (M), the nucleoprotein (N), and the phosphoprotein (P) which forms the polymerase complex association with large (L) protein.

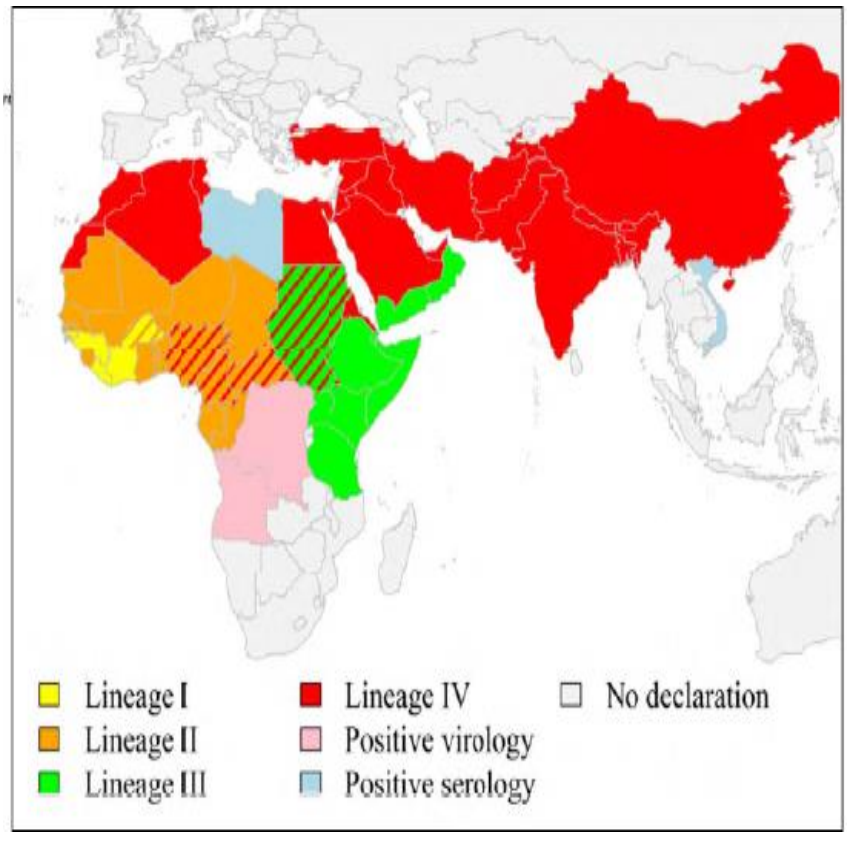

Figure 3: Geographical distribution of PPRV lineages (Source Libeau et al., 2014).

Plate 1: PPR clinical signs (a) and (c) - purulent discharges from nostrils and eyes in a case complicated by secondary bacterial infection; (b) erosive stomatitis with dead cells on the gums of a goat; (d) congestion of conjunctiva. (Source Balamurugan et al., 2014)

The PPRV is genetically grouped into four lineages (I, II, III, and IV) based on the F and N gene sequences analyses which reflect geographical origin as shown in Figure 3 (Banyard et al., 2010; Libeau et al., 2014). Lineage I and II are commonly reported in West Africa (Ashley et al., 2010), lineage III in Eastern Africa except for Sudan that has lineage IV as well lineage III (Ashley et al.,2010; Banyard et al.,2010; OIE 2013). Lineage IV is common in in Central and North Africa, Asia and China (Banyard et al., 2010; OIE 2013). Due to their close genetic makeup vaccination with one lineage confers immunity against the other lineages (Barret et al., 2006; Banyard et al., 2010)

2.4 PPR transmission and clinical signs

Animals infected with PPRV shed large quantities of the virus in secretions and excretions. Transmission occurs via direct contact with infected animals and through aerosols formed by coughing and sneezing of sick animals. Fomites, such as bedding, feed and water troughs also

serve as a means of disease transmission but only for a short period of time as the PPRV does not survive in the environment (Barret et al., 2006; Kumar et al., 2014). The incubation period ranges from 3 to 10 days with clinical signs appearance varying with type of PPRV lineage, species affected, breed and immune status of animal. Although, there is only one serotype, there are several different forms of the disease (acute, peracute, and sub-acute) that determine the severity of the illness. The acute form is the most common course of the disease. The acute form is characterized by an incubation period of 3 to 4 days that is followed by a sudden rise body temperatures of up to 41 degrees Celsius (°C), the hair especially in short-haired breeds stands erect giving the animals a bloated appearance. Affected animals are markedly depressed and refuse to eat or move preferring to stand still or sleep. The febrile stage is soon followed by animals exhibiting bilateral clear watery discharges from eyes and nostrils (Radostits et al., 2000).

The discharges in 1 or 2 days change to become thick and yellow due to secondary bacterial infection (Coucy-Hyman 2013; Kumar et al., 2014). Discharges wet hair below eyes and around the muzzle resulting in matting together of eyelids and difficulty in breathing (Plate 1). Death is usually the result of bronchopneumonia or dehydration due to severe diarrhoea (OIE 2013; Maina et al., 2015). Morbidity and mortality rates vary with the species affected and the age of the population. Morbidity is higher amongst goats than sheep, animals 3 months to 2 years of age are more severely affected than those younger or older (Kumar et al., 2014; Kihu et al., 2015b). Post-mortem lesions are restricted to the respiratory and gastrointestinal tracts. In gastrointestinal tract the mesenteric lymph nodes are congested, enlarged and oedematous. The colon has discontinuous streaks of congestion and haemorrhages (Zebra markings) on the mucosal folds. There is also evidence of pneumonia as lung tissue has areas that have changed from normal pink colour to dark red or purple, the lungs tissue is also firm to the

touch (OIE 2013; Balamurugan et al., 2014; Maina et al., 2015). PPR symptoms can be confused with clinical signs of other important small ruminant diseases. Differential diagnosis for PPR mouth lesions include foot-and-mouth disease, bluetongue, contagious ecthyma "orf" and dermatophilosis (Wabacha et al., 2007). Difficulty in breathing may also be due to pneumonic pasteurellosis or contagious caprine pleuropneumoniae (CCPP). Diarrhoea could may be confused with coccidiosis or gastro-intestinal helminth infestations (Barret et al., 2006; OIE 2013; Gitao et al., 2014).

2.5 PPR diagnosis

PPR is tentatively diagnosed using clinical observation of characteristic symptoms of laboured breathing, ocular and nasal discharges, diarrhoea and presence of mouth sores. Preliminary diagnosis can also be done using post mortem lesions of stomatitis, enteritis and pneumonitis (OIE 2013; AU-IBAR 2014). PPR virus confirmation is important since clinical signs are similar to other economically important diseases of sheep and goats. Confirmatory diagnosis requires laboratory tests that primarily identify the viral proteins or antibodies mounted against the PPR virus. To confirm PPR outbreaks, samples need to be collected for laboratory diagnosis. The type of samples to be collected depends on the stage of the outbreak. During the onset of outbreaks, samples should be obtained from animals with fever that is those in the acute phase of the disease (OIE 2013). The recommended specimens from acutely affected live animals include swabs of conjunctival discharges, nasal secretions, buccal and rectal mucosa. Anticoagulant-treated blood can also be collected for viral antigen identification using polymerase chain reaction (PCR) tests and for haematology investigation. Haematology results will support PPR virus diagnosis as viral infections cause a significant reduction in circulating white blood cells particularly lymphocytes while bacterial infections cause an increase in white blood cells specifically neutrophils (Weiss and Wardrop 2010).

Whole blood for antibody detection will not be useful during the early days of outbreaks as the immunity of animals takes between 2 to 3 weeks to mount an antibody response (OIE 2013). However, some studies have shown that traces of antibodies against PPR virus can be detected as early as day 7 after experimental infections and antibodies continue to rise until day 28 post infection and begin to drop and stabilise after day 30 post infection (Maina et al., 2015). Samples from dead animals should only be collected from fresh carcasses not more than 6 hours after death. The PPR virus has a ribonucleic acid (RNA) genome that is very fragile and disintegrates rapidly in dead tissue or in the presence of secondary bacterial infections. This means that decomposed necrotic tissues and purulent ocular discharges may compromise the quality of PPR virus RNA and are therefore not suitable for PCR tests (OIE, 2013). Necropsy samples should be collected aseptically from two to three animals. The target tissues to be collected include lungs, spleen and intestinal mucosae tissues as well as the mesenteric and bronchial lymph node. All tissue samples should be chilled on ice or put in liquid nitrogen and transported to the laboratory on the same day if possible. Samples of organs collected for histopathology should be placed in 10% neutral buffered formalin (Couacy-Hymann 2013; Dundon et al., 2014; Maina et al., 2015).

In the later stages of the outbreak, after 2 to 3 weeks, blood can be collected for serological diagnosis to demonstrate presence of antibodies mounted against the PPR virus (OIE 2013; AU-IBAR 2014). However, it should be noted that there is no serological test that can distinguish vaccinated animals from those that have recovered from natural infection. This means that all serological samples should always be accompanied with a proper history of PPR vaccination status of animals sampled (OIE 2013; Kihu et al., 2015b). Several confirmatory tests to detect and identify PPR virus antigen/nucleic acid or antibodies are available and approved by OIE (OIE 2013).

Confirmatory PPR tests are grouped into two, the conventional and molecular techniques. Conventional techniques include virus culture and isolation this is the ideal confirmatory test (gold standard). Antibody detection tests include the viral neutralization test (VNT) used for serum samples. This technique also needs a cell culture facility that is largely unavailable in developing countries (OIE 2013). Conventional tests require time for virus isolation and this can cause a significant delay when planning outbreak control response. OIE therefore recommends molecular techniques that require less time to carry out but are expensive (OIE 2013). These include;

i. Antigen detection using Immunocapture enzyme-linked immunosorbent assay ELISA (ICE). The test is sensitive and specific and used to detect the presence of PPRV antigens (Balamurugan et al., 2014).

ii. Antibody detection against PPRV is carried out by using enzyme- linked immunosorbent assay (ELISA) tests. OIE recommends use of competitive PPRV-specific anti-H (H-cELISA) or anti-N (N-cELISA) monoclonal antibodies (Mab) based tests (Libeau et al., 1995; Couacy-Hymann 2013).

iii. Genome detection tests using reverse transcriptase polymerase chain reaction (RT-PCR) is expensive but is the only test that can currently identify the PPR virus genome type. This test is therefore able to distinguish if PPR serological positive cases are due to infection or vaccination (Dundon et al., 2014; Balamurugan et al., 2014).

iv. Pen side tests have been developed to detect PPR virus antigen while in the field. The pen-side tests are based on a simple immune-chromatographic system (Figure 4). The tests are also known as rapid chromatographic tests as results as seen in under 10 minutes (Baron et al., 2014). The pen side prototypes sensitivity and specificity are similar to the RT-PCR (Baron et al., 2014).

Figure 4 gives a graphic representation of the PPR pen side diagnostic test. In brief, The PPRV (antigen=Ag) in sample coloured green is attached to beads coated with PPRV specific monoclonal antibody (MAb) coloured purple. During testing the MAb-Ag bound beads are carried across the test strip by the flow of the buffer and are trapped to test line (T) which also contains anti-PPRV antibodies which binds to the same virus particles in the sample. Spare beads with no Ag bound are then trapped by control line (C) that contains anti mouse Immunoglobulin G (IgG) which confirms sample flow (Baron et al., 2014).

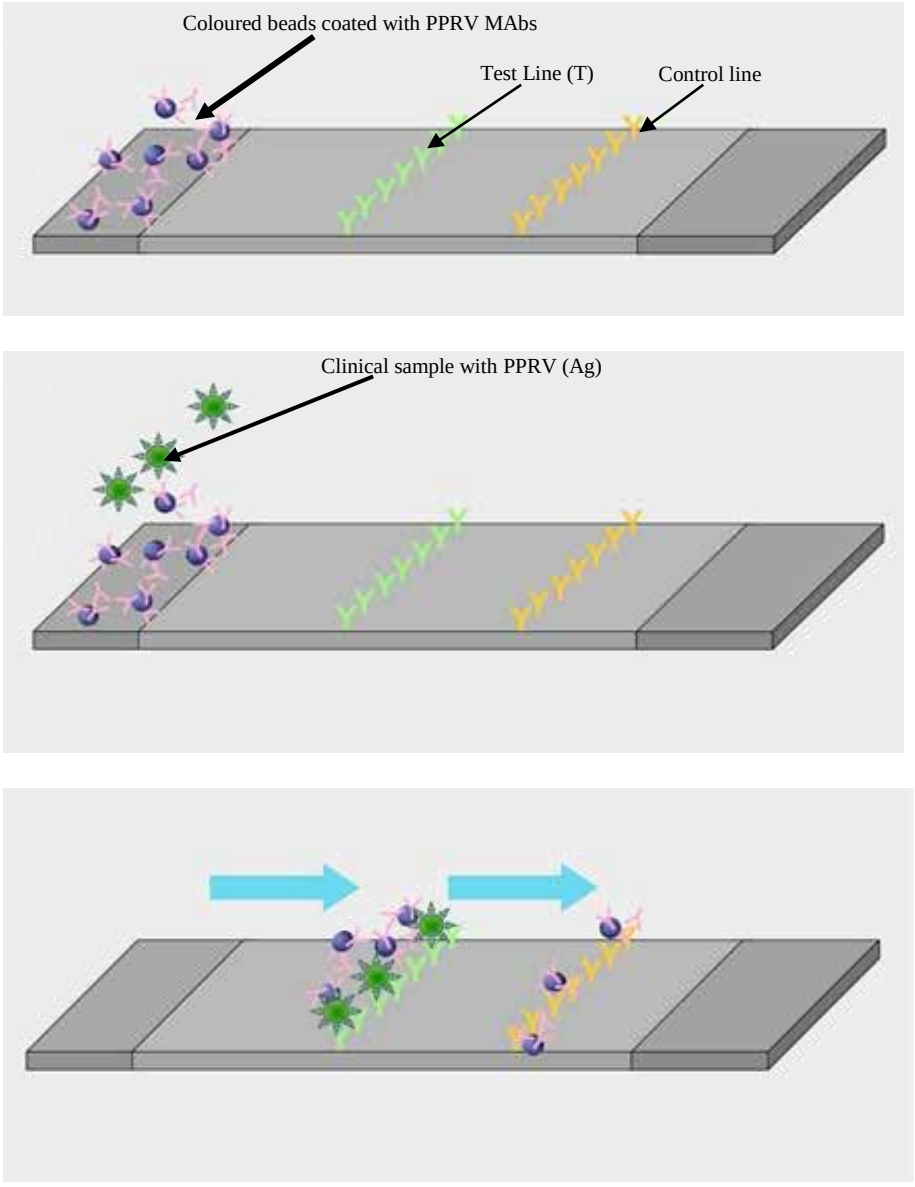

Figure 4: PPR virus pen side diagnostic test (Source Baron et al., 2014)

Current research focus is on the development of a differentiation of infected from vaccinated animals (DIVA) vaccine or test. A DIVA vaccine or test would improve epidemiological data by allowing tracking of infection in areas where there has been vaccination control activities (Balamurugan et al., 2014).

2.6 PPR Treatment

PPR has no specific treatment as it is a viral disease. However, mortality rates can be reduced by using supportive treatment with drugs that will treat or prevent secondary bacterial or parasitic complications. Specifically, long-acting Oxytetracycline or Chlortetracycline are recommended to prevent secondary pulmonary infections as well as use of anthelmintic to reduce worm burden (FAO-UN /OIE 2015). Vaccination remains the most effective and economically justifiable strategy to prevent or control PPR. (OIE 2013; FAO-UN/OIE 2015).

2.7 PPR prevention and control strategies

PPR is a notifiable disease, this means it is listed by OIE and OIE country members as one of the diseases if detected or suspected should be brought to the attention of the veterinary authority, in Kenya this is the DVS (GoK 2014). The term "notifiable disease" is only used for diseases subject to intensive official measures of prevention and control. Notifiable diseases are highly contagious, spread fast across local and international borders and have serious public health or economic impacts (OIE 2013). The veterinary authority in a country with support from the government have enacted laws guiding the management of notifiable diseases. In Kenya, the Animal Diseases Act Chapter 364 is the overarching law that outlines in detail the management of notifiable diseases. The first key requirement punishable by law if contravened, requires every person who is handling or attending to an animal or carcass to report any suspected case of a notifiable disease (GoK 2014).

The main aim of notifiable disease laws is to ensure detailed contingency plans and surveillance systems are in place prior to outbreaks. Proper planning will ensure elimination of the disease or at least return to the status quo in the shortest time possible and in the most cost-effective way (FAO-UN 2011). Most African countries have enacted laws and established institutions and policies guiding notifiable animal disease management. However, the lack of investment in contingency planning often leaves planning to the time when outbreaks have occurred. By doing so, the intense pressure from livestock owners and politicians causes resource misuse and rarely achieves the desired goal. In addition, the unavoidable delays in establishing quarantine zones and initiating vaccination activities means that further disease spread will occur thus increasing the cost of control (AU-IBAR 2012).

The World Organization for Animal Health also known as OIE is an inter-governmental body formed in 1924 with the objective of improving the transparency and international collaboration in the control of devastating epizootic animal diseases. OIE has 180 member countries of which Kenya is a member (OIE 2013). Member countries are obliged to regularly report in a transparent and timely manner the occurrence of OIE listed notifiable diseases using guidelines set in the 22nd edition of the terrestrial animal health Code manual (OIE 2013). The OIE list of diseases is released on the 1st of January every year and each listed disease has a corresponding chapter in the terrestrial animal health code manual to assist member countries in the harmonisation of disease detection, prevention and control guidelines. The manual is available as an open access document in the OIE website (OIE/FAO-UN/WHO (2006). Member countries notify OIE of their disease status through web-based platforms created and managed by OIE. The World Animal Health Information System (WAHIS) which is coupled with the World Animal Health Information Database (WAHID) interface (FAO-UN 2011).

The Global Early Warning System (GLEWS) is also a web based disease reporting platform jointly managed by OIE, FAO-UN and World Health Organisation (WHO) (FAO-UN 2011). The Animal Resources Information System (ARIS-2) is a regional web based initiative by AU-IBAR whose aim is to enhance the information and knowledge management capacity of AU-IBAR African member states. Real time information is available on animal health status of member states as well as information on animal production, fisheries, wildlife and markets (AU-IBAR 2014).

Apart from its main mandate of ensuring transparency and enhancement of knowledge on global animal health situation. OIE is also the only institution through a 1998 official agreement with the World Trade Organization (WTO), authorised to recognise and declare countries or zones disease or pest-free (FAO-UN 2011; AU-IBAR 2014). To do this, OIE using information based on research has set sanitary and phytosanitary standards in accordance with WTO agreement (AU-IBAR 2012). The animal health standards support safe and fair livestock trade practices. One key requirement is that countries should demonstrate transparency in animal disease reporting so as to be able gain the trust of its trading partners, neighbouring countries and international community (OIE/FAO-UN/WHO 2006; FAO-UN 2011). In Africa, only 4 countries out of the 54 have complied with the WTO sanitary and phytosanitary guidelines set by OIE and have been cleared to export beef products to European markets (AU-IBAR 2012). In addition, only another 4 from the Horn of Africa export outside the continent but this is restricted to the Middle East (AU-IBAR 2012). However, the regular outbreak of trade sensitive diseases such as foot and mouth disease and rift valley fever makes access to the Middle East market irregular and unpredictable due to movement and trade sanctions during outbreaks. (AU-IBAR 2012).

2.7.1 Current PPR control strategies

In April 2015, the global campaign aimed at the progressive control and eventual eradication of PPR by 2030 was launched (FAO-UN/OIE 2015). Declaring PPR as a target disease for eradication was based on the fact that the disease directly affects the livelihood of more than 330 million people in Africa, Middle East and Asia (FAO-UN/OIE 2015). PPR virus eradication is possible at the virus exists as a single serotype and the available live attenuated vaccines is effective and confers lifelong immunity against all 4 lineages after a single subcutaneous dose (FAO-UN/OIE 2015). In addition, the absence of evidence of a carrier state or existence of a domestic or wildlife reservoir outside the small ruminant population will also favour rapid control efforts (Elsawalhy et al., 2010; FAO-UN 2013). The global PPR strategy aims at eradicating PPR by integrating 3 key components. Component 1 is PPR eradication in a 4 phased approaches that should take a country 15 years or less to achieve. Component 2 is building the capacity of veterinary Services (VS) to ensure quality services and component 3 is aimed at combining PPR control with the control of other important small ruminant diseases such as Sheep and Goat Pox (SGP), Contagious Caprine Pleuropneumoniae (CCPP), contagious ecthyma (Orf), pasteurellosis and brucellosis (FAO-UN/OIE 2015).

It is envisaged that by combining multiple disease control efforts countries will be able to achieve economies of scale. This will be particularly important for pastoral regions (FAO-UN/OIE 2015). The PPR global strategy suggests implementation of several tools to allow monitoring of successes of the phased eradication activities these include 1. Use of OIE approved PPR vaccine and diagnostic assays 2. Use of OIE performance of veterinary services (OIE PVS) tool which will evaluate VS compliance with OIE standards 3. Use of the PPR Monitoring and Assessment Tool (PMAT) and 4. Post-Vaccination Evaluation tool (PVE) (FAO-UN/OIE 2015).

The PMAT categorises countries according to four different stages identified in the Global Strategy. The PVE tool will enable monitoring of the effectiveness of the vaccination campaign to be evaluated, using various methods such as passive and active surveillance, including participatory disease search, serological surveys, flock productivity surveys and sociological surveys to assess livestock owners' perception of vaccination success (FAO-UN/OIE 2015). The global strategy also recommends its adoption at regional levels so as to allow the coordination and harmonisation of national strategies and activities and on the development of strong partnerships and networks, particularly for laboratories. (GOK 2015a). The global strategy also recommends the establishment of a Global Research and Expertise Network on PPR (PPR-GREN).

Given the transboundary nature of PPR, a single country in an endemic zone cannot achieve PPR control and progressive eradication unless its neighbouring countries share a similar objective. The global strategy also recommends the establishment of PPR regional road maps. The aim of the regional strategies is to reduce the burden of PPR in endemic countries while also developing strategies to prevent entry in PPR-free countries. Reducing PPR at source will therefore be a shared interest and will be considered a global public good. There are 9 regional PPR road maps (Figure 5) that preceded and informed the global Strategy. The regional strategies are anchored in already existing Regional Economic Communities (RECs) such as the Common Market for Eastern and Southern Africa (COMESA) and the Intergovernmental Authority for Development (IGAD) so as to be able to foster ownership and rapid implementation of the strategies .The regional road maps are now being tailored into continental and national PPR strategies (Elsawalhy et al., 2010; FAO-UN 2013). A Regional Advisory Group (RAG) has been constituted for each region. The RAG is chaired by 3 nominated Country Veterinary Officers (CVOs) and is composed of heads of the regional

laboratory and epidemiological networks as members and OIE and FAO representatives as observers. The RAG mandate is to review documents and evidence so as to be able to assign each country a provisional PPR status stage as outlined in the 4 stages of the global strategy. The four stages (Figure 6) correspond to a combination of decreasing levels of epidemiological risk and increasing levels of prevention and control (FAO-UN/OIE 2015).

Figure 5: PPR Control Regional Road Maps (Source FAO/OIE 2015)

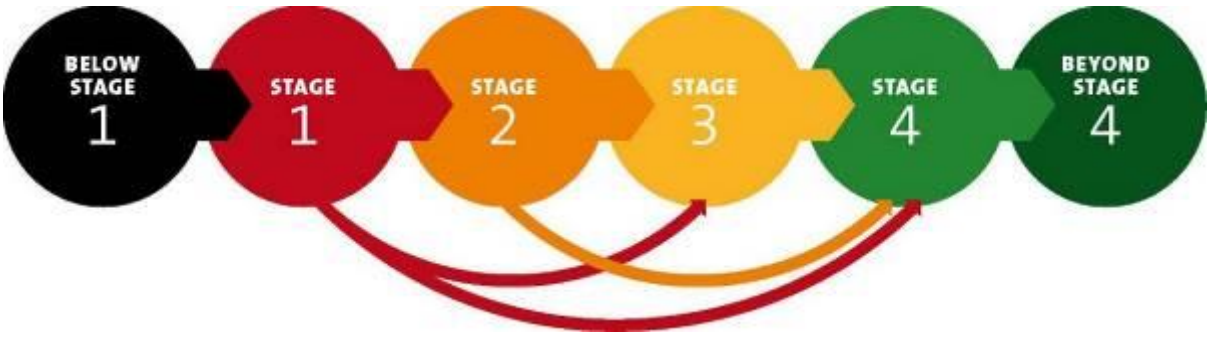

Figure 6: The fast-track procedure for the progressive control and eventual eradication of PPR (Source FAO-UN/OIE 2015)

Stage 1 is where the epidemiological situation in a country is being assessed and Stage 4 is when the country can provide evidence that there is no virus circulation either at zonal or national level and is ready to apply for the OIE official country status of PPR freedom. The Information on annual progress of the regional PPR Roadmaps will then be transmitted to the FAO/OIE PPR global steering Committee also known as the Global Framework for the progressive control of transboundary animal diseases (GF-TADs) (FAO-UN/OIE 2015).A country is classified as below stage 1 if there is insufficient or unstructured epidemiological data to aid in the understanding of the true risk for PPR or there is no PPR prevention and control programme in place. Stage 1 is the assessment stage where epidemiological surveillance activities use serosurveillance and diagnostic tests to zone the country into PPR free or endemic areas. This stage should take a minimum of 12 months and a maximum of 3 years (FAO-UN/OIE 2015).

Stage 2 is the vaccination control phase and should be done either as a mass blanket vaccination of the whole country or a targeted mass vaccination with focus on infected zones and ring vaccination during sporadic PPR outbreaks in high risk zones (FAO-UN/OIE 2015). Post vaccination serosurveillance to determine the small ruminant population vaccination coverage is also important in this stage. This stage should take between 2 and 5 years. Stage 3 is expected to take 2 to 5 years and known as the eradication stage where the occurrence of clinical disease in the sub-population covered by the vaccination programme in Stage 2 is expected to be have been stopped and in sub-populations not covered by the vaccination programme have no PPRV circulation or outbreaks occur sporadically or situation remains endemic but with small socio-economic impact. At the end of Stage 3, no clinical outbreaks should be detected in the whole territory and diagnostic tests should indicate no PPRV circulation in other in contact species of domestic animals such as camels or cattle (FAO-

UN/OIE 2015). Stage 4 is the post eradication phase where the use of vaccine is suspended and no clinical outbreaks have been detected in the country in the previous 24 months. This stage takes 24 months to 3 years and is has supporting evidence that there the PPR virus is no longer in circulation in domestic animals within the country or zone and if there are any, the PPR incidence are very low reduced or zero incidence and limited to occasional incursion from other neighbouring countries or zones. A country can then officially apply to OIE for official recognition of PPR free status (OIE 2013). A country with an already existing official recognition by OIE as PPR free is categorised as beyond Stage 4 (FAO-UN/OIE 2015).

Due to the diverse social, economic and ecological contexts in countries, the PPR global, regional and national strategies are based on risk based and progressive phased approaches. These 2 approaches are founded on sound epidemiological knowledge and are driven by socio-economic incentives (Elsawalhy et al., 2010; FAO-UN 2013). Risk-based approach means that control efforts will target areas and animal populations that are most likely to be affected by PPR while progressive phased approaches means that each phase of the strategy is self-sufficient and will provide economically justified activities that give durable and measurable outputs that are within the financial and human resources capability of the country (FAO-UN 2013).

2.7.2 Vaccine control strategy

Vaccination remains the most effective way to control PPR. Historically, small ruminants were protected against PPR by using the heterologous rinderpest virus vaccine, but this vaccine stopped being used during rinderpest eradication programme to avoid confusion that would be created during serosurveillance for rinderpest antibodies (Diallo 1989; Kumar et al., 2014). A PPR homologous live attenuated vaccine Nigeria 75/1 was developed in 1980

(Diallo 1989). The vaccine is effective against all the 4 PPRV lineages and provides a life-long immunity after administration of a single dose using the subcutaneous route (Banyard et al., 2010). However, the vaccine has low thermal stability with a half-life of 2 to 6 hours at 37°C after being reconstituted. The use of this vaccine under tropical conditions needs a well and sustained cold chain (OIE 2013). In Asia, 3 live-attenuated vaccines using PPRV lineage IV Indian isolates have been developed Sungri 96, Arasur87 and Coimbatore 97 (Balamurugan et al., 2014). Recent research has improved the thermo stability of the Nigeria 75/1 vaccine by incorporating a cryo-protector with trehalose sugar allowing the vaccine to stay for 5-14 days at 45°C in the lyophilized (powder) form and 21 hours at 37°C after reconstitution (Kumar et al., 2014). The PPR vaccine is considered safe without any significant immunosuppressive effect on vaccinated animals. In addition, animals vaccinated are unable to transmit the challenge virus to in contact unvaccinated animals (OIE 2013; Kumar et al., 2014).

Vaccination control strategies are based on a countries disease status there are 3 recognised PPR status; disease free, endemic and high risk. Countries that have been declared free of PPR by OIE have a control policy that advocates for no vaccination. The lack of a DIVA test or vaccine means that PPR free countries cannot vaccinate as sero surveillance will pick up antibodies against PPRV and these antibodies are undistinguishable from those due to infection. In disease free countries any PPR occurrence is controlled by stamping out. Stamping out is a recognized and proven strategy for rapid elimination of an introduced exotic disease. The crucial elements of stamping out are (i) quick identification and delineation of infected zone (ii) intensive disease surveillance to identify infected premises and in contact premises or villages (iii) imposition of quarantine and livestock movement restrictions (iv) immediate slaughter of all infected and in contact animals in the premises or in the infected

area (v) safe disposal of their carcasses and other potentially infected materials (vi) disinfection and cleaning of infected premises and maintaining these premises depopulated of susceptible animals for a suitable period. Stamping out ensures quick eradication of an introduced exotic disease. It also allows countries to have a shorter waiting period before being reinstated as PPR free thus resume international trade of live livestock and livestock products. However, compensation of livestock owners must be done, stamping out is therefore the most costly disease control strategy and is only enforced in developed countries (FAO-UN 1999; FAO-UN/OIE 2015).

In endemic countries PPR is always in occurrence in either seasonal outbreaks or in low incidence levels. Control strategies involves blanket vaccination which is a comprehensive vaccination of all susceptible species animals over a large area and is the preferred option when the disease is well established and there are multiple foci of infection. Quarantine or movement restrictions are rarely enforced in endemic countries as the livestock owners and local VS providers perceive PPR incidence as a normal occurrence. Furthermore, as is the situation in Kenya PPR occurs in pastoral and agro-pastoral systems and it therefore difficult to enforce movement control. Vaccination in endemic areas covers infected and suspected areas together with areas considered to be at high risk for spread of the disease. However, this strategy is also expensive and the PPR global control strategy has recommended targeted/strategic vaccination based on extensive epidemiological surveillance as this will not only reduce wastage of public funds but will also speed up disease eradication (Dhama et al., 2013; FAO-UN/OIE 2015). This means that in Kenya mass blanket vaccination should be done in known endemic regions of Northern Kenya but only done for high risk areas after confirmation of outbreaks (FAO-UN/OIE 2015). The global strategy proposes a 3-year mass vaccination strategy where there is mass blanket vaccination of all sheep and goats above 3

months of age in the first year followed by vaccination of young animals between 3 and 12 months in the second year and a final mass vaccination in the third year. The mass vaccinations of animals should be carried out a month before the expected seasonal movements due to drought or dry spell or increased market activities during religious festivals. The coverage should target 80% of the population targeted (FAO-UN 2015), however a recent study in Turkana showed that a 50% coverage could also offer protection in populations that are remotely and sparsely populated (Kihu et al., 2015b). Case studies in Morocco and Somalia have shown that maintenance of a vaccination coverage of above 60% for 3 consecutive years breaks PPR virus transmission cycle (FAO-UN/OIE 2015). To be able achieve this level of vaccination coverage policy makers need a thorough understanding of the population dynamics especially the rate of yearly restocking (FAO-UN/OIE 2015).

PPR high risk areas are those with high probability of sporadic outbreaks as they are adjacent to endemic areas or have a high number of susceptible small ruminant population that have not been exposed to PPRV through natural infection or vaccination. Most endemic countries have endemic and high risk zones. The main control strategy in high risk areas or countries is quarantine during outbreaks and ring vaccination (FAO-UN 1999). Ring vaccination is the rapid creation of an immune belt around an infected area and should cost less than a blanket vaccination strategy (FAO-UN 1999). The decision to implement a ring vaccination should be made quickly or the rapid spread of the disease may make the infected zone larger and unmanageable given the limited resources. The width of the immune belt should be determined by epidemiological factors and resources available. As a general guide the ring belt should be 20 to 50 kilometres wide from the focal area of first PPR case ((FAO-UN 1999). The target ring vaccination should ideally be completed within a week, and it is prudent to select a narrower ring if human resources, vaccines and other resources are limited

so as to fit within the 1 week time frame (FAO-UN 1999). The vaccination ring can then be extended later as more PPR incidences are reported. Having selected the target area for the ring, vaccination should commence at the outer circumference and move inwards (centripetally) towards the infected herds or flocks (FAO-UN 1999). Separate vaccination teams should be used for herds in which there is a high suspicion of infection (FAO-UN/OIE 2015). The delivery of the vaccine also increases the final cost of PPR vaccination control strategies and this is the main reason the PPR global strategy is advocating for concurrent vaccination against other prevalent small ruminant diseases in the area such as SGP, CCPP, orf and brucellosis (FAO-UN/OIE 2015).

2.8 Economic importance of PPR in Kenya

The contribution of small ruminants to pastoral livelihoods and economies is being limited by the frequent occurrence of diseases. Small ruminant diseases increase the vulnerability of livestock keepers in 3 main ways they (i) Cause death of livestock assets (ii) Reduce productivity and (iii) Constrain market access. Current estimates indicate that direct global annual losses due to PPR are between 1.2 and 1.7 billion USD. Additionally, it is also estimated that the global annual PPR vaccination expenditure ranges from 270 and 380 million USD (FAO-UN/OIE 2015). The first PPR outbreak in Kenya was reported in Turkana County in 2006 and by 2008, it had affected more than 5 million small ruminant herds and had resulted in the death of 2 million animals (GOK 2008). The annual production and control costs associated with PPR outbreaks in Kenya is estimated to be close to 1 billion Kshs. (Table 1). However, a recent study in Turkana county indicates that previous estimates were grossly undervalued, with losses now estimated to be 19.1 million USD with mortality of small stock constituting the greatest losses valued at USD16.8 million (Kihu et al., 2015a).

Table 1: Annual production and control costs associated with PPR outbreak in Kenya

Economic variable	**Annual parameters**
Number of Shoats infected by PPR	3,626,000
Number of Shoats that died from PPR	1,571,293
Number of animals vaccinated	2,500,000
Total cost of vaccination & other control costs (Kshs)	150,000,000
Farm-gate value of total meat loss (Kshs)	716,605,008
Farm-gate value of total milk loss (Kshs)	147,805,560
Total meat and milk loss (Kshs)	864,410,568
Total costs for milk, meat & control costs (Kshs)	**1,014,410,568**

Source GOK 2008

2.9 Risk factors associated with PPR outbreaks

It is a well-recognised epidemiological principle that probability of disease transmission is not uniform across national animal populations (FAO-UN 2011). Risk factors that contribute to the overall risk of disease transmission in a particular community, production system or value chain are often quite simple attributes of the sub-population such as movement and exchange of animals, distance from veterinary services and inter-species contact or interaction (Dhama et al 2013). When the nature and distribution of risk factors for transmission and maintenance of a disease agent are known, it becomes possible to target surveillance and control measures to high risk settings, this maximizes impact and minimizes cost (Dhama et al 2013). Effective targeting of high risk animal populations through participatory disease surveillance was one of the key factors that enabled the eradication of rinderpest and see the world declared rinderpest free in June 2011 (FAO-UN 2011). In Kenya, PPR vaccination activities face complex challenges among them being the lack of understanding of the small ruminant population dynamics.

Small stock in Kenya as well as in other greater horn of Africa countries have high undocumented numbers (FAO-UN 2013; Kihu et al., 2015b). Furthermore, the limited financial and human capacities and unregulated movement of animals across borders as well as lack of regional vaccination coordination has hindered the effective containment and control of PPR (Elsawalhy et al., 2010).

2.9.1 Risk factors due to husbandry practices

Pastoralists are in constant movement with their livestock as they track pasture and water and as they engage in trade activities (Ellis and Swift 1988; Dong et al., 2011). This makes it difficult to quarantine sick animals and since natural resources are shared livestock are always at risk of disease exposure (Elsawalhy et al., 2010; Muse et al., 2012; Kihu et al., 2013). However mobility has worked against the provision of basic services, pastoralists have limited access to veterinary services and have historically relied on indigenous knowledge to diagnose, treat and control through mostly avoidance action to manage livestock diseases (Catley et al., 2011; Onono et al., 2013). PPR control is only achievable through sustained vaccination and it is unlikely that traditional practices of avoidance will stop outbreaks especially in endemic areas where the virus is continuously circulating (FAO/OIE 2015). Other management practices that have been associated with PPR outbreaks include lack of timely reporting of outbreaks, introduction of new animals into the herds, mixing of herds at watering areas, local culture of borrowing and loaning of livestock as well as rustling (Muse et al., 2012; Kihu et al., 2015b). Investment in animal health by livestock owners and governments is up to the point beyond which further investment would no longer be profitable, this is known as the law of diminishing returns (Peacock 2005). Small ruminant production systems are perceived, especially in developing countries as low-input, low-output systems and this generates a vicious cycle in which disease lowers productivity while low

productivity presents an obstacle to investments in animal health (FAO-UN 2015). Another reason that discourages investment in small ruminants is the high off take rate of sheep and goat herds. Small ruminants have a short cycle of reproduction (gestation period of approximately 150 days) that has high twinning rates as well as fast maturity rate with most kids or lambs reaching maturity at 8 to 12 months (Peacock 2005).

2.9.2 Risk factors due to limited access to veterinary services

Veterinary Services means the governmental and non-governmental organisations that implement animal health and welfare measures and other standards and guidelines in the OIE Terrestrial Code and Aquatic Animal Health Code (Aquatic Code) in the country (GoK 2014). Veterinary Services in Kenya are under the overall control of the Department of Veterinary Services (DVS) that is headed by the Director of Veterinary Services in line with the requirements of OIE (GoK 2014). The current challenges seen in animal health provision especially in ASAL regions of Kenya stem from historical marginalisation. The DVS office was established in 1890 during the colonial period to offer animal health clinical services to the white settlers residing in high potential areas (Cinnamond and Eregae 2003). The animal health providers during the colonial period consisted of foreign government employees or private practitioners (Cinnamond and Eregae 2003).

African livestock owners were totally excluded from this service and were served by vet Scouts who were local livestock keepers who had received informal training from the government veterinary staff and were employed by the county council and seconded to the government (Cinnamond and Eregae 2003). The vet scouts lived and provided animal health services to the colonised Africans (Cinnamond and Eregae 2003). After independence provision of veterinary services became an integral part of the public-sector. Evolution of veterinary services during the post-independence period was marked by two distinct phases

the expansion (1963-1986) and reforms (1986-to date) (Cinnamond and Eregae 2003). During the expansion phase, the independent government and its development partners provided highly subsidized clinical services, key among them being Artificial Insemination (AI), dipping and extension services (FAO-UN 2009). The government also allowed movement and provision of veterinary services to ASAL livestock which had been put in a permanent quarantine by the colonial government in an attempt to stem the spread of Contagious Bovine Pleuropneumoniae (CBPP) (FAO-UN 2009). Vet Scouts at village level were gradually phased out and replaced by government employed veterinarians and animal health technicians who were posted at Divisional and Locational level respectively (FAO-UN 2009). The Private Practitioners, many of whom were foreigners left the country (FAO-UN 2009). Although clinical services became more accessible to all in the high potential areas (FAO-UN 2009). This was not the case in the ASALs mainly because there were fewer personnel posted there and those that agreed to stay were faced with numerous challenges such as nomadic herds, vast distances, poor terrain and road network (Cinnamond and Eregae 2003; FAO-UN 2009).

The reforms phase saw a push for liberalisation and enhanced implementation of the Structural Adjustment Programmes (SAPs) introduced by the World Bank (WB) and International Monetary Fund (IMF) (FAO-UN 2009). Most donor support was withdrawn and the government cut back on spending on many sectors including the livestock sector (FAO-UN 2009). Provision of goods and services to the citizens was as no longer a public good but was relegated to a shared responsibility between the public sector, the private sector and the consumers of the goods and services (FAO-UN 2009). Although the reforms brought by this change of policy were well absorbed by the well-resourced livestock keepers who were able to enjoy the diverse benefits of liberalisation of veterinary supplies and services (FAO-UN 2009).

The historically marginalised ASALs were impacted negatively. Furthermore, in the late 1980s the government stopped automatically employing veterinarians and AHTs (Cinnamond and Eregae 2003). The subsequent budgetary reduction led to the establishment of a Decentralised Animal Health (DAH) systems which was an alternative system of service delivery. These was a network of local service providers at community level called Community Animal Health Workers (CAHWs) or 'Trained Livestock Keepers'. The DAH was initiated by Non-Governmental Organisations (NGOs) working in pastoral and agro-pastoral areas (FAO-UN 2009). The CAHWs were selected from the communities and equipped with skills to enable them provide appropriate, reliable and cost effective animal health and extension services (Cinnamond and Eregae 2003). The CAHWS enhanced disease surveillance and were able to link nomadic communities to public and private service providers with varying level of success, several reports have indicated the positive contribution they had on improving pastoral livelihood (Young et al., 2003; FAO-UN 2009). The CAHWs were to operate under the guidance of the District Veterinary Officer (DVO), unfortunately, the regulating and nurturing role of the DVO was limited due to shortage of staff and financial resources. In addition, the lack of a standard guideline on training and inadequate regulation by the DVS and Kenya Veterinary Board (KVB) saw the trainings of CAHWs become haphazard and uncoordinated with sometimes disastrous outcomes (Young et al., 2003; FAO-UN 2009).

However with the enactment of the new constitution in 2010, veterinary services were devolved from the National to County governments (GoK 2014). Veterinary laws also begun being reviewed to conform to the constitution and current trends (GoK 2015b). The Veterinary Surgeons Act, chapter 366 of the Laws of Kenya is the statute that governs provision of veterinary services and practice, this act was revised in 2011 and is now called

The Veterinary Surgeons and Veterinary Paraprofessionals Act (GoK 2015b). The act outlines the roles and functions of the veterinarian and para-professional as well as untrained persons such as CAHWs and livestock owners. The act also mandate the KVB to play a regulatory and supervisory role in delivery of animal health services in Kenya (GOK 2015b). In addition, the recent release of veterinary service guidelines will streamline animal health operations and improve disease reporting linkages between the National and County governments especially in ASAL areas (GOK 2014).

2.9.3 Risk factors due to intestinal parasitic infections

Management of livestock disease outbreaks focus on single-pathogen infections and rarely consider that pathogen-pathogen interactions do occur, as is often the case in livestock reared under extensive pastoral systems of Sub-Saharan Africa (Barret et al., 2006; FAO-UN /OIE 2015). Intestinal parasitism especially with helminth or coccidia parasites alters the overall health status of host animals and may often complicate clinical manifestation of important viral or bacterial diseases (Barret et al., 2006; Thumbi et al., 2013; McNeilly et al., 2014). Helminth infections impair the production efficiency of livestock world-wide as they cause debilitating gastro-intestinal, respiratory and hepatic disorders. It is therefore prudent to continuously monitor their impact especially with regard to change in distribution, virulence and transmission (Perry et al., 2013; Thumbi et al., 2014). The PPR global strategy proposes that control programmes should incorporate management of non-infectious diseases such as those caused by internal or external parasites as they cause minor but significant production losses (FAO-UN/OIE 2015). Gastrointestinal (GI) parasites notably *Haemonchus contortus* and *Eimeria* species are responsible for most production losses in small ruminant production systems worldwide. Infections cause animals to have lower growth rates, reduced production and reproductive performance and increase the susceptibility of animals to diseases (Gatongi

et al., 1998; Maichomo 2004). Infected animals have. A recent longitudinal study carried out in Western Kenya that documented diseases in indigenous calves from birth to one year. Found that calves that had an increase of 1000 strongyle eggs per gram of faeces and that became concurrently infected *Theileria* protozoan parasite that causes East Coast Fever had a 1.5 times likelihood of mortality when compared to calves with lower or no helminth infection (Thumbi et al., 2014).

2.9.4 Risk factors due to lack of livestock disease surveillance systems

Animal disease surveillance plays a central role in providing information that will allow early notification of disease events as well as inform disease control programmes. Surveillance is defined as the systematic and ongoing collection, collation and analysis of information related to animal health as well as the timely dissemination of information so that action can be taken (FAO-UN 2011). Several surveillance methods or approaches are used in livestock disease management these include;

1. Passive surveillance which is a low cost technique that involves livestock owners identifying sick animals in their herd and reporting the information to animal health personnel. This is the most common and inexpensive form of surveillance system used in Kenya (AU-IBAR 2014).
2. Active surveillance is the collection of disease information from a set sample size of the population. This method is expensive as it involves actively going to the field, collecting samples and running diagnostic tests. Sero-surveillance is an example of an active surveillance (AU-IBAR 2014).
3. Syndromic surveillance is based on observing signs/symptoms which have been agreed upon to represent a particular disease and is mostly used in abattoirs (AU-IBAR 2014).

4. Risk-based surveillance is a form of targeted active surveillance that focuses on a certain areas or livestock population based on perceived level of disease threats (Dhama et al., 2013).
5. Participatory disease surveillance or participatory disease search (PDS) is also a form of active surveillance that uses participatory approaches in the search of disease amongst livestock keepers and other stakeholders in the value chain. The information gathered includes knowledge of the disease and practices that prevent or increase disease risk. This technique has proved to be very effective in ASAL (Catley et al., 2011; Kihu et al., 2015a).

Effective surveillance systems should be sensitive, specific, timely and representative (Catley 2011). However, all surveillance system have a weakness and in practice a country uses an integrated system of most of the above methods so as to ensure effective livestock disease surveillance (FAO-UN 2011). Livestock owners, and especially pastoralists, have the ability to recognize and describe most diseases of concern in international trade and this is the main reason that PDS surveillance methods are now more adopted in pastoral systems of Kenya (GoK 2014; FAO-UN/OIE 2015). Surveillance systems in Kenya face several challenges these include inadequate transport and communication infrastructure and lack of sharing and integration of disease surveillance information amongst the various government, private and NGOs charged with provision of veterinary services (FAO-UN 2011; GoK 2014). To address these challenges mobile and web based technologies such as digital pen technology and EpiCollect have been developed and have enhanced livestock disease surveillance especially in remote areas of Kenya, they have also improved the response time to outbreaks (Madder et al., 2012).

2.9.4.1 Application of GIS in livestock disease surveillance and control

Livestock disease surveillance mainly focus on collection of data related to diseases and the host with little or no data on the prevailing environmental variables (Dhama et al., 2013). The first step in any epidemiological analysis of disease outbreak is to visualise its spatial distribution so as to be able to appreciate if there is a pattern or clustering (McKenzie 1999; Faes et al., 2006; Ortiz-Pelaz et al., 2010). Visualisation of disease outbreaks is also important as it eases communication of findings, graphical maps appeal to a wider audience who may not have the technical background to understand scientific terms and figures that indicate disease abundance and impact. Communicating in a simpler manner means that decisions can be made faster thus saving on resources and reducing their economic impacts (Pfeiffer et al., 2008; Thumbi et al., 2010; Jeffery et al., 2014). Geographic information systems (GIS) are computerised information systems that allow data capture, storage, manipulation, analysis, display and reporting of geographically referenced data (Norstrom 2001; Dharma et al., 2013).

GIS combines computerised mapping technology and database management systems (DBMS), in which spatial data sets from diverse sources are managed and analysed. The geographical information is organised in the form of various layers of thematic maps that are linked to their related attributes. Attributes are the items of data which relate to the map but are not part of it, such as the names of rivers or the type of vegetation in an area (Pfeiffer et al., 2008). The main strength of a GIS lies in its overlay capability. Data is stored in separate layers that consist of attribute data such as climatic data, human or livestock population and disease incidence data (Sanson et al., 1991). The different layers can then be overlaid/merged to develop composite maps that allow users to interactively query datasets, analyse spatial information and present the results of these operations in maps, tables, and organized datasets (McKenzie 1999; Pratley 2009; Dhama et al., 2013; Kasiti et al., 2014).

Mapping with GIS allows development of risk maps that identify areas of possible disease outbreaks (Koch 2005; Olabode et al., 2014). Risk mapping can then be used on the ground to facilitate avoidance action and when combined with GIS spatial analysis techniques, can aid in simulating how effective existing or proposed disease control strategies will be (Premasthira 2012; Hussaina et al., 2013; Dhama et al. 2013). Digital maps are stored within GIS in two basic formats vector-based or raster or grid-based (Sanson et al., 1991). In raster based systems, spatial information is aggregated by superimposing a grid over the area of interest; the user can specify the dimensions of the grid pattern. Attribute information is associated either with each individual cell or with groups of cells that are homogeneous with respect to a particular characteristic (Sanson et al., 1991; Dhama et al. 2013). In vector-based systems, geographical features are represented as points, arcs and polygons. Points are single locations; arcs (lines) are generally comprised of their respective straight line segments (vectors); polygons are areas enclosed by arcs (Sanson et al., 1991; Dhama et al., 2013).

A raster consists of a matrix of cells (or pixels) organized into rows and columns (or a grid) where each cell contains a value representing information, such as temperature. Raster's are digital aerial photographs, imagery from satellites, digital pictures, or even scanned maps (Pfeiffer 2008). Raster/grid-based systems are convenient for storage and manipulation of region-type features and information from remotely sensed image data, however, processing speed are slow and resolution often low (Pfeiffer 2008). In order to achieve high resolution, cell size must be very small and this may result in large data sets which are time-consuming to process (Pfeiffer 2008). In contrast, resolution of vector-based systems are high because the actual coordinates of features are stored, however, the drawback of this format is that computer manipulation are much more complex (Sanson et al., 1991; Dhama et al., 2013). Some of the GIS functions that are used for livestock disease surveillance and control include;

1. **Database management of geographically referenced data -** Information on livestock disease outbreaks is available either as continuous spatial data represented in point form by a pair of coordinates (x; y) referred to as Cartesian coordinates, longitude and latitude. The data can also be available as discrete spatial data where the location of a disease incidence is in aggregated form as a subset of the study region called the aggregation unit which is an administrative level such as ZIP code or census tract (Norstrom 2001). The aggregate data are represented as polygons and are often available with a centroid represented by a pair of coordinates. The centroid describes the 'centre' of the unit, and is typically chosen to be the location of the administrative or geographic centre of the unit (Pfeiffer et al., 2008; Jeffery et al., 2014). The advantage of using a GIS rather than traditional database management systems (DBMS) is that the data can be viewed, queried and summarised visually through graphs (Ortiz-Pelaz et al., 2010; Dhama et al., 2013).
2. **Neighbourhood analysis**- This function allows an investigator to find and list all features which meet certain criteria and are adjacent to a particular feature. For example, a veterinary officer may want to identify all livestock units adjacent to an infected farm that can be queried and visualised as points on a map (Sanson et al., 1991).
3. **Buffer generation-** This is an extension of the neighbourhood analysis function that generates buffer zones around, or along, certain features. These buffers can be of variable width and are used to identify features that meet certain criteria that are within certain specified distances of the particular feature. This function could be used to define all at-risk properties within a given distance of an infected farm or along a transport route where it is known that infected animals had passed (Pfeiffer et al., 2008).
4. **Overlay analysis** – This function allows two or more maps themes to be superimposed on top of each other and areas of intersection (overlay) of various features are defined. GIS allows information to be stored as different layers for example, the road network is

stored in one layer, streams in another, current land use, soil types and vegetation maps in others (Sanson et al., 1991). GIS allows complicated queries to be carried out involving the overlay of several layers that meet a certain criteria using Boolean or geometrical overlay tools (Sanson et al., 1991; McKenzie 1999). For instance, a Government agricultural development programme may be seeking to develop land in Africa where the risk from Trypanosomiasis is low. The risk would be defined on the basis of 182 epidemiological indicators for Trypanosomiasis. An overlay analysis of the respective layers would indicate the relative likelihood of the disease in the different areas under consideration (Hendrickx et al., 2004; Thumbi et al., 2010).

5. **Network analysis** – This GIS can be used in the veterinary field for the tracing of animal or product movements from infected properties to other destinations or study the spread of diseases it calculates distances between points of interest (Sanson et al., 1991; Pfeiffer et al., 2008).
6. **Cartography –**This is one of the strengths a GIS has over traditional cartographic (map-drawing) systems as it allows the rapid production maps showing just the features the user wants to display (Pratley 2009; Faes et al. 2013).

GIS has been used in developing Rift valley fever (RVF) risk maps for Kenya. The RVF studies used retrospective analysis of satellite-derived time series vegetation measurements of photosynthetic activity known as Normalized Difference Vegetation Index (NDVI) data (De smith et al., 2015). The NDVI values and climatic variables like rainfall amounts, temperature and humidity were modelled using GIS (Britch et al., 2013). The spatial modelling was able to identify NDVI values and climatic variable thresholds that were significantly associated with RVF outbreaks in Kenya (Britch et al., 2013; Kasiti et al., 2014). GIS was also used to generate a tuberculosis predictive model called EpiMAN-TB. The GIS

model analysed the possum habitat characteristics and was able to identify risk factors as well as predict when bovine tuberculosis (TB) outbreaks would occur based on possum behaviour. This information was useful in the design of on farm and regional TB control strategies in New Zealand (McKenzie 1999; Pfeiffer et al., 2008). The decision support capability of GIS was also shown in a study that mapped fox bites that resulted in confirmed rabies cases in livestock. The risk maps generated aided in the identification of high risk areas. The study found that rabies incidences were significantly associated with a combination of factors such as human settlements, livestock rearing and favourable terrain. The study determined that rabies transmission operated on local scales and investigators recommended that control efforts be targeted to hot spot areas rather than applying blanket vaccination strategies that were costly (Hussaina et al. 2013).

The specific literature on application of GIS spatial tools to determine veterinary service accessibility in Kenya is largely lacking (Dhama et al 2013). Accessibility to veterinary services in pastoral areas in Kenya is complex due to social and geographical barriers. Veterinary service location points are based on the cost containment concept that typically involves rationalizing healthcare service delivery through centralization of services to achieve economies of scale (Schuurman et al., 2006; Davis et al., 2014). Since pastoral areas are sparsely populated and inhabitants are highly mobile most policy makers will not invest in health facilities that they perceive will be underutilised (Schuurman et al., 2006). The current study demonstrated functionality of a GIS as a tools that can be used to assess the effectiveness of veterinary services and livestock vaccination programmes.

CHAPTER 3

3.0 GENERAL METHODOLOGY

3.1 Selection of Study areas

Selection of high risk and endemic PPR areas was based on official PPR disease incidence reports of 2006 to 2008 from the DVS office as well as scientific publications and unofficial disease incidence reports from government, NGOs and multilateral developmental aid agencies (Elsawalhy et al., 2010; Gitao et al., 2014; FAO-UN/OIE 2015). Selection of areas to be included in the study was purposive and based on the available financial resources as well as the following criteria. The area;

1. Is classified as a PPR endemic or high risk area based on DVS records (GOK 2015a),
2. Inhabitants are pastoralists with high sheep and goat populations (KNBS 2009),
3. Is an important small ruminant stock route to neighbouring countries (Aklilu 2008; Muthee 2006),
4. Veterinary officials were willing to support the research work with community entry and mobilisation at no or minimal cost to the researcher,
5. Prevailing security situation especially for the Northern located Counties (National Drought Monitoring Authority (NDMA) early warning bulletin reports of November 2013 to January 2015).

Based on the above criteria 2 counties were selected. These were Kajiado and Marsabit counties to represent a PPR high risk and an endemic areas respectively (Figure 7).

Figure 7: Map of Kenya showing geographical location of Study Counties marked ★ in relation to the other Counties in Kenya and neighbouring Countries (Source Soft Kenya website)

3.2 Kajiado County

The first PPR outbreak in Kajiado was reported in 2010 in Namanga a border area adjacent to the Kenya-Tanzania border (GOK 2009). Sample sites in Namanga were purposively selected based on previous reports of PPR outbreaks identified from passive surveillance records and information from chief's and local disease reporters.

3.2.1 Location, Size and Administrative Units

Kajiado is a semi-arid County located in the Southern part of Kenya. It borders Nairobi County to the North East, Narok County to the West, Nakuru and Kiambu Counties to the North, Taita-Taveta County to the South East, Machakos and Makueni Counties to the North East and East respectively and the Republic of Tanzania to the South (plate 8). Kajiado County lies between longitudes 36º 5' and 37º 5' East and Latitudes 1º 0' and 3º 0' South. The County covers an area of 21,900.9 square km (Km^2) and is divided into 5 constituencies namely: Kajiado North, Kajiado Central, Kajiado East, Kajiado West and Kajiado South. The constituencies are further divided into 5 wards giving a total of 25 wards (Kajiado County Integrated Development Plan (Kajiado- CIDP) 2013).

3.2.2 Physiographic and Topographic Features

The main physical features of Kajiado County are plains, valleys and volcanic hills that range in altitude from 500 metres above sea level at Lake Magadi to 2500 metres above sea level at Ngong Hills. Topographically, the county is divided into three features the Rift Valley, Athi Kapiti plains and Central Broken Ground. The Rift Valley feature ranges in altitude from 600 to 1740 metres above sea level and includes steep faults that give rise to plateaus, scarps and structural plains. There is a low depression located on the Western side of the County that runs from North to South.

The depression has important physical features such as Mount Suswa and Lake Magadi. The lake has substantial deposits of soda ash that are commercially exploited (Bekure et al., 1991). The Athi Kapiti Plains consist mainly of undulating slopes that transform into connected hills known as Ngong hills. The plains ranges in altitude from 1580 to 2460 metres above sea level. The Ngong hills are catchment areas for Athi River. The Central Broken Ground is an area stretching 20-70 kilometres wide from the North-Eastern boarder across the County to the Southwest where the altitude ranges from 1220 to 2073 metres above sea level (Kajiado-CIDP 2013).

3.2.3 Climate and Agro-Ecological Zones (FAO-UN-IIASA 2002)

Rainfall pattern is dependent on the topography and is bimodal rainy with the short rainy season occurring in October to December and long rains falling between March to May. Long rains are more pronounced in the Western part of the County, while short rains are heavier in the Eastern part. The average annual rainfall from 500 millimetres (mm) in the Amboseli basin to as high as 1250 mm in Ngong hills and Mt. Kilimanjaro slopes. The coolest period is between July and August, while the hottest months are from November to April. The highest ambient temperatures are recorded within Lake Magadi region with a high of 34 degrees Celsius (^{o}C) and the lowest temperatures of 10 ^{o}C recorded in Loitokitok along the slopes of Mt. Kilimanjaro. Kenya is divided into seven agro ecological zones using a moisture index (FAO-UN-IIASA 2002). The index used is annual rainfall expressed as a percentage of potential evaporation. Areas with an index of greater than 50% have high potential for cropping and are designated as zones I, II and III. These zones account for 12% of Kenya's land area (Kajiado- CIDP 2013).

The semi-humid to arid regions (zones IV, V, VI and VII) have indexes of less than 50% and mean annual rainfall of less than 1100 mm and are referred to as Kenyan rangelands and account for 88% of Kenya's land Area. Kajiado County falls in agro ecological zones III, IV, V and VI. The humid zone III covers 10% of the County and is found at the foot of Mount Kilimanjaro, Ngong hills and Ngurumani Escarpment (FAO-UN-IIASA 2002). The main land use in the humid zones is crop farming and dairy farming (Bekure et al., 1991; Kajiado-CIDP 2013). The semi-humid to semi-arid ecological zone IV covers 30% of the County and is located in Meto near Tanzania boarder along Oldonyo Orok hill, Athi-kapiti plains, part of central division and Mashuru Maparasha hills. The zone is currently being used for agro-pastoralism. Zone V is classified as semi-arid and is found between Kilimanjaro, Chyulu hills and Amboseli. The zone also extends to Mbirikani along Isinya-Kiserian road and the southern part of Central division and covers 50% of the County (Kajiado- CIDP 2013).

The current land use for this ecological zone is pastoralism. Zone VI is classified as arid and covers 10% of Kajiado County and is located around Lake Magadi and part of Amboseli Park whose land use is reserved for wildlife (Kajiado- CIDP 2013). Vegetation type in the county is determined by altitude, soil type and rainfall, overtime it has been modified by animal and human activities. Grazing, browsing, charcoal burning, extraction of fuel wood and cultivation have resulted in a major reduction of vegetation (Kajiado-CIDP 2013). Vegetation is scarce in low altitude areas and increases with altitude. Ground cover throughout the county varies with the rainfall season and grazing intensity. Canopy cover ranges from less than 1% on heavily settled areas to 30% on steep hills. The vegetation cover includes: wooded grassland, bushed grassland, scrub land and Savannah. Wooded grassland account for 15% of the County's vegetation and is found along Chyulu hills, Oldonyo-Orok hills in Namanga, Kilimanjaro and Ngong hills. Bushed grassland is the predominant vegetation and cover 45%

of the county, it is mainly found in Kajiado central and Mashuru sub counties. Savannah vegetation accounts for 30% of the County's vegetation cover and is located in the Athi-Kapiti plains, Isinya Sub County, Oloyiomkalani and Kisaju areas (Kajiado-CIDP 2013). Scrubland covers only 10% of Kajiado and is found in around Lake Magadi, Mbirikani along Isinya–Kiserian road as well as parts of Amboseli National Park. (Bekure et al., 1991; Boone et al., 2005; Kajiado-CIDP 2013). Invasive weed species mainly *Prosopis juliflora* and *Ipomoea kituensis* species are reducing the range of palatable grass species relied on for grazing (Kajiado-CIDP 2013).

3.2.4 Population Size and Social Cultural Base

The 2009 housing and population census put the population of the County at 687,312 persons comprising of 345,146 males and 342,166 females. The annual population growth rate is 5.5 %, the population density in 2009 was 31 persons per Km^2 and is expected to increase to 46 persons per Km^2 by 2017. Kajiado is predominately inhabited by the Maasai community whose main livelihood is pastoralism. The Maasai are the second biggest group of pastoralists in Kenya (Bekure et al., 1991). In the past, Maasai households lived together in large compounds called '*bomas'* or '*enkang'* that were composed of over 10 families/households. The *bomas* were made up of a nuclear family of husband, wives and unmarried children, and was often extended to include married sons and their wives, the husband's mother (and his siblings if their father was dead) and impoverished dependants. The *bomas* controlled local grazing and permanent watering resources. The *bomas* always had a group of people usually the elderly, women and children who resided in the *bomas* permanently (Bekure et al., 1991). However, in the last 20 years, the average size of *bomas* has declined markedly to a single nuclear family as the Maasai take a more sedentary lifestyle and move towards individualisation of production (Kajiado- CIDP 2013).

Sedentary lifestyles are attributed to land use change and high rate of urbanization as well as more incidences of climatic variability that causes drought and loss of livestock (Bekure et al., 1991). The recent change of land use from pastoralism to real estate developments has led to increased sale and sub division of pastoral land. This has led to a further reduction in the amount of forage leading many pastoralists to abandon nomadic lifestyles and adopt settled lifestyles (Morara et al., 2014). Livelihood strategies linked to sedentary lifestyles include crop production, bee keeping, and commercial ventures, formal and informal employment. Urbanization is a population shift from rural to areas and the ways in which society adapts to the change. The main urban areas in the County are inhabited mostly by other tribes with very few Maasai settling in the urban areas. The urban towns include Kitengela, OngataRongai, Kiserian, Ngong in Kajiado north, Loitokitok, Namanga, Isinya and Kajiado town. Ngong town holds the highest number of urban population at 41% when compared to Kitengela (23%), Ongata Rongai(16%) and Kajiado (6%). Loitokitok and Namanga have still not developed like the rest of the urban towns in the County (Kajiado-CIDP 2013; Morara et al., 2014).

3.2.5 Livestock Production

Livestock rearing is the main economic activity in the County making it the most important Natural resource for majority of the rural households. In the past, livestock production was carried out in group ranches that were started in the 1960s and entrenched in the 1980s under the financing of the World Bank during the structural adjustment programmes. The main aim was to transform subsistence pastoralism to commercial ranching that would produce livestock products for the cash economy of Kenya (Bekure et al., 1991). However due to population growth and urbanisation as well as increased incidences of ineffective management of ranches and land grabbing by community elites the ranches have over the last 20 years been

subdivided into individually owned land parcels (Bekure et al., 1991). The main livestock species kept in the County are sheep estimated to be approximately 718,950 in number, goats (699,658), beef and dairy cattle (411,840), commercial chicken (276,291), indigenous chicken (267,913), donkeys (63,980), pigs (6,127) and camels (1,597) (KNBS 2009). The major livestock species kept are indigenous and improved breeds of cattle and small ruminants. Sheep breeds include Dorper, Black Head Persian and Red Maasai and their crosses. Goats include the Small East African goat and the Galla breed (Kajiado-CIDP 2008). Livestock products in the county include, beef, milk, skins and hides. These products undergo very few value addition commercial ventures. Livestock production has not been effectively utilised due to the following limiting factors; Inadequate pasture and water due to prolonged drought, colonisation of range lands by invading weeds and current trends of land use changes that have led to rapid subdivision of land for sale and development leading to the loss of grazing land for livestock. There is also inadequate access to wider markets due to low adoption of technologies and lack of road and communication infrastructure. The endemic presence of livestock pests and diseases due to limited access to professional veterinary services. Endemic small ruminant diseases include CCPP, Orf and SGP (Kajiado-CIDP 2013).

3.3 Marsabit County

The first PPR report in Marsabit was in March 2008 in Laisamis, Ngurunit area. Since then outbreaks continued and are now reported in most of the Southern part of Marsabit with isolated outbreaks in the North especially in areas bordering the Ethiopia border. Based on the National Drought Monitoring Authority (NDMA) monthly early warning bulletins with the most recent outbreak reported in January to April 2014.

3.3.1 Location, Size and Administrative Units

Marsabit County covers an area of approximately 70,961 km^2 and is located at the upper eastern region of Northern Kenya. It occupies about 11.2% of the total landmass of Kenya and is the second largest County of Kenya's 47 after Turkana. Marsabit shares an international border with the Republic of Ethiopia to the North and borders Lake Turkana to the West, Samburu County to the South and Wajir and Isiolo Counties to the East (plate 8). The County lies between latitudes 02°45' and 04° 27' North and longitudes 37° 57'and 39°21' East (Marsabit County Integrated Development Plan (Marsabit –CIDP) 2013). Administratively, the county is divided into 4 sub counties namely: Marsabit Central, Laisamis, North Horr, and Moyale. Sub-counties are further divided into 20 wards and administrative villages. North Horr sub-county is composed of Dukana, Maikona, Turbi, North Horr and Illeret wards while Laisamis is composed of Laisamis, Loiyangalani, Kargi/South Horr , Korr/Ngurunit and Loglogo wards (Marsabit –CIDP) 2013).

3.3.2 Physiographic and Topographic Features

The County has a varied topography, which includes Lake Turkana (fed by River Omo from Ethiopia and other seasonal rivers) to the West, Lake Paradise on Mount Marsabit, and extensive plain and mountain ranges to the North. It has a volcanic mountain (Mt Kulal), Hurri hills and Marsabit hill in the West and Central respectively. Most of Marsabit County is an extensive plain that slopes gently towards the South East and lies between 300m and 900m above the sea level. The West and North plains are bordered by hills and mountain ranges and the plains continuity is broken by volcanic cones and calderas. The most notable topographical features are: Ol Donyo Ranges (2066m above sea level) in the South West, Mt. Marsabit (1865m above sea level) in the Central part of the County, Hurri Hills (1685m above sea level) in the North Eastern part of the county,

Mt. Kulal (2235m above sea level) in North West and the mountains around Sololo-Moyale escarpment (1400m above sea level) in the North East. There is a marked difference as one moves from Chalbi to North Horr, ubiquitous rocks and boulders are the principle feature distinguishing Gabbra from Rendille land. Rendille land has sand and intermittent stretches of gravel that support significantly more bush and trees. The main physical feature is the Chalbi desert which forms a large depression covering an area of 948 Km^2 and is the lowest land surface in the County. This depression lies between 435m and 500m above sea level and is separated from Lake Turkana, which is 65-100m lower in elevation, by a ridge that rises to 700m. The Chalbi desert is a saline lake bed and is a true desert. The high parts of Mt. Marsabit, Hurri hills and surrounding areas are characterized by volcanic rocks and volcanic soils which are well developed and have a high water retention capacity (Schwartz et al., 1991). The area between the hills of Mt. Marsabit, Mt. Kulal, Hurri Hills and the bed of the seasonal Lake Chalbi are covered by recent volcanic sediments. The rest of the County is covered by rocky, stony and rugged lava plains with poor soil development. Some of these soils in the western part of the County have acidic moisture and are saline more so in Chalbi desert (Schwartz et al., 1991; Marsabit- CIDP 2013).

3.3.4 Climate and Agro-Ecological zones (FAO-UN-IIASA 2002)

Most parts of the County is classified as arid, with exception of high altitude areas such as those around Mt. Marsabit, Mt. Kulal, Hurri Hills and the Moyale-Sololo escarpment. The County experiences extreme temperatures ranging from a minimum of 10 ° C to a maximum of 38 °C. January and April are the hottest months while May to August are relatively cool. Due to variations in the terrain, rainfall also varies and there is a high evaporation rate. The rainfall displays both temporal and spatial variation and is bimodal in distribution. Short rains are received in October and November while long rains are received

in March, April and May. The duration, amount and reliability of rainfall increase with altitude, North Horr which is 550m above sea level has a mean annual rainfall of 150mm while Mt. Marsabit and Mt. Kulal that are above 1800 m above sea level receive an annual amount of 800mm while Moyale receives a mean annual rainfall of 700mm. The overall annual rainfall in Marsabit ranges between 200 mm and 1,000 mm. Drought is a common natural occurrence in many parts of the County (Schwartz et al., 1991). The County is divided into 4 agro – ecological zones namely sub – humid III, semi- arid 1V and V, and very arid. Zone III is composed of mountainous area of Mt. Marsabit, Karare hills and Kofia Mbaya hills. These Mountain areas have high rainfall and low evaporation rates which have induced dense ever green forest. These forests are extensive and serve as water catchment area. However some forested areas have been degraded. Below these forests lies a belt of vegetation characterized by deciduous thorn tree (5-15 high) and tall perennial grasses. This zone is suitable for agriculture and horticultural crops such as maize, beans, pawpaw, tomatoes, bananas and coffee. Zone 1V covers the low parts of Mt. Marsabit and the surrounding hills and is suitable for livestock grazing mainly cows, sheep and goats and sedentary cultivation of maize, millet, fruits and vegetables (Marsabit –CIDP 2013).

Ecological Zone V is mainly found in the plains and is characterized by acacia- commiphora woodland, tufted and annual grasses and areas of dry rocky bare grounds (Marsabit-CIDP 2013). The vegetation cover of Marsabit barely covers 15% of the land in the County. This is because 60% of the average annual rainfall of 350-800 mm ends up as run-off from the bare hill slopes. The run-off carries an estimated 50 tons per hectare of sediment to the seasonal rivers. Approximately 15,280 hectares of forest is found in Mt. Marsabit, 45,729hectares in Mt. Kulal biosphere. There are also woodlands of Hurri Hills, Funan Nyata, Uran and Somare. Rural indigenous forests and woodland have been destroyed at a

rate of 5% annually posing a threat to catchment areas and land resources, (Marsabit –CIDP 2013). In addition, the large population around Mt. Marsabit has exacerbated the vegetation loss as it is the only source for wood for building material and fuel hence leading to soil erosion and further siltation of dams and water pans. The County is dominated by semi desert scrubland, bush land, dwarf scrub grassland, deciduous bush and scrubland, annual grassland and barren land. The forested areas in the ecological zone III harbours tree species like Olea *Africana* and others (Schwartz et al., 1991; Marsabit- CIDP 2013).

3.3.4 Population Size and Social Cultural Base

The population distribution of an area determines the economic activity and provision of infrastructure and services. The vastness of the County makes the population density relatively small. The County has an average population density of 4 persons per Km^2 (KNBS 209). Saku Constituency has the highest population density at 25 people per Km^2 and is expected to increase to 27 and 29 people per Km^2 in 2015 and 2017 respectively. North Horr has the least population density at 2 persons per Km^2 and is expected to remain the same in 2015 and 2017. Projections based on the 2009 National Population and Housing Census and using an annual growth rate of 2.75% estimated that in 2012 the County's population was at 316,206 people comprised of 164,105 males and 152,101 females. The population is projected to increase to 343,399 persons comprising of 178,218 males and 165,181 females by 2015 and to 372,931 persons comprising of 193,544 males and 179,387 females by 2017. Majority of the population in the County is confined to the age group 0-24 years, this group makes up 68% of the total population (KNBS 2009; Marsabit-CIDP 2013). There are 2 major towns and 3 urban centres in the County. The towns are Moyale and Marsabit while the urban centres are Sololo, Loiyangalani and Laisamis (Marsabit- CIDP 2013).

The town and urban centres have a population of 70,868 as at 2012, representing 22% of the County's total population Marsabit- CIDP 2013). The urban population is expected to increase to 77,078 and 99,869 in 2015 and 2017 respectively. Moyale town had the highest population estimated at 40,663 persons in 2012 followed by Marsabit town which is the county headquarter with a population of 16,213 persons. The high population in Moyale and Marsabit is due to availability of employment and business opportunities and a fairly good communication and transport networks. Laisamis has the least population of 2,875 persons in 2012 (Marsabit-CIDP 2013).

Marsabit is inhabited by a diverse mix of communities that include the Borana, Gabra, Samburu/Ariaal, Rendille, Somali, Burji, Turkana, El Molo, Dassanech and Dorobo. Although the various pastoral groups have distinct cultures, languages, and customs, their social organization and livestock production system are similar. Each of these groups live in semi-nomadic settlements, where domestic livestock are herded in home and distant territories. East African pastoralists are no longer long distance nomads like the Fulani and Tuareg of West Africa and are described as practicing transhumance pastoralism (Fratkin and Roth 2005). The Marsabit pastoral communities move their animals in mobile herding groups that are managed by male headed household units, the households utilize their children and occasionally hire kinsmen to help herd animals. Furthermore, the communities are organized into patrilineal kinship groups, and often reside close to one another in one homestead called *'manyatta'* or '*ola'* based on kinship ties. The homesteads can vary from a few male stockowners and their families (as among Samburu and Borana living in highland areas) to large communities of over fifty stockowners and their families, as seen in Gabra, Rendille and lowland Ariaal (Kaufmann et al., 2012) .

In the past, Marsabit communities were highly mobile moving with their livestock and entire households but since 1960's households have become sedentary. Permanent settlements have sprung up around water points and infrastructure such as schools, mission stations, churches, dispensaries and shops which were developed mostly by Christian missionaries or NGOs. The households in the *manyattas* are spilt into two the core permanent households that reside in settlements and the highly mobile satellite households that track pasture and water throughout the year and are termed to be as at '*Fora*' (Fratkin and Roth 2005). The main economic activity in the County is livestock rearing, small-scale fishing, sand harvesting, stone mining, salt mining, mining of gems and precious stones and small scale trading (Marsabit-CIDP 2013). It is also common for a family to support one or two children through school, in the hopes they will obtain wage-earning jobs and contribute to the family income (Fratkin and Roth 2005).

3.3.5 Livestock Production

Pastoral production system forms the bulk (85%) of the main livelihood strategy in the County. Other minor livelihoods include agro-pastoralism and fishing that is restricted to Lake Turkana areas. The main livestock species kept are goats approximated to be 1,143,480, sheep at 960,004, cattle at 424,603, camels at 203,320, donkeys 63,861 and poultry 50,690. There are also 2,691 beehives/apiaries. The main livestock products are milk, beef, mutton and camel meat. The close to 2.2 million small ruminants produce approximately 3,700 tonnes of meat per year. There are no registered group or company ranches, however different communities have their own grazing areas. This contributes to resource based conflicts especially during the drought season where communities compete for grazing fields (Marsabit-CIDP 2013). The animals in one *manyatta* are grazed communally, each household in the *manyatta* splits its livestock herds into 2 the *fora* /satellite herd has majority of animals

and the home-based herd left in the permanent settlements is composed of lactating animals and their calves, this herd provides milk and meat to the household either for consumption or sale (Kaufmann et al., 2012). The satellite herds spends most of the year in far-away grazing areas in order to make use of the heterogeneous pasture vegetation that is spatially and temporally distributed. The permanent households in settlements do not have access to satellite herds other than during ceremonies when they can swap animals that have stopped lactating or are in poor body condition (Kaufmann et al., 2012). Historically Marsabit pastoral communities kept large herds of multiple livestock species but the constant drought episodes have seen communities adopt fewer livestock species based on the vegetation available to them. Borana, and Samburu raise cattle and small stock (goats and sheep), living mainly in or near highlands where cattle thrive due to grass and water availability. Gabra, Rendille, and Somali groups concentrate on camel and small stock production in the lowlands, where animals survive on a diet of browsing (leaves and bushes) (Kaufmann et al., 2012).

These ethnic/livestock divisions are not absolute, as some Gabra will own cattle and some Samburu keep camels. In addition, the smaller mixed pastoral groups including the Dassanech who live on the Northern edge of Lake Turkana, grow millet, may engage in fishing but mainly keep cattle and small stock, the El Molo are Samburu-speaking and are purely fishermen, they live on the Eastern side of Lake Turkana, the Dorobo are hunter and gatherers who may rear small stock, they live in the forests of the Ndoto Mountains which separate Samburu and Marsabit Districts. The Burji are mainly a sedentary agricultural community living on Marsabit Mountain, they originally migrated from Ethiopia when the British were building the Marsabit road in the 1930s (Fratkin and Roth 2005). Small ruminants thrive in the desert like condition also, but like cattle need water every 2 to 3 days and must be grazed near the desert springs and wells (Fratkin and Roth 2005).

The challenges constraining livestock production in the County include deteriorating pastures due to overgrazing and periodic droughts and floods (Njanja et al., 2003; Kosgey et al., 2008). In addition, there is a high prevalence of disease and pests that has resulted in most TADs to be endemic (Njanja et al., 2003; Kosgey et al., 2008). This is attributed to limited access to veterinary services as well as lack of a system to monitor and control outbreaks (Njanja et al., 2003). The porous nature of the County borders, underdeveloped physical and marketing infrastructure have also contributed to limited access of veterinary services (Njanja et al., 2003; Marsabit- CIDP 2005).

The increased permanent settlements has affected the availability of pasture resources for home-based herds (Kauffmann et al., 2012). In addition, the permanent settlements deplete tree vegetation cover especially the thorny branches of the acacia trees as they are used for fencing the livestock night enclosures (*Kraals*/ *bomas*) for home-based herds. This fencing material degrades rapidly due to high temperatures and termite damage. In addition, night enclosures are shifted from time to time for sanitary reasons and need to be rebuilt approximately every 2 months (Kaufmann et al., 2012). Another constraint is lack of livestock marketing systems, marketing structures in the County are few and irregular. In addition, areas close to Ethiopian border like Dukana and Illeret are sparsely populated due to conflict and offer little in terms of trading opportunities for communities residing there. However an exception is Moyale town that has a vibrant livestock market (Marsabit-CIDP 2013). Subsistence pastoralists in Marsabit sell between 5–10% of their herds annually, mainly steers and male goats to local shopkeepers or urban markets. Livestock marketing is the principle income generating activity for Marsabit pastoralists (Fratkin and Roth 2005).

CHAPTER 4

4.0 Small ruminant disease control practices amongst Kajiado and Marsabit pastoralists and their effects on *Peste des petits ruminants* control strategies

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Abstract

The contribution of sheep and goats to pastoralist livelihood is limited by the frequent occurrence of trade sensitive diseases such as *Peste des Petits Ruminants* (PPR). A descriptive risk based cross-sectional survey was undertaken to characterise small ruminant disease control and husbandry practices in two pastoral regions of Kenya. The overall aim of the survey was to characterise pastoralist small ruminant husbandry practices so as to enable a more focused PPR control measures in pastoral areas of Kenya. A total of 63 livestock owners were surveyed, 55% (35) were from Kajiado while 45% (28) were from Marsabit. The study findings revealed that only 57% of livestock owners in Kajiado relied entirely on livestock keeping compared to 75% of livestock owners in Marsabit. Additionally, Kajiado livestock owners had an individually based small ruminant management practice that allowed investment in animal health inputs. All (100%) livestock owners in Kajiado regularly purchased and used anthelmintic, antibiotic and tick control products while only 57% invested in the purchase of preventive vaccines for their sheep and goat herds. In contrast, all Marsabit (100%) livestock owners did not invest in the purchase of tick control products or preventive vaccines. However, when available, 42.9% of Marsabit livestock owners occasionally purchased anthelmintic products while only 28.6% purchased antibiotic drugs for their small ruminant herds. An important finding with regard to PPR, was that all livestock owners in both Kajiado and Marsabit study sites ranked contagious caprine pleuropneumoniae (CCPP) disease in goats and helminthiasis infections in sheep as more important than PPR as they resulted in higher production and mortality losses. The three main constraints facing disease control efforts in Marsabit were lack of veterinary services (52.4%), lack of veterinary drug outlets (35.7%) and lack of inclusion when planning livestock disease control programmes (7.1%). In Kajiado, 60% of livestock owners felt that lack of quality veterinary drugs especially anthelmintics was the main constraint followed by lack of veterinary services

(31.4%) and lack of early warning information of livestock disease outbreaks (8.6%). The main policy interventions recommended by majority of Kajiado (90.5%) and Marsabit (84.5%) livestock owners was the provision of regular and timely veterinary services. In conclusion, the survey findings revealed that small ruminant husbandry practices in Kajiado and Marsabit counties differed and were influenced by access to veterinary services, animal health inputs and livestock markets. The study recommends that PPR disease control programmes in pastoral systems of Kenya be targeted to specific geographical areas based on the disease prevalence while taking into account the social and economic setting of the pastoralists' communities.

***Key words*:** *Animal health input, descriptive analysis, herd management.*

4.1 Introduction

Pastoralism is a way of life characterised by raising livestock species mainly small ruminants, cattle and camels on extensive natural rangelands (Fratkin and Roth 2005). Pastoralists have developed management systems based on strategic mobility that is driven by factors such as seasonal availability of grazing and water resources, avoidance of areas with known livestock disease outbreaks as well as availability of markets (Notenbaert et al 2012). Although pastoralism is a traditional way of life, it is highly adaptive to trends that allow new economic opportunities such as livestock insurance (Chantarat et al 2013) or better access to livestock market price information using mobile phone communication technology (Food and Agriculture Organisation of the United Nations (FAO-UN) 2013a; Mwanyumba et al 2015). Sheep and goats represent a significant composition of pastoralist livestock herds. Their small body size, rapid rate of reproduction and low market price makes them easy to sell and buy when compared to larger ruminants such as cattle and camels (Kosgey et al 2008). In addition, income from their sale is able to cater for 60% of household needs for grain food, medical and

education expenses (Behnke and Muthama 2011). The global consumption of mutton will increase to 7 million tonnes per year, with mutton production in Sub-Saharan Africa which is mostly under pastoral production systems expected to reach 1.8 million tonnes (FAO-UN/OIE 2015). However, the endemic presence of small ruminant diseases such as PPR will not only affect productivity of small ruminants but will hinder pastoralists from accessing lucrative international markets to meet this increasing global demand for mutton and chevon (FAO-UN/OIE 2015).

PPR, is a highly contagious viral disease of sheep and goats. Exposure of susceptible herds to PPR virus results in a high morbidity and mortality rates of 90 and 70 % respectively (Barret et al 2006; OIE 2013). PPR causes significant livelihood disruption of livestock keepers in Africa, the Middle East and Asia with global estimates indicating that annual losses due to PPR outbreaks are between 1.2 and 1.7 billion USD (FAO-UN/OIE 2015). In Kenya, the first outbreak of PPR occurred in 2006 in Turkana County which is located in the extreme Northern part of Kenya (Nyamweya et al 2010). By the year 2008, the disease had spread to all Northern located counties of Kenya. PPR spread in Kenya has continued despite government efforts to control it through the implementation of a 5 year free vaccination campaign that begun in 2008. The mass vaccination activity targeted all sheep and goat herds in the arid and semi-arid counties of Kenya (GoK 2008). It is estimated that the government incurs an annual cost of 1 billion Kenya shillings on expenditure spent during PPR vaccination and revenue foregone during trade bans (GoK 2008). The underlying factors causing PPR outbreaks in Kenya are not well understood but risk factors are associated with husbandry practices, uncontrolled livestock movement and mixing of herds during communal herding and watering (Gitao et al 2014; Kihu et al 2015a). A risk based cross-sectional questionnaire survey was therefore undertaken to characterise small ruminant husbandry practices in two pastoral systems of Kenya.

The study hypothesized that heterogeneous husbandry practices related to disease control may increase the susceptibility of small ruminant herds to PPR infections. This concept of heterogeneity emphasizes that although pastoral communities experience similar socioeconomic disruption due to drought or livestock diseases. They have differing vulnerabilities due to differences in their coping and adaptive strategies (Fratkin 2001). This means that PPR disease control programmes in pastoral systems of Kenya should not apply blanket interventions but should consider the heterogeneous social, ecological and economic settings (Kihu et al 2015b).

4.2 Methods

4.2.1 Study area

The study areas were purposively selected based on the following criteria (i) area is classified as a PPR endemic or high risk zones based on the Director of Veterinary Services (DVS) records (GoK 2015a) (ii) area inhabitants are pastoralist and own significant populations of small ruminant (KNBS 2009) (iii) area is an important small ruminant transhumance and trade stock route to neighbouring countries (Muthee 2006). The study areas selected and meeting the criteria above were Kajiado and Marsabit counties. Kajiado county is classified as a semi-arid area located in at the South Western part of Kenya and lies between longitudes 36º 5' and 37º 5' East and Latitudes 1º 0' and 3º 0' South (Kajiado-CIDP 2013). The predominant inhabitants of Kajiado are the Maasai community, who are the second biggest group of pastoralists in Kenya after the Somali community (Bekure et al., 1991). The first PPR outbreak in Kajiado was reported in 2010 in Namanga an area located close to the Kenya-Tanzania border (GoK 2015a). Marsabit county, is classified as an arid county that is located at the upper Eastern region of Northern Kenya, the county is vast and is the second largest county in Kenya after Turkana. Marsabit shares an international border with the Republic of Ethiopia to the North and lies between latitudes 02°45' and 04° 27' North and longitudes 37°

57’and 39°21’ East (Marsabit-CIDP 2013). Marsabit inhabitants comprise of a diverse mix of pastoral, agro-pastoral and fishing communities. The purely pastoral communities include the Borana, Gabra, Samburu/Ariaal, Rendille, Somali, Turkana and Dassanech (Schwartz et al., 1991; Kaufmann 2012). PPR was first reported in Laisamis area of Marsabit in March 2008. Since then outbreaks occur in all regions located in Marsabit South with isolated incidences reported in the Northern parts of the county in areas close to the Ethiopian border (GoK 2015a).

4.2.2 Survey design

The type of questions included in the questionnaire were informed by literature findings as well as risk factors associated with PPR from previous studies conducted in similar pastoral settings (Luka et al. 2011; Muse et al., 2011; Gitao et al., 2014; Kihu et al., 2015b). A pilot baseline survey to pre-test the questionnaire was carried out in Mashuru, Kajiado County in December 2013. This pilot survey allowed the determination of the length of time it would take to complete the questionnaire as well as to clarify ambiguous or difficult questions. A cross-sectional survey was then carried out in Kajiado and Marsabit counties at between January 2014 and February 2015. The sampling unit was the homestead also known in the local dialect as *‘manyatta*’ for Marsabit communities and ‘*boma/enkang’* for Kajiado communities. A *boma* or *manyatta*, is a cluster of households composed of related families who herd their livestock together and pursue similar socioeconomic activities. (Bekure et al., 1991; Fratkin and Roth 2005; Kihu et al., 2013). Homesteads to be visited were selected using the ‘snowball’ sampling technique (Biernacki and Waldorf 1981; Muse et al., 2012; Gitao et al., 2014). This technique involved initial contact with either the county veterinary officer, chief or local disease reporter who then introduced the researcher to the first homestead-head (HH) (Gitao et al., 2014). The HH in turn, introduced the research team to the next HH. In total 63 HH were interviewed from 35 sites in Kajiado and 28 sites in Marsabit.

4.2.4 Data collection

The ethical clearance for the study was obtained from the University of Nairobi, Faculty of Veterinary Medicine, Biosafety, Animal use and Ethics Committee (Appendix 1).

A verbal and written consent was also obtained from the livestock owners who agreed to participate in the study. Qualitative and quantitative data was then collected using a pre-tested questionnaire (Appendix 2), after the HH signed the consent form (Appendix 3). In the case where the HH was illiterate he gave an affirmative verbal consent and authorised either the local disease reporter or another literate family member to sign on his behalf. The questionnaire was administered to HH and it took between 30 and 45 minutes. All interviews were conducted by the researcher in Swahili language (plate 2). A Global Positioning System (GPS) unit was used to determine the geographical location of homesteads included in the survey.

Plate 2: Homestead Head (HH) interviews in Marsabit (a) and Kajiado (b)

Where the HH was not conversant with Swahili, interviews were conducted in the local dialect with the help of an interpreter who in all cases was the local disease reporter. Data collected included demographic characteristics of homesteads, small ruminant husbandry practices including size of herds kept, breeds kept, disease control practices and animal health inputs used. Information was also noted on the type of small ruminant diseases prevalent in the area as well as the HH perceptions on factors hindering small ruminant disease control and possible policy interventions. To triangulate the questionnaire responses, the researcher also observed and validated HH responses before recording them. This was critical for demographic questions such as number of wives, number of children and their school attendance. This was also important for husbandry questions on breeds kept and herd size. The researcher also conducted key informant interviews (KIIs) in form of group discussions with local area disease reporters, veterinary officers and animal health technicians. The KIIs responses were recorded at the back of the questionnaire. The KIIs responses allowed the researcher to validate HH responses on access to small ruminant vaccines, veterinary services and animal health as well as the type of small ruminant diseases prevalent in the area.

4.2.5 Data entry and analysis

Questionnaire responses were entered, coded and analysed for descriptive statistics using the Statistical Package for Social Sciences (SPSS) version 16.0 (SPSS Inc., Chicago, Illinois). Categorical data was analysed using frequencies and multiple response set while continuous data had the mean, median, mode and standard deviation determined. The GIS map indicating surveyed sites was developed using ArcGIS desktop version 10.1 (ESRI Corp., USA)

4.3 Results and Discussion

4.3.1 Socio-ecology of study sites

A total of 63 homesteads were surveyed, of this, 35 sites were in Kajiado county across 7 administrative wards while 28 sites were in Marsabit county across 5 administrative wards (Figure 8).

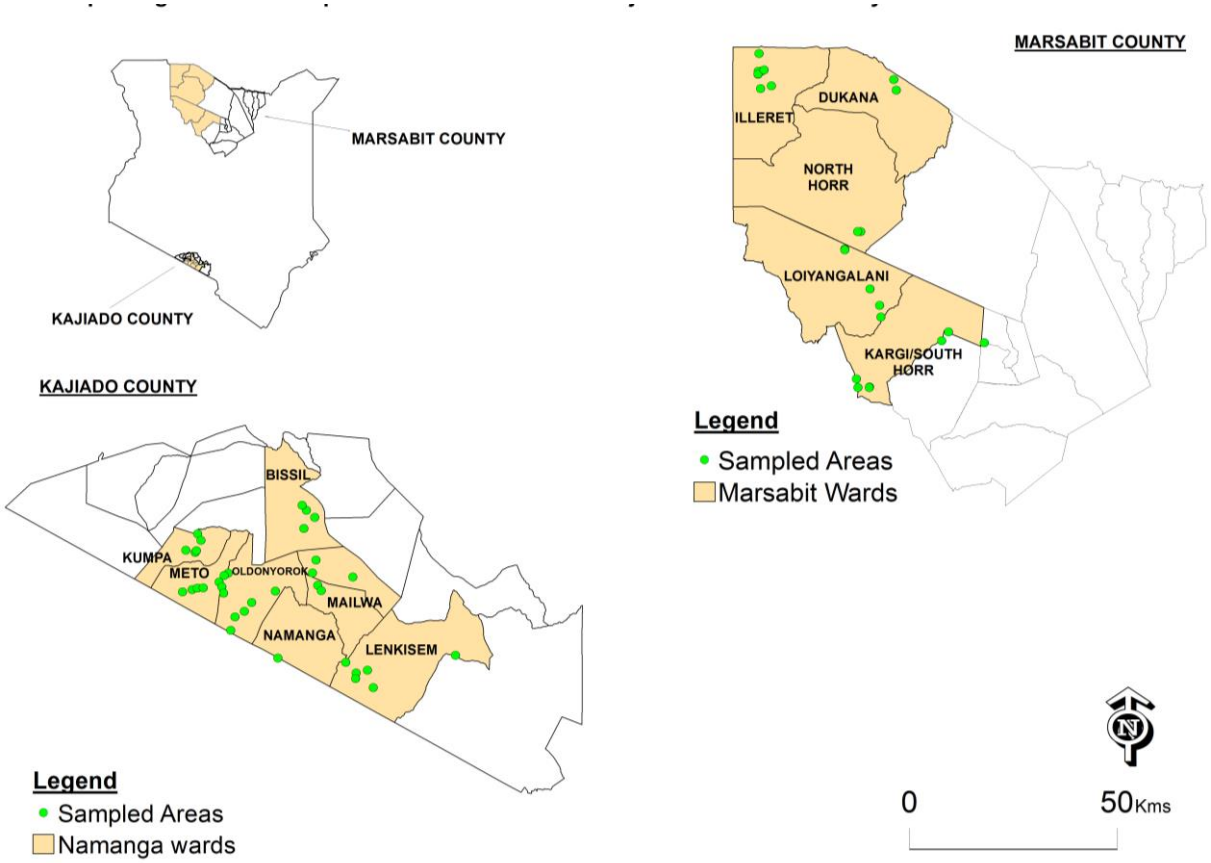

Figure 8: Map showing geographical location of survey sites (green dots) during the PPR study in Kajiado and Marsabit counties, Kenya in January 2014 – February 2015

Only one of the 63 HH identified for the survey refused to participate in the study and measures were taken to replace the HH. The main reason given by the HH was that a recent sheep and goat vaccination campaigns in his herd had resulted in abortions in pregnant goats. The low non-response rate observed in this survey demonstrates that most pastoral

communities are willing to engage in activities that will benefit them but will reject policies that do not include them in decision making or those that negatively impact on their livestock assets (Fratkin 2001; AU-IBAR 2010). All 35 Kajiado homestead surveyed were located in individually owned parcels of land and the composition of households was mainly nuclear family members that is the husband, wives, young or unmarried children and immediate extended paternal family members in most cases his elderly parents. This was in contrast to what was observed in Marsabit, where both the permanent and satellite homesteads were located in clan or communally owned land. In Marsabit, homestead households were composed of paternal extended family members. That is, the husband, wives, young children, married sons and their children, married brothers and their children and elderly parents. All 35 homestead sites in Kajiado were permanent settlements compared to 18 of the 28 in Marsabit. In both Kajiado and Marsabit permanent settlements were located around trading centres, schools and permanent watering areas. Watering areas in Kajiado were mostly boreholes while in Marsabit they were natural springs or wells. Kajiado settlements were composed mainly of nuclear family members that is the husband, wives, young or unmarried children and immediate extended paternal family members, the elderly mother and father and in some cases unmarried younger siblings. However, this was not the case in Marsabit, where in both the permanent and satellite homesteads, households were composed of paternal extended family members. That is, the husband, wives, young children, married sons and their children, married brothers and their children and elderly parents and young or unmarried siblings.

Kajiado county is located near Nairobi county which is Kenya's capital city (Kajiado-CIDP 2013). The human population pressure in the capital as well as in other regions of the country has resulted in increased migration and settlement of communities from all over Kenya (Morara et al., 2014).

This has resulted in fear of land grabbing amongst Kajiado pastoralist community, this has resulted in a rapid change of land ownership and the once expansive group ranches have now been subdivided into individually owned parcels of lands (Boone et al 2007; Morara et al 2014). This may explain why in this study, the surveyed Kajiado livestock owners had a more individual nuclear family settlement when compared to Marsabit's clan based or extended family settlements on communally owned land.

The sedentary lifestyle as seen in this study also meant that pastoralist also diversified their livelihoods, this trend is similar to other studies carried out in Kenya (Fratkin and Roth 2005). In the current study, livestock keeping was the main livelihood strategy for 57.1% of Kajiado and 75% of Marsabit livestock owners. In Kajiado, 3 supplementary livelihood strategies were the most common these were, taking up salaried employment (25.7%), crop farming (8.6%) and setting up commercial ventures (8.6%) such as milk parlours, butcheries and grocery shops. In Marsabit, supplementary livelihood strategies were based on the geographical location of the community, as this determined the soil type, terrain and water resource availability (Schwartz et al. 1991). Samburu and Rendille livestock owners interviewed, engaged in irrigated crop agriculture as they resided in South Horr, a lush and green valley between Ol Donyo Mara and Mt. Ngyiro mountain ranges (Plate 3). The other livelihood diversification strategy was fishing among the Dassanech community residing at the Northern edge of Lake Turkana (Plate 4). Pastoral sedentarization has been driven by several factors key being prolonged droughts episodes that require them to settle so as to access relief food (Ellis and Swift 1988; McCabe 1990), population growth that has resulted in land subdivisions (Boone et al., 2007; Morara et al., 2014), opening up of alternative lucrative economic opportunities such as crop agriculture (Ekaya 2005), political insecurities including civil wars and ethnic conflicts (Kaye-Zwiebel et al., 2014).

Changing conservation, land tenure and service delivery policies have also encouraged sedentarization (Fratkin 2001; Kaufmann 2012).

Plate 3: A banana plantation in South Horr, Marsabit (August 2014)

Plate 4: Dassanech children in a boat at the shores of Lake Turkana (March 2015)

4.3.2 Demographic characteristics of respondents

The study surveyed 5 pastoral communities the Maasai in Kajiado and the Samburu, Rendille, Dassanech and Gabra in Marsabit. As per the custom of most pastoralist communities the head of the family interacts first with visitors and they are assumed to have more knowledge on livestock husbandry practices (Fratkin 2001). The demographic characteristics of respondents are summarized in Table 1. In summary, the survey revealed that 71.4% of HH in Kajiado and 85.7% in Marsabit had no formal education training. This finding is in agreement with most social settings of pastoralist which directs youth-life to learning indigenous pastoral knowledge (Fratkin 2001; Mwanyumba et al., 2015). Current studies indicate that some pastoral communities are changing and have adopted modern way of life which gives more consideration to formal education (Fratkin and Roth 2005; Ng'asike 2011). This was the case in Kajiado where 60% of HH interviewed indicated that children in their homesteads attended formal schooling compared to Marsabit where only 42.9% of children who had attained school going age attended school.

On further probing, Marsabit HH explained that children still played a significant role in providing labour for herding, this was especially so for small ruminants, this finding is supported by previous studies carried out in similar pastoral settings (Fratkin and Roth 2005; Mwanyumba et al., 2015). In addition, settlements located away from trading centres (which in most cases had schools), were also disadvantaged as available schools were located far away and since they had no boarding facilities, the daily commute by children was impossible to make (Marsabit-CIDP). However, it should also be noted that the universal understanding of education ignores the nomadic culture which has high levels of undocumented environmental and livestock husbandry knowledge and specialisation (Fratkin 2001; Kaufmann 2012).

Furthermore, most pastoralist perceive formal education training as one of the factors that is causing cultural erosion of their societies (Ng'asike 2011). This perception of social erosion was confirmed in this study by one HH from the Dassanech community who remarked that formal schooling was only for children who could not herd, thus could not be trusted with livestock assets. Formal schooling was therefore a second chance that would allow the children to contribute to the household economy through formal employment. On average, the family size of sampled homesteads consisted of 2 wives in both Kajiado (SD 0.7; Range 1 -3) and Marsabit (SD 0.9; Range 1 – 4) and an average of 5 children (SD 1.8; Range 2 -8) in Kajiado and 8 children (SD 2.9; Range 1 - 14) in Marsabit. This finding is in agreement with the 2009 Kenya household census report that indicated that pastoral households had on average more children than the average national fertility of 4.6 children per woman. This is mainly because, child-bearing for pastoral women starts at an earlier average age of 16 years or less when compared to urban or rural women in non-pastoral communities who start child bearing after formal education training which on average is after 18 years (Ferrè 2009).

Table 2: Homestead head responses within each demographic characteristic trait surveyed in Kajiado and Marsabit counties, Kenya

	Kajiado (n=35)		Marsabit (n=28)	
Parameter	No. HH Respondents	%	No. HH Respondents	%
Gender				
Male	34	97.1	26	92.9
Female	1	2.9	2	7.1
Age Group				
<20-35 years	13	37.1	2	7.1
36-50 years	15	42.9	14	50.0
>51 years	7	20.0	12	42.9
Level of Education				
No formal education	25	71.4	24	85.7
Lower primary	3	8.6	4	14.3
Upper primary	2	5.7	0	0.0
Secondary	2	5.7	0	0.0
Tertiary	3	8.6	0	0.0
Children attend formal school				
Yes	21	60.0	10	35.7
No	1	2.9	5	17.9
Too young	6	17.9	1	3.6
Not all	7	20.0	12	42.9
Livelihood strategy				
Livestock keeping only	20	57.1	21	75.0
Livestock and crop farming	3	8.6	3	10.7
Livestock and Salaried employment	9	25.7	1	3.6
Livestock and Business	3	8.3	0	0.0
Livestock and Fishing	0	0.0	3	10.7

4.3.3 Small ruminant husbandry practices

All pastoral communities in the survey kept more than three species of livestock at a time (Table 2). However the Maasai in Kajiado and Dassanech in Marsabit did not keep camels. Breeds of small ruminants reared differed with more than half (68.6%) of Kajiado communities predominantly rearing crosses of Red Maasai and Dorper sheep breed. Similarly, 74.3% of livestock owners in Kajiado maintained crosses of the Small East African Goat and Galla goat breed. In Marsabit, 50% of livestock owners that participated in the survey maintained the Black Head Persian breed of sheep that was mainly reared by the Gabra, Samburu and Rendille communities. The Dassanech also reared the Black Head Persian sheep breed but they crossed it with the Horro sheep breed that originates from Ethiopia. The predominant goat breed reared in Marsabit was the Small East African Goat (71.4%) followed by crosses of Galla goat breed and the Small East African Goat (10.7%), The Small East African Goat breed was mainly found in the Samburu, Rendille and Dassanech homesteads. The Gabra community only reared the Galla goat breed (17.9%).

The findings suggest that Kajiado pastoralists are transforming to a more commercial form of small ruminant production system so as to be able to meet the growing demands of the urban human population within and outside the county (König et al 2015). However, Marsabit communities were observed to be producing for subsistence consumption due to lack of market access (Muthee 2006; Rutto et al 2013). Pastoralists own a wide range of indigenous livestock species and breeds that are selected on the basis of adaptive traits, such as resistance to diseases and droughts as well as productive traits, such as increased growth and carcass weight (Kosgey 2008; König et al 2015). In addition, keeping more than one livestock specie means pastoralists can generate a wider variety of livestock products and make better use of the available natural grazing resources during the different seasons of the year (Notenbaert et al 2012).

Table 3: Homestead head responses within each small ruminant husbandry practice surveyed in Kajiado and Marsabit counties, Kenya

	Kajiado (n=35)		Marsabit (n=28)	
Parameter	No. HH Respondent	%	No. HH Respondent	%
Number of Livestock Specie kept				
1 to 4 Species (Cattle and Shoats, donkey)	25	71.4	8	28.6
1 to 4 Species (Camel and Shoats)	0	0.0	20	71.4
>5 Species (Cattle, Shoats , donkey, chicken)	10	28.6	0	0.0
>5 Species (Camel, Shoats , donkey, chicken)	0	0.0	0	0.0
Type of Market Access				
Local Market	29	82.9	11	39.3
External Market	6	17.1	0	0.0
No Market	0	0.0	17	60.7
Current Market Price				
Goat Price				
Ksh. 2,000 – 3,000	0	0.0	22	78.6
KSh. 4,000-5,000	29	82.9	0	0.0
Ksh. >6,000	6	17.1	0	0.0
Don't know	0	0.0	6	0.0
Sheep Price				
Ksh. 2,000	0	0.0	0	0.0
Ksh.3,000	35	100	0	0.0
Don't know	0	0.0	0	0.0
Sheep herd size				
<50 (small herd)	20	57.1	6	21.4
51-100 (medium herd)	8	22.9	6	21.4
>100 (large herd)	7	20.0	16	57.2
Goat herd size				
<50 (small herd)	11	31.4	2	7.1
51-100 (medium herd)	10	28.6	5	17.9
>100 (large herd)	14	40.0	21	75.0
Sheep breeds kept				
Red Maasai	11	31.4	0	0.0
Dorper X Red Maasai	20	57.1	0	0.0
Black Head Persian	0	0.0	14	50.0
Black Head Persian X Horro	0	0.0	8	28.6
Black Head Persian X Red Maasai	4	11.4	6	21.4
Goat Breeds kept				
Small East African Goat	9	25.7	20	71.4
Galla X Small East African Goat	26	74.3	5	10.7
Galla	0	0.0	3	17.9

This is supported by the current survey findings indicating that 82.9% of Kajiado HH sold or bought sheep and goats from the local market, with the current market prices for goats reported as being favourable as it was immediately after the December 2013 rain and festive seasons. In Marsabit, market linkage for small ruminants was largely lacking based on 60.7% of livestock owners responses (Table 3). Furthermore, Marsabit HH interviewed only sold goats to local butchers or middle men when in financial distress and they indicated that the purchase price was always low. All HH in Marsabit also indicated there was no market for sheep who were mainly kept to meet household milk, fat and meat needs. The finding of lack of market access for Marsabit communities largely concurs with past studies done in Marsabit by Aklilu (2008), Kosgey (2008) and Rutto and others (2013). In all these studies, the main recommendation was for policy makers to support livestock market development by investing in the construction of roads and setting up of communication infrastructure.

Studies in pastoral communities in Somalia and Ethiopia have demonstrated that even with limited investment in animal health inputs, milk off-take in goats reared under pastoral systems can increase by 550%. However, pastoralists still resist in the investment of animal health inputs for their small ruminant herds when compared to investment done for large ruminants ((FAO-UN 2013). This is mainly because, sheep and goats have a higher reproductive rate when compared to large ruminants. This translates to larger herd sizes that are costly to maintain especially when the market purchase prices are low to meet the cost of animal health input investment (FAO-UN/OIE 2015). All (100%) livestock owners in Kajiado regularly used anthelmintic, antibiotic and tick control products, while only 57% of those interviewed invested in the purchase of preventive vaccines for their sheep and goat herds (Table 4). In contrast, all Marsabit (100%) livestock owners did not invest in the purchase of tick control products or preventive vaccines (Table 4). However, when available, 42.9% of Marsabit livestock owners indicated that they occasionally purchased anthelmintic products

while only 28.6% purchased antibiotic drugs for use in their small ruminant herds. With regard to access to veterinary services, 57.1% of Kajiado livestock owners indicated that they had access to veterinary services, this was in contrast with what was reported in Marsabit where 78.6% of livestock owners indicated that they had no access to veterinary services. Veterinary services was defined by the livestock owners interviewed in both Kajiado and Marsabit counties as the provision of free vaccination services, extension services and rapid response during disease outbreaks. Furthermore, 40% of Kajiado HH indicated that they did not report to veterinary authorities or local authorities like the chief or disease reporter disease incidences in their small ruminant herds. However, in Marsabit and despite not having access to veterinary services, 53.6% of HH indicated that they always reported incidences of small ruminant diseases to the chief or local disease reporter (Table 4).

These findings are largely in agreement with previous studies carried out in pastoral systems of Kenya (Njanja et al., 2003; Onono et al., 2013), these studies have reported that due to the historical marginalisation of pastoral areas by both the colonial and post-independence governments, pastoralist communities have learned to rely on their indigenous knowledge and ethno-veterinary practices to control diseases in their livestock herds (Catley et al., 2011; Onono et al., 2013). In addition, as observed in Kajiado the access to animal health inputs meant that Kajiado livestock keepers could treat their own animals without informing the veterinary authorities (Onono et al., 2013). It can then be hypothesised that in Marsabit, lack of access to animal health input may have been the reason that drove reporting of diseases as chief or local disease reporter are often the first contact person veterinary authorities get in touch with when they want to pass information to the communities (Catley et al., 2011).

Table 4: Homestead head responses within each small ruminant health management practice studied in Kajiado and Marsabit Counties

	Kajiado (n=35)		Marsabit (n=28)	
Parameter	No. HH Respondent	%	No. HH Respondent	%
Anthelmintic use				
Albendazole	23	65.7	12	42.9
Levamisole	5	143	0	0.0
Using both oral and Ivermectin Injection	7	20.0	0	0.0
None	0	0.0	16	57.1
Antibiotic use				
Only Tetracycline	3	8.6	8	28.6
Using all 3 products (Tetracycline, Penicillin/Amoxycillin , Tylosin)	32	91.4	0	0.0
None	0	0.0	20	71.4
Tick/flea control product use				
Only 1 product Synthetic pyrethrin	26	74.2	0	0.0
Using 2 products (Synthetic pyrethrin and Organochlorine)	8	22.9	0	0.0
None	1	2.9	28	100
Preventive Vaccine use				
Yes (CCPP, Enterotoxaemia, and SGP)	20	57.1	0	0.0
None	15	42.9	28	100
Accessibility to veterinary services				
Yes always	20	57.1	0	0.0
Yes but it is limited	7	20.0	6	21.4
No	8	22.9	22	78.6
Reporting of small ruminant diseases				
Yes to Chief or local disease reporter	11	31.4	15	53.6
Yes to Vet or Animal health technician	10	28.6	0	0.0
No	14	40.0	13	46.4

Key: CCPP- Contagious Caprine Pleuropneumoniae

SGP – Sheep and Goat Pox

4.3.4 PPR knowledge and control strategies

PPR is still a new disease phenomenon amongst pastoralist communities in Kenya, it therefore has no local name and is often referred by the presenting clinical signs (Kihu et al 2012). PPR is described by pastoralists as a disease that is unresponsive to treatment and has clinical manifestation of tearing, nasal discharge, emaciation, diarrhoea, mouth lesions and death. (Nyamweya et al., 2010; Kihu et al., 2012; Gitao et al., 2014). In Kajiado, PPR is referred to as 'Ngoroti' or "Oludua" which means persistent diarrhoea, this was the most common sign reported as a PPR clinical sign by HH interviewed in Meto area in Kajiado. In Marsabit PPR was referred to as 'Lookiyooi' which is a Samburu and Rendille local name describing PPR clinical signs. Knowledge of PPR clinical signs (Table 5) was higher (71.4%) amongst Marsabit HH surveyed when compared to Kajiado HH (51.4%). However, for both Kajiado and Marsabit the small ruminant owners interviewed indicated that the greatest risk for PPR introduction into herds was from mixing herds at watering areas (Table 5).

PPR clinical signs especially in Kajiado and North Horr ward in Marsabit was mostly confused with other diseases such as Contagious Caprine Pleuropneumoniae (CCPP), helminthiasis and tick borne disease such as babesiosis. This is similar to findings reported by Nyamweya and others in 2010 and most recently by Kihu and colleagues in 2015. More than half of HH interviewed indicated that they had not accessed the PPR vaccine for their sheep and goats herds (Table 5). In addition, 62.9% of Kajiado livestock owners indicated that the main challenge seen in PPR vaccination campaigns was the lack of allocation of enough vaccine numbers and activity days so as to ensure coverage of all animals in the herd (Table 5).

Table 5: Homestead head knowledge on PPR and control strategies

	Kajiado (n=35)		Marsabit (n=28)	
Parameter	No. HH Respondents	%	No. HH Respondents	%
List PPR Clinical signs				
Correctly listed signs	18	51.4	20	71.4
Confused clinical signs	10	28.6	3	10.7
Don't know signs	7	20.0	5	17.9
Given the listed signs has PPR occurred in your herd?				
Yes	8	22.9	17	60.7
No	27	77.1	11	39.3
How do animals get infected with PPR?				
Introduction of new stock into	11	31.4	5	17.9
Mixing of animals at watering areas	24	68.6	23	82.1
Don't know	0	0.0	0	0.0
How do you control PPR?				
Vaccination during outbreaks	30	85.7	11	39.3
Avoid infected areas	5	14.3	17	60.7
Don't know	0	0.0	0	0.0
Have you vaccinated your animals against PPR?				
Yes	16	45.7	11	39.3
No	19	54.3	17	60.7
What are the challenges facing small ruminant vaccination activities?				
Lack of access especially for satellite/*Fora* herds	10	28.6	17	60.8
Too few vaccines/days given the large small ruminant herds	22	62.9	2	7.1
Financial constraints to pay for the whole herd	3	8.5	9	32.1

In Marsabit, 60.8% indicated that the main challenge was access to vaccination sites especially for the mobile satellite based small ruminant herds, livestock owners in Marsabit noted that that vaccination campaigns mostly targeted permanent settlement areas such as around trading centres and watering areas. PPR vaccine has been shown to be highly effective in eliciting protective antibodies against all 4 lineages of the PPR virus. Furthermore, PPR vaccination or natural infection confers lifelong immunity on vaccinated animals (Banyard et al., 2010; FAO-UN/OIE 2015). All respondents in Kajiado and Marsabit elucidated these two facts. The surveyed owners indicated that PPR vaccination was effective in stopping morbidity and mortality rates in herds even if administered during outbreaks and that once a herd was vaccinated or infected, the adult animals did not succumb to future outbreaks.

4.3.5 Small ruminant production Constraints and Preferred policy interventions

Table 6 summarises HH multiple response sets regarding the most important diseases affecting their sheep and goat herds as well as their constraints and suggestions on disease control strategies. Interestingly, PPR was not ranked first when surveyed livestock owners were asked to name in order of importance goat diseases that caused them the highest disease burden in terms of morbidity or mortality. In Marsabit, PPR was ranked second to CCPP in goats while in Kajiado it was ranked third, the first being CCPP and second helminthiasis. These finding supports the view of the global PPR strategy that recommends that PPR control programmes should run concurrently with the control of other important small ruminant diseases such as CCPP and helminthiasis control (FAO-UN/OIE 2015).

4.3.5.1 Small ruminant production constraints

Sixty percent of small ruminant owners in Kajiado indicated that lack of quality drugs especially anthelmintics was the main problem hindering their livestock disease control

efforts. The also identified lack of regular veterinary health and extension services (31.4%) and lack of early warning of disease outbreaks (8.6%) as among the 3 important constraints. In Marsabit, the main constraint was lack of veterinary animal health services (52.4%) specifically vaccines and extension services, the second constraint was lack of outlets to buy drugs like anthelmintics (35.7%) and the third challenge was the lack of inclusion when disease control decisions were being made with 7.1% of respondents remarking that they wanted to be included in the decision of when and what type of vaccine should be given to their herds (Table 6). The survey findings indicate that pastoralists are aware of the main drivers of diseases in their production systems and their views are largely similar with those of research findings. Drivers of disease burden include climatic variability that is changing the transmission dynamics of vector borne pathogens such as Rift valley fever virus (Perry et al 2013), land tenure systems have also resulted in movement restriction (Boone et al 2007) hence limiting the pastoralist traditional practice of avoidance. Pastoralist sedentarization that also increases pathogen contamination load in the environment resulting in increased incidences of disease outbreaks (Perry et al 2013).

Table 6: Multiple Response set of homestead head responses on prevalent diseases, constraints hindering disease control and preferred policy interventions

	Kajiado (n=105)		Marsabit (n=84)	
Parameter	No. Responses	%	No. Responses	%
Prevalent Sheep diseases				
Helminthiasis/diarrhoea in young	35	33.4	26	31.0
Enterotoxaemia	18	17.1	17	20.2
Pneumonia	25	23.8	21	25.0
Sheep and Goat Pox (SGP)	27	25.7	20	23.8
Prevalent Goat diseases				
CCPP	40	38.1		32.1
PPR	10	9.5	14	19.0
Helminthiasis/diarrhoea in young	37	35.2	8	9.5
Tick borne infections (Babesiosis and Heart water)	7	6.7	12	14.3
Contagious ecthyma (Orf)	11	10.5	2	2.4
Sheep and Goat Pox (SGP)	0	0.0	6	7.1
Constraints in disease control				
Lack of quality drugs (anthelmintics)	63	60	30	35.7
Lack of veterinary services (Vaccination and Extension services)	33	31.4	44	52.4
Lack of early warning of outbreaks so as to allow avoidance of areas or vaccinate herds	9	8.6	0	0.0
High prevalence of diseases when compared to the past	0	0.0	4	4.8
Lack of inclusion when designing disease control activities	0	0.0	6	7.1
Preferred small ruminant disease control policy interventions				
Provision of regular and timely veterinary services(vaccination, extension, response to outbreaks)	85	90.5	71	84.5
Set up drug outlets (at local market centres) and ensure they stock quality drugs (anthelmintics)	10	9.5	10	11.9
Improve market, communication and transport infrastructure	10	9.5	3	3.6

4.3.5.2 Preferred policy interventions for disease control

Livestock owners were asked to mention policy interventions that could be implemented to complement their small ruminant disease control practices (Table 6). Multiple set responses indicated that 90% of Kajiado HH wanted provision of regular veterinary services such as extension and vaccination services. In addition, 9.5% of HH indicated that ensuring drug outlets sold quality drugs especially anthelmintics as well as improving mobile phone connectivity would enhance their disease control strategies. In Marsabit 84.5% of small ruminant owners indicted that better access to veterinary services was key in supporting their disease control efforts. In addition, 11.9% of HH felt that setting up veterinary drug sale outlets would also support small ruminant disease control efforts. The policy suggestions suggest that small ruminant owners know what disease control policies can support them. It is therefore important that any livestock disease control strategy engages them especially with regard to ensuring regular provision of extension and animal health services. Additionally, public-private sector initiatives can improve access to animal health inputs as well as enable setting up of marketing, communication and transport infrastructure (Muthee 2006).

4.4 Conclusion and Recommendations

Based on the survey findings, the study can conclude that sheep and goat production is still an important livelihood strategy for Kajiado and Marsabit pastoralist communities. However, there exists differences in small ruminant disease control practices amongst Kajiado and Marsabit communities that are driven by the level of access to veterinary services, animal health inputs and livestock markets.

The study recommends that small ruminant disease control programmes be tailored to specific geographical areas based on the areas social and economic settings. In addition, with regard to PPR control, Kajiado communities would be willing to pay for vaccines when compared to Marsabit communities as they are able to recover the input expense after sale of their animals. While in Marsabit PPR vaccination programmes should continue to be offered as free public good services as the small ruminant production systems in Marsabit are still driven by subsistence consumption. In addition, PPR vaccination campaigns should target small ruminant herds that are in satellite or mobile settlements as they usually have a higher number of animals when compared to permanent settlement herds (Kauffmann 2012). Policy makers in both Kajiado and Marsabit should include CCPP vaccination as recommended in the PPR global strategy (FAO-UN/OIE 2015). Further, during PPR vaccination campaigns the anthelmintic product selected should first be tested for efficacy (Gicheha et al., 2005; Kenyon et al., 2013) this will be especially important for Kajiado county small ruminant herds.

4.4.1 Future research areas

Future research areas should determine the efficacy and resistance of anthelmintic drugs especially in Kajiado county, Kenya.

CHAPTER 5

5.0 Sero-survey as a tool for assessing *Peste des petits ruminants* vaccination control strategies in pastoral systems of Kenya

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Abstract

Background: *Peste des petits ruminants* (PPR) is a highly infectious viral disease of sheep and goats that causes significant production losses for livestock owners. PPR outbreaks continue to occur in Kenya despite vaccination control measures being in place. A risk based cross-sectional serosurveillance study was carried out to determine PPR antibody seroprevalence levels in sheep and goat herds reared in pastoral production systems of Kenya. The association between intestinal parasitic infections and PPR susceptibility was also investigated. The study was carried out between January 2014 and March 2015 through sampling of 535 small ruminants (245 sheep and 290 goats) from 63 herds in selected vulnerable areas of Kajiado and Marsabit counties in Kenya.

Results: The overall PPR seroprevalence for Marsabit small ruminant herds was 22.4% (95% Confidence Interval (CI): 19.5 – 25.4) when compared to 37.1% (95% CI: 31.3 – 42.9) for Kajiado herds. PPR seropositivity in Kajiado was associated with geographical location of sheep and goat herds, animals from Lenkisem ward were 64.0 times ($p< 0.0001$) more likely to be seropositive when compared to animals from Bisil ward. Herd size of goats in Kajiado was also a significant predictor, goats sampled from large herds consisting of more than 100 goats were more likely to be seropositive when compared to medium sized herds composed of between 51 to 100 animals (β-estimate = - 2.19, O.R. = 0.112, $p= 0.001$). In addition, small ruminants herds in Kajiado that received regular doses of combined oral (Levamisole or Albendazole) and injectable (Ivermectin) anthelmintic products had a significantly ($p=0.001$) higher likelihood of being PPR seropositive when compared to animals receiving only oral Levamisole products (β-estimate = -1.623, O.R. = 0.197, $p=0.001$). Prevalence of intestinal parasites and age of animals in Kajiado were not significant predictors of PPR seropositivity. Geographical location of small ruminant herds was also significantly ($p< 0.0001$) associated with PPR seropositivity of animals in Marsabit, sheep and goat herds sampled from

Loiyangalani ward had a 36.6 times ($p<0.0001$) probability of being PPR seropositive when compared to animals sampled from Dukana ward. Animals sampled from herds that had reported past PPR outbreaks in Marsabit were 96.2 times ($p<0.0001$) more likely to be PPR seropositive when compared to those from herds that had not reported outbreaks. Further, Marsabit sheep and goat herds that had access to PPR vaccines had a 5.5 times ($p= 0.002$) probability of being seropositive when compared to herds that had no access to PPR vaccine. Age of animal was also significantly ($p<0.0001$) associated with PPR seropositivity in Marsabit, adult animals that were above 3 years of age were 11.9 times more likely to be seropositive when compared to young animals between 6 and 12 months of age. Prevalence of intestinal parasites in Marsabit was not a significant predictor of PPR seropositivity. The average prevalence of intestinal parasites in Kajiado small ruminant herds was 54.5% (95% CI: 47.9 -61.0) for coccidia parasite and 82.2% (95% CI: 77.0 – 86.9) for helminth parasites. In Marsabit, the average prevalence of intestinal parasites was 48% (95% CI 42.2- 54.0) for coccidia and 30.7% (95% CI: 25.8 – 36.0) for helminths. *Haemonchus* nematode specie was the most common larvae identified after faecal culture. Co-infection prevalence for both helminth and coccidia intestinal parasite was 51.2% (95% CI: 44.6 -57.7) for Kajiado herds and 21.7% (95% CI: 17.1 -26.4) for Marsabit herds.

Conclusion: Our results demonstrate that PPR seroprevalence levels in both study areas was lower than the recommended 70% that prevents virus circulation in endemic and high risk areas. Seronegative study animals and presumably many of the sheep and goat herds in the study area were therefore not protected against future PPR outbreaks. We suggest that post vaccination serosurveys be included as monitoring tools that can be used to access the effectiveness and coverage of future PPR vaccination campaigns. In addition, vaccination activities should target endemic areas as this will increase prevention and control efforts.

Key words: Intestinal parasites, PPR, Risk factors, Small ruminants

5.1 Introduction

Peste des petits ruminants (PPR) is a highly infectious viral disease of small ruminants with goats suffering the most severe form of the disease when compared to sheep (Banyard et al., 2010). Clinically, PPR is characterised by fever, necrotic stomatitis, gastroenteritis, and pneumonia. The disease was first reported in Ivory Coast in 1942 and current reports indicating it has spread to Central Africa (Ashley et al., 2010; Banyard et al., 2010), Eastern Africa (Muse et al., 2011; Kabaka et al., 2012; Kihu et al., 2012), Middle East (Ashley et al., 2010; Banyard et al., 2010) and Asian countries of India, Nepal, Bangladesh, Pakistan and Afghanistan (Banyard et al., 2010). PPR morbidity rates vary and range from 10 to 90 percent (%) while mortality rates range from 30 to 70% (OIE 2013). The wide range of morbidity and mortality rates observed are due to susceptibility differences between species (sheep or goats) as well as immune status of animals. Animals previously infected with PPR virus or vaccinated against the disease acquire a lifelong immunity (FAO-UN/OIE 2015).

In Kenya, losses to PPR are mostly experienced in small ruminant pastoral production systems where production losses are estimated to be close to 19.1 million USD with mortality of goats less than 2 years of age constituting the greatest economic losses valued at 16.8 million USD (Kihu et al., 2015a). The first confirmed report of PPR outbreak in Kenya occurred in Turkana County in 2006 (Nyamweya et al., 2010). Since then, the disease has spread and is now endemic in all Northern counties, with sporadic outbreaks occurring in semi-arid counties located in the Southern parts of the country (GoK 2015a). Outbreaks of PPR continue despite vaccination control measures being instituted in 2008 (GoK 2008, GoK 2015a). Control of PPR in endemic areas is mainly achieved through the use of a live attenuated vaccine that was developed after isolation of PPR lineage 1 virus from Nigeria (Diallo et al 1989).

The live PPR vaccine is protective against all 4 virus lineages and confers a lifelong immunity to vaccinated animals after a single subcutaneous dose (Kumar et al., 2014). The vaccine is also safe and can be administered to pregnant animals at any stage of gestation (Couacy-Hyman 2013). Vaccination of dams induces production of antibodies against PPR virus that are passively transferred to young through the colostrum. The colostral antibodies are protective to the young for their first 5 months of life (Couacy-Hyman 2013). However, PPR vaccine has a low thermal stability, with studies indicating that after reconstitution, the vaccine has a half-life of between 2 to 6 hours when maintained at 37 °C (Kumar et al., 2014). This means that its use in arid tropical conditions requires a sustained cold chain and this poses a challenge to vaccine delivery in pastoral areas in Kenya which often lack basic cold chain facilities (Kihu et al., 2015b). The global PPR control strategy adopted in April 2014 developed a PPR Post-Vaccination Evaluation tool (PVE). The PVE tool outlines surveillance methods that countries can adopt so as to be able to assess the effectiveness and coverage of vaccination activities (FAO-UN/OIE 2015).

One proposed PVE method is passive surveillance, which is a rapid and cost effective method that utilises participatory techniques to assess livestock owners' perception of vaccination success (Catley et al., 2011; Kihu et al., 2015b). The other method is active surveillance, which requires substantial investment in human and financial resources as it aims at acquiring biological evidence of immune development through serological testing (Kihu et al., 2015b). However, the active surveillance method requires a reliable animal identification system so as to ensure that animals that were vaccinated are the same ones sampled for the post vaccination sero survey (FAO-UN/OIE 2015). PPR vaccination activities in Kenya rarely follow up with post-vaccination serological surveys of vaccinated herds (GoK 2015a; Kihu et al., 2015b).

The risk based cross-sectional study was therefore carried out to determine PPR antibody seroprevalence levels in small ruminant herds in pastoral production systems of Kenya. The study targeted areas that were earmarked for the 5 year PPR vaccination campaign that began in 2008 and was projected to end in 2012 (GoK 2008; Gitao et al., 2014; Kihu et al., 2015b). The overall aim of the study was to determine if small ruminant herds in Kajiado and Marsabit counties of Kenya had acquired protective antibody levels against PPR virus exposure. The findings from this study generated information necessary for the design of future PPR post vaccination serosurveillance surveys in Kenya. In addition, the findings also highlighted risk factors associated with PPR seropositivity in the study areas. Additionally, the study explored the association between the prevalence of intestinal parasites and PPR susceptibility.

5.2 Methods

5.2.1 Study area

The study areas were purposively selected based on the following criteria. The area (i) was classified as a PPR endemic or high risk zone (GoK 2015a), (ii) inhabitants are pastoralist with significant population of small ruminant herds (KNBS 2009) and (iii) is an important small ruminant transhumance and trade stock route to neighbouring countries (Muthee 2006; Aklilu 2008). In addition to the mentioned criteria, the prevailing security situation (National Drought Monitoring Authority (NDMA) 2012-2015) and ease of access given the available mode of transport was also considered. The study areas selected and meeting the above set criteria were Kajiado and Marsabit counties in Kenya. Kajiado is located in the Southern rangelands of Kenya and is classified as a semi-arid zone with an annual rainfall amount of between 500 to 1250 mms (Kajiado-CIDP 2013).

Rainfall pattern is dependent on the topography and is bimodal with short rains occurring in October, November and December and long rains in March, April and May, the vegetation type also differs with the terrain and consists of open grasslands to bush or woody grasslands (Plate 5) (Kajiado-CIDP 2013). Kajiado county is classified as a PPR high risk area as it reports sporadic outbreaks (GoK 2015a), the first PPR outbreak was reported in 2010 in Namanga area which is an area located close to the Kenya-Tanzania border (GoK 2015a).

Marsabit County is located in the Northern rangelands of Kenya and is classified as predominately arid with most of the county lying in an extensive plain that is interspersed with volcanic rocks (Plate 6), hills and mountain ranges (Marsabit-CIDP 2013). Annual rainfall amounts range from 200 to 800 mms, short rains occur in October and November while Long rains occur in March, April and May (Marsabit-CIDP 2013). Marsabit county is classified as a PPR endemic zone, the first PPR outbreak was reported in March 2008 in Laisamis, an area located in the Southern part of Marsabit (GoK 2008). Since then, incidences of the disease are reported annually from all areas located in Marsabit South with sporadic PPR incidences reported from areas close to the Ethiopian border in Marsabit North (GoK 2015a; NDMA 2012-2015).

Plate 5: Woody grassland vegetation in Kajiado (January 2014)

Plate 6: Volcanic rock terrain in Marsabit (March 2015)

5.2.2 Study design

A pilot baseline survey to validate the field sampling techniques was carried out in Mashuru, Kajiado County in December 2013. A risk-based cross-sectional serosurveillance study was conducted between January 2014 and March 2015. The sampling unit was the individual animal belonging to a village herd that was purposively selected based on previous PPR outbreak incidence. The number of animals to be sampled in each herd was determined using the formula, $n = Z^2 [p (1-p)/L^2]$, used for sample size calculation for field epidemiological surveys (Dohoo et al., 2010). Where n = sample size, Z = 95% confidence level (Standard value of 1.96), P = prevalence of PPR which was taken to be 30% (0.3) based on a previous seroprevalence study in the region (Muse at al., 2012; Kihu et al., 2015b). L is the precision of sample size estimate and was set at 5% (0.05). Based on these input parameters, the total number of animals to be sampled was 323 for each study County. The pastoral communities in both study areas resided in villages/homesteads consisting of a cluster of households of often-related families that pursue similar animal husbandry and socio-economic activities (Bekure et al., 1991; Kaufmann 2102; Kihu et al., 2015b).

To arrive at the number of animals to be sampled in each homestead the sample size (323) was divided by 30, the minimum number of statistical sampling clusters recommended (Dohoo et al., 2010). This meant that for each herd cluster a minimum of 10 animals was targeted to be sampled from 33 herds in Kajiado county and 33 herds in Marsabit county. The homesteads to be sampled were identified using the 'snowball' sampling technique (Biernacki and Waldorf 1981; Muse et al., 2012; Gitao et al., 2014). This technique involved initial contact with either the local veterinary officers, chief or local disease reporters who introduced the researcher to the first homestead head (HH) that had reported previous PPR incidences. The HH in turn, introduced the research team to the next homestead.

5.2.3 Sample collection

5.2.3.1 Ethical statement

The ethical clearance for the study was obtained from the University of Nairobi, Faculty of Veterinary Medicine, Biosafety, Animal use and Ethics Committee (Appendix 1). Consent for the study was also sought from the Director of Veterinary Services (Appendix 2. A verbal and signed consent was obtained from livestock owners before animal sampling was done, after the researcher explained the confidentiality and voluntary participation features of the study (Appendix 3).

5.2.3.2 Data capture

After consent was obtained from the homestead head, the geographical coordinates of the location of each sampled herds was recorded using a hand held Global Positioning System (GPS) unit. A laboratory form was filled for each animal to accompany the samples collected. The laboratory form contained information regarding sampled animal's age, sex and breed; PPR vaccination status (vaccinated or not); Previous incidence of PPR disease outbreak in herd and PPR disease control measures in place.

5.2.3.3 Sampling of animals

Twelve animals were randomly selected from each herd, the section criteria was based on previous studies conducted in similar pastoral settings (Luka et al. 2011; Muse et al., 2011; Kihu et al., 2015b). Animals were selected based on their specie (Sheep or goat), sex (male or female) and age (classified as young for animals 6 to 12 months of age, juvenile for animals between 1 and 2 years of age and adults for animals over 3 years) this criteria was used so as to ensure each specie had both sexes and the 3 age categories represented. Age of animal was first determined by visual selection. Before being restrained, visual inspection was conducted to identify clinical pathology signs (Plate 7). Animals were then restrained using techniques (Plate 8) that caused minimal stress to the animals (Mbithi et al., 2003).

Plate 7: Visual examination found bilateral mucous nasal discharge in a sheep

Plate 8: Restraint technique used for sample collection

A physical examination was then carried out to confirm the age of animal (Plate 9) based on the number of erupted permanent incisors (Vatta et al., 2006) attached in appendix 4. The physical examination also determined other clinical pathology signs (Plate 10). Clinical indicators of intestinal parasitism were determined using the body condition score (BCS) chart (1 = emaciated animals, 2= thin animals and 3 = optimal weight) in appendix 5 and the FAMACHA© anaemia score chart (Plate 11) (1=not anaemic, 2 and 3 = borderline anaemic, 4 and 5= severely anaemic) in Appendix 6 (Vatta et al., 2006).

Plate 9: Ageing of animals using eruption of lower incisors, the picture shows eruption of one pair of central permanent incisors in a juvenile goat estimated to be between 1 and 2 years of age

Plate 10: Physical examination of the perineum area of a female goat revealing heavy tick infestation

Plate 11: Conjunctiva mucosa colour scoring using the FAMACHA® anaemia guide chart

5.2.3.3.1 Blood sample collection and laboratory analysis

Experienced animal health personnel collected blood samples with no or minimal pain to the animals. Blood samples for serum (5 mls) and haematology (5 mls) analysis were collected from the jugular vein using sterile evacuated tubes. The tubes were then labelled and label details recorded in each individual animal laboratory form. After labelling, evacuated tubes with uncoagulated blood for haematology analysis were placed in a cool box with ice packs and were later maintained at 4 °C refrigeration temperature until they were ready for Packed Cell Volume (PCV) analysis (Plate 12) that was carried out in the field on the same day of sample collection, PCV determination was based on a procedure outlined by Latimer and colleagues (2003) and Weiss and Wardrop (2010). The evacuated tubes with silicone coating as a clot activator were left to stand indoors at ambient temperatures for between 6 to 8 hours, serum was collected using sterile single use Pasteur pipettes (Plate 12), the collected serum was stored in 2ml cryovial tubes that were maintained at -20°C until the day for testing.

Serum samples from the field were delivered to the serology laboratories located in the department of Veterinary Public Health, Pharmacology and Toxicology at the University of Nairobi where they were tested for the presence of PPR antibodies using the competitive enzyme linked immuno-sorbent assay (c-ELISA) test kit procedure (BDSL, Aryshire Scotland, UK) that is based on a method developed by Libeau and colleagues (1995). Optical density (OD) values were read using an ELISA microplate reader with an inference filter of 492 nm. The reader was connected to a computer loaded with ELISA Data Information (EDI) software which was used to automate the reading and calculation of the percentage inhibition (PI) values. Samples with PI ≥50 % (cut-off) were considered positives for PPR antibodies (Libeu et al., 1995; Kihu et al., 2015b).

(a)

(b)

(c)

Plate 12: Field blood sample processing (a) Capillary tubes loaded into a microheamatocrit centrifuge (b) PCV readings done with a haematocrit reader (c) Serum harvesting from whole blood using a pasture pipette and placed into a cryovial tube.

5.2.3.3.2 Faecal sample collection and laboratory analysis

About 10 grams of faecal pellets was collected (Plate 13) from the rectum of animals using a gloved lubricated finger (Zajac and Conboy 2012). The samples were then labelled in a similar manner as the blood samples so as to ensure that each blood and faecal sample could be traced back to the individual animal sampled. The faecal samples were then refrigerated at 4 °C and maintained at this temperature until the day of analysis. Faecal samples were analysed within 1 week after field collection and this was carried out in the veterinary parasitology laboratories located at the University of Nairobi. The faecal samples were evaluated for intestinal helminth strongyle eggs (Plate 14) or coccidia oocysts protozoa parasites using the McMaster and pooled faecal culture quantitative techniques (Plate 15) as outlined by Zajac and Conboy (2012).

Plate 13: Faecal sample collection using a lubricated gloved finger

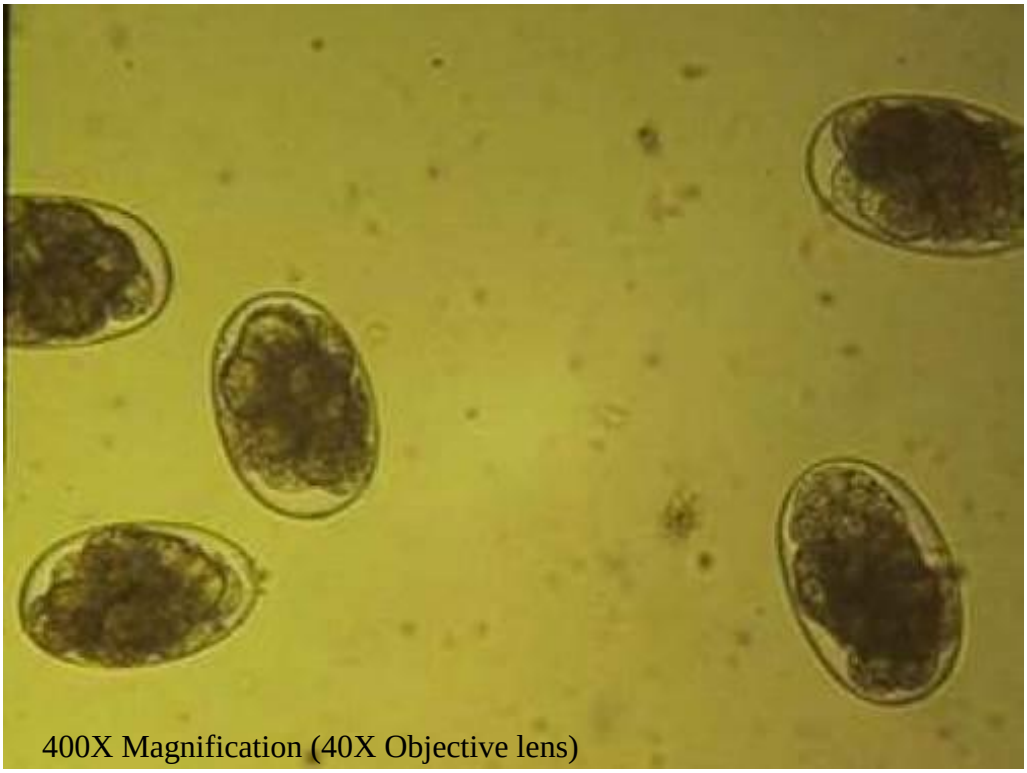


Plate 14: Helminth Strongyle eggs observed under the 40X microscope objective lens

Plate 15: *Haemonchus* helminth specie as observed under 40X microscope objective lens

5.2.4 Data analysis

Field and laboratory results were coded into appropriate variables and analysed using the Statistical Package for Social Sciences software version 16.0 (SPSS Inc., Chicago, Illinois). Data from the two study areas was analysed separately and the sample unit of interest was the individual animal. The result of the c-ELISA test (positive/negative) was the outcome variable. The apparent PPR seroprevalence was calculated by dividing the number of positive samples in each herd by the total number of animals sampled. Odds ratio (OR) were used to assess the association between outcome and explanatory variables. Nineteen explanatory or risk factor variables were grouped into 4 categories these were geographical location, animal demographic characteristics, husbandry practices and intestinal parasitism status of animals. The choice of statistical test for association were based on previous similar studies carried out in the region (Muse et al., 2012; Salih et al., 2014; Kihu et al., 2015b).

A Pearson chi-square (χ^2) test was used to check for simple association between categorical data and PPR seroprevalence at a significance level of $p \leq 0.05$ (Kihu et al., 2015). While continuous data simple association with PPR antibody seroprevalence was determined using an independent sample T-test. Explanatory variables identified as significant were then inputted into a multivariable logistic regression model using a backward fitting procedure, the model significance was set at $p \leq 0.05$. The final model identified factors that were associated with PPR seropositivity in vulnerable areas of Kajiado and Marsabit counties of Kenya.

5.3 Results

5.3.1 Descriptive results

A total of 1070 blood (535) and faecal (535) samples were collected from 290 goats and 245 sheep from 63 herds in Kajiado and Marsabit counties of Kenya. The overall PPR seroprevalence was 22.4% (95% CI: 19.5 – 25.4) for Marsabit herds and 37.1% (95% CI: 31.3 – 42.9)) for Kajiado herds. In Kajiado, 35 herds were sampled across 7 administrative ward units, of the total 213 animals sampled in Kajiado 111 were goats and 102 were sheep. In Marsabit, 322 animals from 28 herds were sampled across 5 administrative ward units, of the 322 animals sampled, 179 were goats and 143 were sheep.

The apparent PPR seroprevalence varied across study area administrative wards, animals sampled from Kumpa in Kajiado County had a PPR seroprevalence of 60% while those sampled from Loiyangalani ward in Marsabit county had a PPR seroprevalence level of 64%. PPR seroprevalence levels also varied across the specie and age of animal, in Marsabit, goats had a higher PPR seroprevalence of 25% when compared to sheep (18%), adult animals also had a higher PPR seroprevalence of 36% when compared to animals categorised as juvenile (20%) and young (13%). Additionally in Marsabit, animals sampled from the satellite/'Fora' herds had a lower (14%) PPR seroprevalence when compared to animals sampled from herds in permanent settlements (Figure 9). In Kajiado, the apparent PPR seroprevalence levels did not vary across the sex and species of animals (Figure 10), however animals that were classified as young had a lower PPR seroprevalence of 29% when compared to 42% for adult animals (Figure 10).

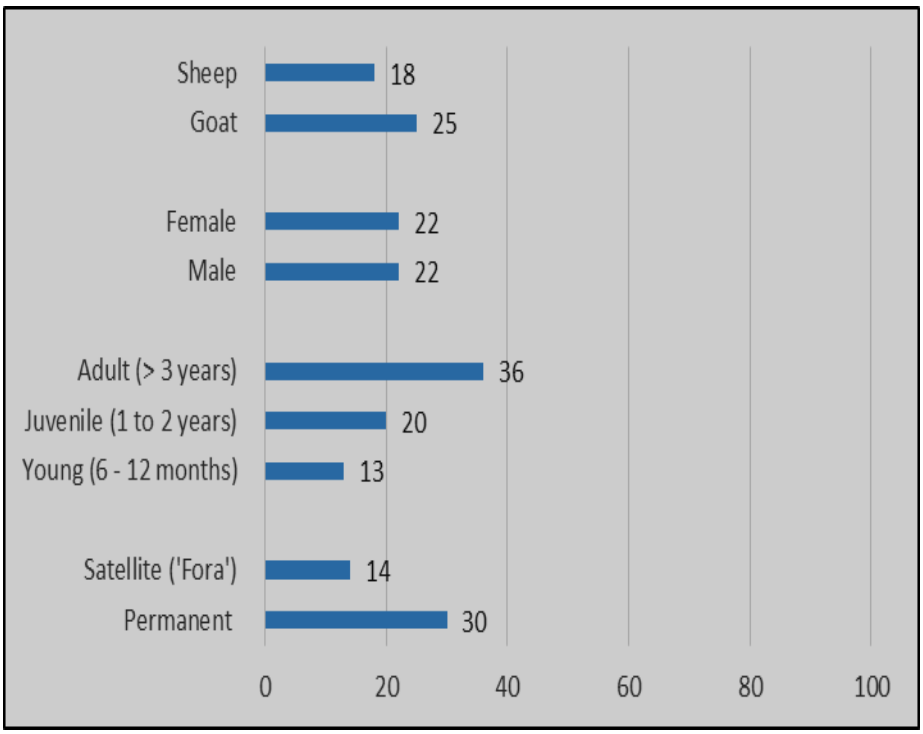


Figure 9: Percentage distribution of apparent PPR seroprevalence levels across various risk category groups in Marsabit County, Kenya

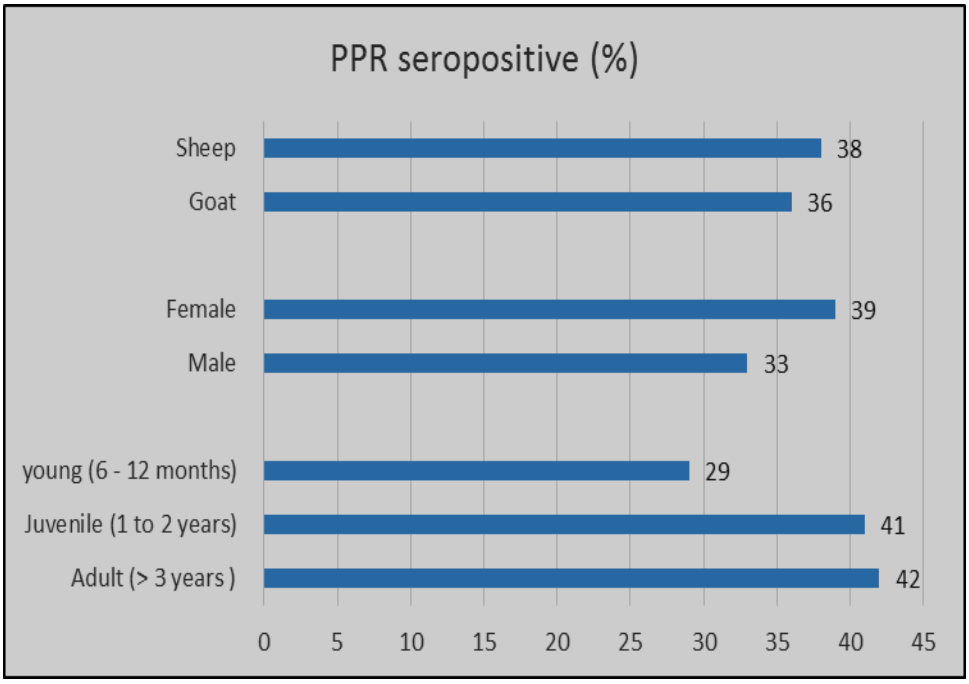


Figure 10: Percentage distribution of apparent PPR seroprevalence levels across various risk category groups in Kajiado County, Kenya

Almost all sampled animals in Marsabit (67.1%) and in Kajiado (78.4 %) scored 2 on BCS chart indicating a thin body condition. In Kajiado, most animals (95.3%) had a score of 2 or 3 on FAMACHA© chart while 83% of Marsabit animals had a FAMACHA© score of 2 or 3. Using a reference range based on Latimer and colleagues (2003) PCV% was set at 22 to 38% for goats and 27 to 45% for sheep. The mean PCV% for Kajiado goats was 23.8% (95% CI: 23.1 -24.6) and 24.2% (95% CI: 23.4- 25.1) for sheep. In Marsabit, the average PCV% was 23.9% (95% CI: 23.3-24.5) for goats and 26.0% (95% CI: 25.2- 26.8) for sheep. The average prevalence of intestinal parasites in Kajiado small ruminant herds was 54.5% (95% CI: 47.9 - 61.0) for coccidia parasite and 82.2% (95% CI: 77.0 – 86.9) for helminth parasites. In Marsabit, the average prevalence of intestinal parasites was 48% (95% CI 42.2- 54.0) for coccidia and 30.7% (95% CI: 25.8 – 36.0) for helminths. *Haemonchus* nematode specie was the most common larvae identified after faecal culture. The average *Haemonchus* larvae count was 32.7 (95% CI: 29.8 – 35.7), 18.5 (95% CI: 16.5 – 20.6) for *Trichostrongylus* species and 4.2 (95% CI: 3.2 – 5.2) for *Oesophagostomum* species. In Marsabit, *Haemonchus* species larvae average larvae count 4.7 (95% CI: 4.1 – 5.3), followed by 1.7 (95% CI: 1.5 – 2.0) for *Trichostrongylus* species. There were no *Oesophagostomum* nematode species cultured in Marsabit.

The prevalence for infection for both helminth and coccidia parasite (co-infection prevalence) was 51.2% (95% CI: 44.6 -57.7) for Kajiado herds and 21.7% (95% CI: 17.1 -26.4) for Marsabit herds. The average strongyle egg count in Kajiado was 1155.4 (SD1832) with a range of 0 to 11,200 strongyle egg count. Animals sampled in Meto had the highest average strongyle egg count of 1800 strongyle egg count. In Marsabit the average strongyle e.p.g was 112.1 (SD254.7) with a range of 0 to 2000 strongyle e.p.g.

The association between PCV%, strongyle egg per faecal gram count and FAMACHA© score chart was investigated using correlation analysis. In Kajiado, a PCV% of 1 was significantly ($p<0.0001$) but negatively associated with FAMACHA© score chart (-0.53) and faecal strongyle egg count (-0.48). However strongyle egg count was significantly ($p<0.0001$) and positively (0.70) associated with FAMACHA© score chart. Marsabit results were similar, with PCV% (1) having a significant ($p<0.0001$) but inverse association with FAMACHA© score chart (-0.51) and strongyle egg per faecal gram count (-0.36). Similarly, strongyle egg count (1) was significantly ($p<0.0001$) and positively (0.26) associated with FAMACHA© score chart. This meant that a high FAMACHA© score of 4 or 5 (indicating low PCV% thus anaemia) was positively correlated with a high strongyle egg count indicating a high helminth worm burden.

5.3.2 Risk factors associated with PPR seropositivity in Kajiado

In Kajiado, only livestock owners from Meto ward indicated they had observed past PPR incidence in their small ruminant herds. Out of the 19 risk factors investigated, only 5 categorical variables were found to be significantly ($p\leq0.05$) associated with PPR seropositivity on chi-square analysis (Table 7). These were geographical location at ward level ($\chi^2 = 34.7$, $p<0.0001$), herd size of goats ($\chi^2 = 24.1$, $p<0.0001$), use of antibiotics ($\chi^2 = 12.3$, $p<0.0001$), use of anthelmintics ($\chi^2 = 6.7$, $p<0.035$) and previous PPR vaccination of animals ($\chi^2 = 155.9$, $p<0.0001$) (Table 7). There were no significant (Table 8) continuous variables.

Table 7: Relationship between categorical variable risk factors in Kajiado and PPR seropositivity using Chi-square (χ^2) test analysis

Risk factor Parameters	*No. of animals sampled*	*No. animals Positive*	*Sero prevalence (%)*	χ^2	*df*	*p-value*
Geographical location						
1.Kajiado wards	**213**	**79**	**37.1**			
Meto	30	6	20.0			
Kumpa	30	18	60.0			
Oloimirmir	33	16	48.5	34.7	6	**<0.0001***
Oldonyorok	28	4	14.3			
Mailwa	31	14	45.2			
Lenkisem	31	18	58.1			
Bisil	30	3	10.0			
Animal characteristics						
2.Age						
Adult	74	31	41.9			
Juvenile	69	28	40.6	3.3	2	0.195
Young	70	20	28.6			
3.Species						
Goat	111	40	36.0			
Sheep	102	39	38.2	0.1	1	0.777
4.Breed						
Small East African Goat (SEAG)	33	8	24.2			
Galla X SEAG Goat	78	32	41.0			
Red Maasai X Black Head Persian Sheep	36	12	33.3	3.5	3	0.323
Dorper X Red Maasai	66	27	40.9			
5.Gender						
Male	90	30	33.3	0.9	1	0.389
Female	123	49	39.8			
Husbandry practices						
6.Herd size goat						
< 50 animals small	72	36	50.0			
51- 100 animals medium	57	6	10.5	24.1	2	**<0.0001***
>51 animals large	84	37	44.0			
7.Herd size sheep						
< 50 animals small	123	42	34.1			
51- 100 animals medium	48	22	45.8	2.1	2	0.356
>51 animals large	42	15	35.7			
8.Antibiotic use						

1 product)	19	0	0.0	12.3	1	**<0.0001***
2 or more products)	194	79	40.7			
9.Dewormer use						
Levamisole only	139	43	30.9			
Albendazole only	31	16	51.6	6.7	2	**0.035***
Combination of oral and injectable	43	20	46.5			
10.PPR Vaccine given						
Yes	95	79	83.2	155.6	1	**<0.0001***
No	118	0	0.0			
Clinical indicator for intestinal parasitism						
11.Past PPR Incidence						
Yes	61	20	32.8	0.68	1	0.254
No	152	59	38.8			
12.Body condition Score						
1(emaciated)	24	9	37.5			
2 (Thin)	167	66	39.5	3.8	2	0.150
3 (Optimum)	22	4	18.4			
4(Fat)	0	0	0.0			
5 (Obese)	0	0	0.0			
13.FAMACHA/Anaemia score						
1 (optimum colour)	0	0	0.0			
2(Acceptable colour)	173	61	35.3			
3(Borderline anaemic)	30	13	43.3	1.46	2	0.481
4(Anaemic)	10	5	50.0			
5(Severely anaemic)	0	0	0.0			
14.Coccidia infection						
No infection	97	27	27.8			
Mild	81	35	43.2	8.8	3	0.332
Moderate	28	12	42.9			
High	7	5	71.4			

*significance at $p \leq 0.05$

Table 8: Relationship between continuous variables risk factors in Kajiado and PPR seropositivity using T-test analysis

Physiological status Risk parameter	No. of animals	No. of animals positive	Positive animals Mean and SD (±)	t-value	df	p-value	95% Confidence interval of the difference in Means	
							Lower	Upper
15. Packed cell volume percentage (PCV %)	213	79	23.35 ±4.1	1.773	211	0.078	-0.12	2.23
16. Strongyle egg per faecal gram count	213	79	1421.5 ±2094.4	-1.634	211	0.104	-933.4	87.35
17. Haemonchus	213	79	35.0 ±22.6	-1.136	211	0.257	-9.72	2.61
18. Oesophagostomum	213	79	1.7 ±2.5	4.927	211	0.008	2.0	6.01
19. Trichostrongylus	213	79	18.7 ±16.4	-0.139	211	0.889	-4.49	3.90

*significance at $p \leq 0.05$

Multivariate logistic regression analysis identified only 3 factors (Table 9) to be significantly ($p<0.05$) associated with PPR seropositivity in Kajiado. Geographical location of sheep and goat herds was a significant predictor with animals sampled from Lenkisem ward having a 64.0 times ($p< 0.0001$) likelihood of being seropositive when compared to animals sampled from Bisil ward. Herd size of goats in Kajiado was also a significant predictor, goats sampled from large herds consisting of more than 100 goats were more likely to be seropositive when compared to medium sized herds composed of between 51 to 100 animals (β-estimate = -2.19, O.R. = 0.112, p= 0.001). In addition, small ruminants herds in Kajiado that received regular doses of combined oral (Levamisole or Albendazole) and injectable (Ivermectin) anthelmintic products had a significantly ($p=0.001$) higher likelihood of being PPR seropositive when compared to animals receiving only oral Levamisole products (β-estimate = -1.623, O.R. = 0.197, $p=0.001$). Prevalence of intestinal parasites and age of animals in Kajiado were not significant predictors of PPR seropositivity.

Table 9: Multivariate logistic regression of risk factors significantly associated with PPR seropositivity in Kajiado

Risk factor Parameters	*Sero prevalence (%)*	*β estimate*	*Exp (B) Odds Ratio O.R*	*95% confidence Interval for Exp (B)*		*p-value*
				Lower	**Upper**	
Geographical location						
1. Kajiado Wards						
Meto	20	2.845	17.2	2.3	126.6	0.005*
Kumpa	60	3.490	32.8	5.4	196.7	<0.0001*
Oloimirmir	48.5	2.286	9.8	1.8	52.6	0.008*
Oldonyorok	14.3	1.576	4.8	0.7	32.5	0.105
Mailwa	45.2	3.296	27.0	5.7	127.8	<0.0001*
Lenkisem	58.1	4.158	64.0	12.2	334.6	<0.0001*
Bisil (Ref)	10.0					<0.0001*
Husbandry practices						
2.Herd size goat						
< 50 animals small	50.0	0.74	1.1	0.5	2.9	0.882
51- 100 animals medium	10.5	-2.191	0.1	0.03	0.39	0.001*
>51 animals large (Ref)	44.0					0.02*
3.Anthelmintic use						
Oral and injectable (Ref)	46.5					
Oral levamisole	30.9	-1.623	0.2	0.07	0.65	0.002*

*p≤0.05 was considered significant; Exp (B) = exponent B, representing the odds ratio

5.3.1.3 Factors associated with PPR seropositivity in Marsabit

In Marsabit almost all livestock owners except those from North Horr ward indicated that they had observed PPR clinical signs in their small ruminant herds. No *Oesophagostomum* nematode larvae was isolated from the pooled faecal culture hence this variables was not included in the analysis. Of the 17 risk factors investigated for association with PPR seropositivity, only 8 (Table 10) were significant ($p< 0.05$) on Chi-square test analysis. These were geographical location ward ($\chi^2 = 42.1$, $p<0.0001$), age of animal ($\chi^2 = 16.5$, $p<0.0001$), breed of animal ($\chi^2 = 17.3$. $p=0.002$), herd size of goats ($\chi^2 = 7.6$, $p=0.022$), herd size of sheep ($\chi^2 = 11.6$, $p=0.003$), use of anthelmintics ($\chi^2 = 22.5$, $p<0.0001$), previous PPR vaccination of animals ($\chi^2 = 103.4$, $p<0.0001$) and past PPR outbreak in herds ($\chi^2 = 47.1$, $p<0.0001$).

Geographical location of small ruminant herds was also significantly ($p< 0.0001$) associated with PPR seropositivity of animals in Marsabit, sheep and goat herds sampled from Loiyangalani ward had a 36.6 times ($p<0.0001$) likelihood of being PPR seropositive when compared to animals sampled from Dukana ward (Table 11). Animals sampled from herds that had reported past PPR outbreaks were 96.2 times ($p<0.0001$) more likely to be PPR seropositive when compared to those from herds that had not reported outbreaks. Further, Marsabit sheep and goat herds that had access to PPR vaccines had a 5.5 times ($p= 0.002$) probability of being seropositive when compared to herds that had no access to PPR vaccine. Age of animal was also significantly ($p<0.0001$) associated with PPR seropositivity in Marsabit, adult animals that were above 3 years of age were 11.9 times more likely to be seropositive when compared to young animals between 6 and 12 months of age (Table 11). Prevalence of intestinal parasites in Marsabit was not a significant predictor of PPR seropositivity.

Table 10: Relationship between categorical variable risk factors in Marsabit and PPR seropositivity using Chi-square (χ^2) test analysis

Risk factor Parameters	No. of animals sampled	No. animals Positive	Sero prevalence (%)	χ^2	df	p-value
Geographical location						
1. *Marsabit Wards*	**322**	**71**	**22.0**			
Kargi/South Horr	62	19	30.6			
Loiyangalani	28	18	64.3	42.1	4	**<0.0001***
Illeret	111	23	20.7			
North Horr	53	4	7.5			
Dukana	68	8	11.8			
Animal characteristics						
2. *Age*						
Adult	101	36	35.6	16.5	2	**<0.0001***
Juvenile	105	21	20.0			
Young	116	15	12.9			
3. *Species*						
Goat	179	45	25.1			
Sheep	143	27	18.9	1.8	1	0.114
4. *Breed*						
Small East African Goat (SEAG)	114	39	34.2			
Galla X SEAG Goat	19	3	18.9			
Galla	46	3	15.8	17.3	4	**0.002***
Black Head Persian X Horro Sheep	32	6	18.8			
Black Head Persian	111	21	6.5			
5. *Gender*						
Male	146	33	22.6	0.001	1	0.515
Female	176	39	22.2			
Husbandry practices						
6. *Herd size goat*						
< 50 animals small	16	8	50.0			
51- 100 animals medium	59	11	18.6	7.6	2	**0.022***
>51 animals large	247	53	21.5			
7. *Herd size sheep*						
< 50 animals small	46	19	41.3			
51- 100 animals medium	72	16	22.2	11.6	2	**0.003***
>51 animals large	204	37	18.1			

8. ***Dewormer use***						
Levamisole only	10	7	70.0			
Albendazole only	121	36	29.8	22.5	2	**<0.0001***
None used	191	29	15.2			
9. ***PPR Vaccine given***						
Yes<2years 2013	63	44	69.8			
Yes >3years	23	5	21.7	103.4	2	**<0.0001***
Never given	236	23	9.7			
Physiological Status						
10. ***Past PPR Incidence***						
Yes	202	70	34.7	47.1	1	**<0.0001***
No	120	2	1.7			
11 ***Body condition Score***						
1(emaciated)	71	16	22.5			
2 (Thin)	216	47	21.8			
3 (Optimum)	32	9	25.7	0.3	2	0.872
4(Fat)	0	0	0.0			
5 (Obese)	0	0	0.0			
12. FAMACHA/Anaemia score						
1 (optimum colour)	31	8	25.8			
2(Acceptable colour)	157	35	22.3			
3(Borderline anaemic)	110	23	20.9	3.8	4	0.430
4(Anaemic)	23	5	21.7			
5(Severely anaemic)	1	1	100.0			
13. Coccidia infection						
No infection	167	42	25.1			
Mild	74	14	18.9	1.8	3	0.612
Moderate	55	10	18.2			
High	26	6	23.1			

*Significance set at $p \leq 0.05$

Table 11: Relationship between continuous variables risk factors in Marsabit and PPR seropositivity using T-test analysis

Physiological status Risk parameter	*No. of animals*	*No. of animals positive*	*Positive animals Mean and SD (±)*	*t-value*	*df*	*p-value*	*95% Confidence interval of the difference in Means*	
							Lower	Upper
14. Packed cell volume percentage (PCV %)	322	71	24.9 ±4.5	-0.201	320	0.841	-1.33	1.08
15. Strongyle egg per faecal gram count	322	71	125.4 ±221.5	-0.496	320	0.621	-84.42	50.50
16. Haemonchus	322	71	4.1 ±4.7	1.093	320	0.275	-0.63	2.20
17. Trichostrongylus	322	71	1.8 ±1.3	1.82	320	0.070	-0.05	1.12

Table 12: Multivariate logistic regression of risk factors significantly associated with PPR seropositivity in Marsabit

Risk factor Parameters	Sero prevalence (%)	β estimate	Exp (B) Odds Ratio O.R	95% confidence Interval for Exp (B)		*p*-value
				Lower	Upper	
Geographical location 1. Marsabit Wards						
Dukana (Ref)	10.3					0.10*
Kargi/South Horr	30.6	0.880	2.4	0.6	9.7	0.217
Loiyangalani	64.3	3.599	36.6	4.6	289.5	0.001*
Illeret	20.7	1.157	3.2	1.0	10.0	0.049*
North Horr	7.5	0.698	2.0	0.5	8.5	0.344
Animal attributes						
2. Age						
Young< 1 year (Ref)	12.9					<0.0001*
Adult> 2 years	34.7	2.480	11.9	4.4	32.2	<0.0001*
3. Past PPR outbreak						
Yes	34.2	4.567	96.2	13.7	677.1	<0.0001*
4. PPR vaccine given						
Yes	57.0	1.697	5.5	1.9	15.6	0.002*

*p≤0.05 was considered significant; Exp (B) = exponent B, representing the odds ratio

5.4 Discussion

The overall post vaccination seroprevalence for PPR differed across the two study counties as well as within the counties at administrative ward levels. Kajiado which represented a high risk PPR area had a higher PPR seroprevalence when compared to Marsabit which is classified as an endemic area (GoK 2015a). This finding is similar to the post vaccination PPR seroprevalence survey carried out in 2009 by the director of veterinary services (DVS) (GoK 2009). In addition, based on questionnaire survey of small ruminant owners and chi-square analysis, the higher PPR seroprevalence in Kajiado was attributed to access to either government funded of privately funded PPR vaccines. This is also supported by a recent study carried out in Kajiado in 2013 that investigated factors influencing choice of veterinary service providers, the study found that 88% of livestock owners surveyed sourced for animal health services drug stockists (Onono et al., 2013), this may have been the reason in Kajiado where regular use of combined anthelmintic product was significant.

The PPR seroprevalence in Marsabit were in contrast to what was expected given that the area is PPR endemic and animals are constantly being challenged with PPR virus either through natural infection or vaccination. The seroprevalence was expected to be higher than what was observed in Kajiado. Furthermore, the low seroprevalence level of 22% was lower than the previous 33% reported after the 2009 PPR post vaccination serosurveillance (GoK 2009). However, the low trend was similar to that of 2009, where it was found that the PPR pre-vaccination seroprevalence was 44% compared to a 33% post vaccination seroprevalence. This may indicate that animals presented during the post vaccination survey may not have been the ones initially vaccinated (FAO-UN/OIE 2015). The current study findings reveal that post vaccination PPR seroprevalence trends in both Kajiado and Marsabit did not have a significant upward trend as expected (FAO-UN/OIE 2015).

Given that vaccination activities were to continue for another 3 years after 2009 (GoK 2008) it is likely that this was not sustained after 2009. This may have been due to the political setting of the country after 2009 (GoK 2014). In 2010, the new constitution devolved veterinary services to counties (GoK 2014) and since the funding set aside in 2008 was from the national government it is likely that county governments no longer had access to the PPR vaccination campaign funds (GoK 2014) and this may have resulted in the collapse of the PPR vaccination campaigns that begun in 2008 and were projected to end in 2012 (GoK 2008; GoK 2009). The PPR global control strategy launched in April 2015, indicates that a sustained annual PPR vaccination in endemic and high risk areas should achieve a herd post vaccination seroprevalence of 70% in 3 years (FAO-UN/OIE 2015). This level of herd immunity if attained has been shown to break the PPR virus transmission cycle in endemic areas resulting in significant reduction of clinical PPR cases (FAO-UN/OIE 2015). This fact is further supported by a recent research carried out in Kenya.

The study used participatory, serosurveillance and statistical modelling techniques and found that vaccinating 50% of the small ruminant population was effective in significantly reducing PPR outbreaks in Turkana county (Kihu et al., 2015a). Turkana county is also classified as a PPR endemic zone and was the first entry point for the disease into Kenya in 2006 (Nyamweya et al., 2010; Kihu et al., 2012). The PPR global strategy indicates that post vaccination serosurveillance can be used to assess the effectiveness or access of livestock keepers to veterinary services (FAO-UN/OIE 2015). Based on this suggestion, it can therefore be assumed that in this study, Kajiado livestock keepers had a better access to veterinary services as their small ruminant herds had on average higher levels of PPR seroprevalence when compared to Marsabit herds.

The goat herd size maintained in Kajiado significantly had an effect on PPR seropositivity with animals sampled from herds classified as large with more than 100 animals having a significantly higher PPR seroprevalence when compared to small and medium herds with less than 100 and 50 animals respectively. This fact may be an indicator of the socio-economic status of the small ruminant owners in Kajiado (Onono et al., 2013). Pastoralists' communities store their wealth in form of livestock assets and large herd sizes are linked to wealthy owners (Fratkin 2001). It is therefore plausible that small ruminant owners with large goat herds in Kajiado were able to invest in PPR vaccines. In addition, large herds have the benefit of economies of scale due to bulk purchase of animal health inputs and veterinary services (Onono et al., 2013), and this may have further motivated livestock owners in Kajiado county to invest in PPR vaccines.

Age of animal was a another significant predictor of PPR seropositivity in Marsabit with young animals that were between 6 and 12 months of age having a lower PPR seroprevalence when compared to adult animals. This findings concurs with most studies done in similar pastoral settings, in Sudan (Salih et al., 2014) and in Kenya (Kihu et al., 2015b), in both these studies young animals under 1 year of age were at highest risk for PPR infections. Small ruminants have a higher reproductive rate when compared to large ruminants and under normal conditions when there is no drought, lambing or kidding can occur at least three times in 2 years (FAO-UN 2013). Dams that have had prior exposure to PPR virus either through infection or vaccination pass antibodies to their young animals through the colostrum, however this protection wanes off after 6 months making this age group the most vulnerable especially in endemic areas like Marsabit where the PPR virus is always in circulation (Elsawalhy et al., 2010; FAO-UN/OIE 2015).

PPR is a relatively new disease in pastoral systems of Kenya and is often confused with other diseases presenting with pneumonia and diarrhoea clinical signs such as CCPP and helminthiasis respectively (Gitao et al., 2014). Although co-infecting parasite prevalence were not a significant risk factors for PPR seropositivity in the current study. In Kajiado, Meto ward had a high average strongyle egg count of 1800 and one of the lowest PPR seroprevalence levels of 20%. Furthermore, all small ruminant owners in Meto ward indicated that they had experienced past PPR outbreaks but it is likely the increased PPR reporting was due to deaths and diarrhoea caused by heavy *Haemonchus* helminth infections (Gatongi et al., 1998; Gicheha et al., 2005) rather than actual PPR cases.

Infection with intestinal parasites causes alteration in the clinical manifestation of important livestock diseases Thumbi and colleagues (2014), the study was carried out in Western Kenya where it investigated indigenous calves disease and mortality incidences from birth to one year. This longitudinal study found that calves that had an increase of 1000 strongyle eggs had a 1.5 times likelihood of death if they also became infected with East Coast Fever, which is a disease which is caused by a blood- borne protozoan parasite (Thumbi et al., 2014). The association of intestinal parasitic infection with PPR seropositivity could not be proved and this may have been due to the study design. Intestinal parasites infections with *Haemonchus* and protozoan parasites such as coccidia or other blood borne parasites like *Babesia* and *Anasplama* could cause immune deficiencies that increase susceptibility to PPR virus as well as to other important small ruminant diseases (Gicheha et al., 2005; Fenton 2013; Gustafson et al., 2015) The prevalence of intestinal parasites in the current study was low for both helminth and coccidia parasites in Marsabit. This was contrary to previous studies (Gatongi et al., 1998; Maichomo et al., 2004; Gicheha et al., 2005). The low prevalence in Marsabit was attributed to the season samples were collected.

The collection of samples during the dry season meant that environmental conditions did not support the development of parasites passed into the environment (Gatongi et al., 1998; Maichomo et al., 2004). In addition, previous studies have shown that helminths especially *Haemonchus* species have a high rate of hypobiosis as well as reduced egg production by during the dry season. (Gatongi et al., 1998). However, the findings in Kajiado where faecal samples were collected one month after the rainy season indicate that helminthiasis is still an important disease in small ruminant production pastoral systems in Kenya (Onono et al., 2013; Gitao et al., 2014). Waruiru and colleagues (1997) found that the most common gastrointestinal helminth species of sheep and goats in Kenya were *Haemonchus contortus*, *Strongyloides papillosus*, *Trichostrongylus columbriforms*, *Oesophagostonum columbianum*, *Fasciola* and *Moniezia* cestode species, the current study largely agrees with these findings.

5.4.1 Conclusions and Recommendations

In conclusion the study found that;

1. PPR seroprevalence in the study herds was lower than the recommended 70% that prevents PPR virus circulation in endemic and high risk areas. This means that majority of Kajiado and Marsabit small ruminant herds were susceptible to future PPR outbreaks.
2. Post-vaccination serosurveillance was found to be an important tool that can be used to monitor the effectiveness and coverage of existing vaccination control programmes.
3. The 5 risk factors significantly associated with PPR seropositivity in the study were (i) age of animal (ii) geographical location of herds that determined accessibility to veterinary services (iii) goat herd size that determined livestock owners willingness to invest in PPR preventive vaccines (iv) past PPR outbreak incidence and (5) PPR vaccination status that ensured animals immunity against the PPR virus.

4. The significant correlations between packed cell volume, FAMACHA© score as well as strongyle egg count means that in the absence of laboratory services as is often the case in pastoral systems of Kenya, the FAMACHA© score chart can be used to determine the helminth burden especially for *Haemonchus* nematode specie.

Given that Marsabit county is listed as an endemic PPR zone, the findings from this study indicate that vaccination control strategies had a low coverage of the population. The study recommends that national and county government focus PPR vaccination resources and activities to PPR endemic zones like Marsabit. This support will be able to achieve a herd PPR seroprevalence of 70% that has been shown to stop PPR virus circulation resulting in a dramatic reduction of clinical PPR cases. This will in turn result in less cases spilling to high risk area like Kajiado as well as a more efficient use of the already scarce small ruminant disease control resources (FAO-UN/OIE 2015). In addition, PPR vaccination campaigns should target young animals under 1 year and focus in areas with limited access to veterinary services such as herds in satellite settlements that often have larger small ruminant populations.

5.4.2 Future research areas

The current study found a significant positive correlation between strongyle egg count and FAMACHA® score. Future studies using longitudinal study designs should determine the applicability of FAMACHA® score as a biological indicator for susceptibility to important small ruminant diseases like PPR. Research should also continue on the development of vaccines or diagnostic tests that can differentiate PPR seropositivity due to vaccination or natural infection (DIVA). This will greatly enhance the tracking of vaccinated animals in pastoral systems of Kenya.

Chapter 6

6.0 Risk mapping as a tool for designing *Peste des petits ruminants* control strategies in pastoral systems of Kajiado and Marsabit Counties in Kenya

Abstract

Geographical information system (GIS) is an important epidemiological tool that can be used to evaluate the effectiveness of livestock disease surveillance and control programmes. GIS uses computer based sets of procedures to combine mapping technology and database management. The major strengths of a GIS are its overlay and data base management capabilities. Information from different data bases are stored in separate layers representing different map themes. The utility of GIS in Kenya has only been applied to the surveillance and management of livestock diseases such as Trypanosomiasis or Rift Valley Fever that have an intervening vector agent that relies on environmental variables for their transmission. A cross-sectional sero-surveillance study was therefore carried out to determine the applicability of GIS in PPR disease management. The main aim of the study was to apply GIS spatial analysis function to map PPR risk factors so as to determine their interactive effects on PPR control strategies in Kajiado and Marsabit counties of Kenya. GIS functional tools of directional distribution, overlay and Boolean geometric analysis were used to identify the risk factors interactions. The study also investigated the effectiveness of veterinary service delivery in the study areas through Euclidean straight line distance calculation and Voronoi polygon development. A digital elevation model raster file was also used to determine the role of terrain in veterinary service delivery. The spatial analysis revealed that PPR seroprevalence in Kajiado and Marsabit was determined by access to veterinary services with areas closer to veterinary services having a higher PPR seroprevalence, however, other factors such as terrain of area, distance to be covered, small ruminant population and disease control policies hindered the effective coverage of the small ruminant population during PPR vaccination

campaigns. GIS spatial analysis techniques were therefore found as useful tools that can support decision making when planning, implementing and monitoring PPR control strategies in pastoral areas. The study findings therefore indicate that use of GIS at county and national levels will increase the efficiency of veterinary services as it will improve data capture, storage, predictive analysis and communication.
Key words: GIS; Spatial analysis; Surveillance

6.1 Introduction

Livestock disease prevention and control programmes whether funded by the government or with private resources must be planned and implemented in proportion to the level of disease risk (Prattley 2009; Dharma et al., 2013). Geographical information system (GIS) is an important epidemiological tool that can be used to target livestock diseases surveillance and control programmes (Davis et al., 2014). GIS uses computer based sets of procedures to combine mapping technology and database management (Sanson et al., 1991). GIS is defined as a computer based system that is used to collect, store, integrate, analyse and display geo-referenced data sets (Norstrom 2001; Pfeiffer et al., 2008). The major strength of a GIS lies in its overlay capability (Sanson et al., 1991). Information from different data bases are stored in separate layers representing different map themes. Layers can be used to create composite maps by overlapping the layers, this feature allows the user to identify risk factors that may explain the spatial and temporal distribution of diseases such as climatic conditions and demographic characteristics (McKenzie 1999; Koch 2005; Pfeiffer et al., 2008). Each layer feature in a GIS has an attribute table linked to it. The attribute table is joined to its geographical connection layer through a common identifier (ID). This ID can be the name of farm or region (Pfeiffer et al., 2008; Dharma et al., 2013).

The first step in any disease outbreak investigation is to map its spatial distribution so as to be able to appreciate patterns present and generate hypothesis about factors that might influence the observed pattern (Koch 2005; Davis et al., 2014). Disease mapping also aids in communicating findings to a wider audience who may not have the technical background to understand scientific terms and figures that indicate disease burden and impact (Koch 2005; Christopher and Marusic 2013). Communicating in a simpler manner means that decisions can be made faster by non-technical policy makers (FAO-UN 2011; Dharma et al., 2013). However, in Kenya GIS use as a decision support tool is limited to mapping disease outbreak locations (GoK 2009; GoK 2015) and predicting incidences of vector-borne diseases such as Rift valley fever (Kasiti et al., 2014). There is limited literature on application of GIS techniques in the management of infectious livestock diseases that do not have an intervening vector agent (Dharma et al., 2013; FAO-UN/OIE 2015).

A cross-sectional sero-surveillance study was therefore carried out to determine the applicability of GIS in PPR disease management. The main aim of the study was to apply GIS spatial analysis tools to map PPR risk factors so as to determine their interactive effects on PPR control strategies in Kajiado and Marsabit counties of Kenya. PPR is a highly infectious viral disease of sheep and goats that does not require an intervening vector for its transmission (OIE 2013). The virus is secreted in ocular and nasal discharges as well as in secretions from coughing and faeces of infected animals (Kumar et al., 2014). Close contact between animals, especially through inhalation of fine droplets, which are released when animals cough and sneeze is the main transmission route (OIE 2013). Since its introduction into Kenya in 2006, control strategies that begun in 2008 have failed to control the disease and it is estimated that the government incurs a cost of 1 billion Kenya shillings due to vaccination expenditure as well as due to revenue forgone during trade bans (GoK 2008; Kihu et al., 2015b).

6.2 Methods

6.2.1 Study area and design

A cross-sectional sero-surveillance study was carried between January 2014 and March 2015 in Kajiado and Marsabit counties of Kenya. The selection of study sites was purposive based on whether the county was classified as a PPR high risk or endemic area (GoK 2008). Kajiado is a semi-arid county located in the Southern part of Kenya it lies between longitudes 36º 5' and 37º 5' East and Latitudes 1º 0' and 3º 0' South (Kajiado-CIDP 2013). Kajiado is classified as a high risk PPR area with the last PPR outbreaks reported in 2010 in an area called Namanga, located close to the Kenya-Tanzanian border (GoK 2009). The predominant inhabitants of Kajiado are the Maasai community, who are the second largest group of pastoralists in Kenya after the Somali (Bekure et al., 1991). Marsabit county is classified as an arid area county located at the upper Eastern region of Northern Kenya. It is the second largest county in Kenya after Turkana and lies between latitudes 02°45' and 04° 27' North and longitudes 37° 57'and 39°21' East (Marsabit-CIDP 2013). Marsabit inhabitants comprise of a diverse mix of pastoral, agro-pastoral and fishing communities (Schwartz et al., 1991; Kaufmann 2012). Marsabit is classified as a PPR endemic area with reports indicating that PPR occurs in the southern parts of the county as well as in areas located near the Ethiopian-Kenya border in Northern parts of Marsabit (GoK 2009; NDMA 2012-2015). The sampling unit was the individual animal of a specified age group belonging to a homestead herd purposely selected on the basis of previous PPR outbreaks. The number of animals to be sampled in each county was determined using the formula for sample size calculations for field epidemiological surveys by Dohoo et al. (2010), ($n = Z^2 [p (1-p)/L^2]$) Where n = sample size, Z = 95% confidence level (Standard value of 1.96), P = prevalence of PPR 30% (0.3) based on seroprevalence study in the region (Muse et al., 2012; Kihu et al., 2015b) and L is the precision of sample size estimate and is normally set at 5% (0.05). Based on these input

parameters, the calculated sample size was 323 animals in each study area were targeted for sampling. However, due to logistical challenges only 213 animals from Kajiado and 322 from Marsabit were sampled from 63 sheep and goat herds, 35 herds in Kajiado and 28 in Marsabit.

6.2.2 Data collection and laboratory analysis

Geographical coordinates of each sampled herds was recorded using a hand held Global Positioning System (GPS) unit. A laboratory form was filled for each animal to accompany the blood and faecal samples collected. The form contained information regarding demographic characteristic of the animal that is age, sex and breed; PPR vaccination status (vaccinated or not); Previous incidence of PPR disease outbreak in herd and PPR disease control and preventive measures in place. A random selection of 12 animals was done based on animal's specie, age and gender (Luka et al. 2011; Muse et al., 2011; Kihu et al., 2015b). Serum PPR antibody levels was determined using the competitive Enzyme Linked Immunosorbent Assay (c-ELISA) kit based on a method described by Libeau and colleagues (1995), samples with percentage inhibition (PI) of over 50 % (cut-off) were considered positives for PPRV antibodies. Packed Cell Volume (PCV) determination was done in the field using routine techniques (Weiss and Wardrop 2010). Faecal samples were also analysed in a laboratory using routine quantitative diagnostic tests (Zajac and Conboy 2012).

6.2.3 Data analysis

6.2.3.1 Statistical analysis

Laboratory results and homestead head information captured in the laboratory forms concerning PPR knowledge, control practices and risk factors were coded into appropriate variables, entered and analysed using Statistical Package for Social Sciences (SPSS) version 16.0 (SPSS Inc., Chicago, Illinois). Descriptive and multivariate regression analysis was done to identify risk factors associated with PPR antibody seropositivity in Kajiado and Marsabit

counties. GIS analysis was done using ArcGIS Desktop version 10.1 (ESRI Corporation, Redland, USA).

6.2.3.2 Data processing and GIS analysis

6.2.3.3 Data processing

Geographical coordinates of each sampled herds and location of each government veterinary office was recorded using a hand held Global Positioning System (GPS) unit (Pfeiffer et al., 2008). The coordinates were then inputted as separate fields titled 'latitude', 'longitude' and 'elevation' in the SPSS spread sheet that had animal demographic and laboratory results information entries. GIS spatial analysis was carried out at administrative ward level as the variation between households within the wards were minimal to indicate on a map a spatial change (Koch 2005) the spread sheet was then saved as a comma separated value (csv) file titled PPR_risk

6.2.3.4 Source of base maps for GIS analysis

1. Administrative units of Kenya were included as polygon vector based shape files sourced from an open source website http://www.gadm.org/country with the following projection Geographic Coordinate System: GCS_WGS_1984; Datum: D_WGS_1984; Prime Meridian: Greenwich; Angular Unit: The shape file was then clipped to create a new shape file polygons of Marsabit and Kajiado counties with administrative boundaries up to location/village level (Ortiz-Pelaez et al., 2010).
2. Marsabit permanent water areas were sourced from the following open source website; http://www.marsabitwater.com/download.php and were included as point vector data that were transformed to shape files (Leta and Mesele 2014).
3. Digital Elevation Model (DEM) was a raster surface sourced for free from the United States Geological Survey (USGS) data distribution portal. Data images were captured

using the Shutter Radar Topographic Mission (SRTM) Satellite at 30 meter resolution (Pfeiffer et al., 2008; De Smith and Longley 2015.

4. The SPSS spreadsheet saved as a csv file titled PPR_risk was imported into ArcGIS using the add data icon with similar geographic coordinate projections to those of the administrative county polygons. The new shape file created had the locations of herds sampled as point features and an attribute table containing the animal demographic and laboratory results data (PPR seroprevalence, PCV% and strongyle egg count). The PPR_risk layer was then overlaid over the county administrative polygons so as to ensure the study sites were projected correctly Ortiz-Pelaez et al., 2010; Leta and Mesele 2014).
5. Past PPR outbreak reports with specific locations were not available at the Director of Veterinary Services (DVS) offices as well as in the respective study county veterinary offices. Where available at DVS offices, the reports lacked clarity if the PPR seroprevalence results were due to vaccination or disease (GoK 2009; GoK 2015a). However, unofficial reports of PPR disease incidence were available only for Marsabit these were sourced from drought early warning monthly bulletins posted in the website of the National Drought Monitoring Authority (NDMA). The outbreak information location was in form of administrative location names. A new shape file was created using the Marsabit polygon shape file by clipping out the locations where the drought early warning bulletins reported PPR incidences (Ortiz-Pelaez et al., 2010; Leta and Mesele 2014; De Smith et al., 2015).

6.2.3.5 Past PPR outbreak trend using GIS Directional Distribution (Standard Deviational Ellipse) tool

The directional distribution (Standard Deviational Ellipse) is a spatial statistic measuring tool in GIS that determines the trend for a set of points or areas by calculating the standard

distance of the x- and y- coordinates (ESRI 1995-2010a). The ellipse is known as the standard deviational ellipse since the method calculates the standard deviation of the x-coordinates and y-coordinates from the mean centre to define the axis of the ellipse. The compactness of the ellipse demonstrates that there is a greater directional trend (ESRI 1995-2010a). All mathematical computations were based on the output coordinate reference of Marsabit county administrative base layer polygon. Calculations were based on Euclidean distance. The standard deviational ellipse tool created a new feature class containing elliptical polygons, one for each year of PPR outbreak report in Marsabit (ESRI 1995-2010a). In this study, the distribution tool was used to determine the directional trends of past PPR outbreaks from the time period March 2008 to April 2014.

6.2.3.6 Risk mapping using GIS Overlay tool sets, colour graduated symbols and Boolean algebra condition

Overlay analysis tool in a GIS answers basic questions such as "What's on top of what?" For example: What land use is on top of what soil type? What disease incidence areas are on top of which administrative unit? (Sanson et al., 1991) Before GIS technology cartographers would create maps on clear plastic sheets and overlay these sheets on a light table to create a new map of the overlaid data. Overlay analysis approach is often used to find populations or locations that are susceptible to a particular risk (Koch 2005; Cecchi et al., 2010; Noremark and Widgren 2014). In this study, past PPR outbreak risk maps showing permanent watering areas as a risk factor for PPR was developed by overlaying the Past_outbreak shape file layer with the shape file of permanent water points in Marsabit (ESRI 1995-2010d). The colour graduated symbols tab was used to develop the study wards PPR seroprevalence choropleth maps (ESRI 1995-2010b). The PPR seroprevalence values were in percentages and were derived from calculating how many animals were positive on PPR c-ELISA over all the animals sampled at ward level.

The PPR seroprevalence percentage were grouped into classes and each class identified by a particular colour using the symbology tab, the colour ramp was then selected. The natural break category was reclassified based on the percentage distribution of cut off points from the study data (ESRI 1995-2010d). The output was a Kajiado and Marsabit Ward seroprevalence choropleth map layer that was saved. Boolean geometric conditions are an algebra formula developed by a mathematician and logician George Boole (1815 – 1864) (Pfeiffer et al., 2008). Boolean algebra is a binary logical operation that forms a mathematical structure that is based upon the values 1 (true) and 0 (false). In addition, Boolean algebra provides different links that can be "true" or "false" but never both (Pfeiffer et al., 2008) The Boolean operators that are used in GIS for linking two spatial selection criteria are AND, OR, OR, and NOT (ESRI 1995-2010e). Risk maps of animals at risk for PPR virus due to intestinal parasitism and low PPR seroprevalence levels were generated based on the Boolean query of animals that were anaemic FAMACHA® score 4 and 5, had a PPR seroprevalence of less than 30% and had coccidia infections level that were high or moderate with an e.p.g strongyle egg count of 500 for Marsabit and > 1500 for Kajiado. The Boolean algebra query used was:

(Fama_score" = ‘4’ OR "Fama_score" = '5' AND "HH_PPR_prevalence_percentage" < '30' AND "Coccidiacsyst_presence" = 'Moderate_infestaion' OR "Coccidiacsyst_presence" = 'High infestation' AND "epgstrongyle_number" > '500'AND "HH_Haemonchus" > '0')

The query output which was a new feature layer was then overlaid on the PPR seroprevalence base layer map for Marsabit and Kajiado generated earlier (Koch 2005).

6.2.3.7 Assessing effectiveness of veterinary services using GIS Proximity tool set

The Proximity toolset contains tools that are used to determine the proximity of features within one or more feature classes or between two feature classes. These tools can identify infected farms features that are closest to one another or calculate the distances between or around them (Premasthira 2012; Olabode et al., 2014). The GIS proximity tool was used to

calculate the Euclidean distance also known as aerial or crow-fly approximate straight line distance. The proximity tool has been used to measure the accessibility of human health care facilities. The tool incorporates travel time and distance thresholds thus indicating how accessible existing health centres are in meeting the service demand of the target population around them (Schuurman et al., 2006; Davis et al., 2012). The Voronoi polygon also known as Thiessen polygon is based on mathematics and computational geometry that must satisfy the criteria for Delaunay triangles. Delaunay criteria states that all locations within an area are closer to the object it surrounds than to any other object in the set (De Smith and Longley 2015). Voronoi polygons are often used to delineate areas of influence around geographic features. Voronoi polygons are named after the Ukrainian mathematician Georgy Fedoseevich Voronoi (1868-1908). Delaunay triangles cannot exist alone; they must exist as part of a set or collection that is typically referred to as a triangulated irregular network (TIN) (ESRI 1995-2010c; De Smith and Longley 2015).

Effectiveness of veterinary services delivery in the study areas was analysed using the proximity tool set of ArcGIS. The study used the Euclidean distance proximity tool to allocate sampled herds to a specific veterinary office by calculating a straight line distance from the veterinary office to a specific sampled herds based on a cut off distance of 100 kilometres (kms) (Premasthira 2012). The 100 kms cut off distance was based on the available mode of transport which was a motorbike in both Marsabit and Kajiado. The motorbike engine size was capable of covering 100 kilometres one way. The Euclidean distance tool was also used to develop Voronoi polygons which divided the study area into cells that were then allocated to the nearest input feature which was the existing or proposed veterinary office. (Ortiz-Pelaez et al., 2010; Noremark and Widgren 2014). The straight line distance calculation maps were overlaid on the Digital Elevation Model (DEM) raster layer. The DEM shape files were

sourced for free from the United States Geological Survey (USGS) data distribution portal. Data images were captured using the Shutter Radar Topographic Mission (SRTM) Satellite at 30 meter resolution (ESRI 1995-2010d). PPR vaccination planning maps were created using information from the attribute table of a new layer/shape file created from the livestock 2009 census data (Kenya National Bureau of Statistics (KNBS). The census data was in form of an excel spreadsheet that contained administrative ward names of Marsabit as well as the small ruminant population numbers in each ward. The spreadsheet was saved as a csv file and using the unique identifier that is ward name, the small ruminant population information was projected using ArcGIS as a choropleth map (Ortiz-Pelaez et al., 2010; Leta and Mesele 2014).

To get the target number of animals to vaccinate in each ward in the Southern part of Marsabit. A new field was created in the census data layer attribute table. A mathematical formula was used to get how many animals needed to be vaccinated in each ward by multiplying the total small ruminant population at ward level with 70 and dividing the number by 100 (ESRI 1995-2010e). This was based on the target set in the global PPR control strategy, which states that if 70% of the population in an endemic area is vaccinated then PPR virus circulation can be stopped (FAO-UN/OIE 2015). The other attribute table field query was how many days it would take to vaccinate these target animals given at any one time the vaccination activity has 5 trained animal health personnel who together vaccinated a total of 5000 small ruminants in a day (Personal communication from the veterinarians based in Laisamis government office). The target population figure was divided by 5000 to get how many vaccination days. Vonoroi polygons previously created were then overlaid on the vaccination day's choropleth map so as to delineate the veterinary service area of operation (ESRI 1995-2010d).

6.3 Results

6.3.1 Statistical analysis results

A total of 535 serum were randomly collected from 290 goats and 245 sheep of various age groups from 63 herds in Kajiado and Marsabit. The overall PPR seroprevalence in Kajiado was 37.1% (79/213) while in Marsabit it was 22.4% (72/322). Risk factors that were associated with PPR post vaccination seropositivity were heterogeneous across Kajiado and Marsabit and included geographical location of animal, age of animal and previous PPR virus exposure through vaccination or natural infection. PPR seroprevalence was largely due to access of PPR vaccines (79/213) in Kajiado and previous PPR outbreaks (70/322) in Marsabit. The average prevalence of intestinal parasites in Kajiado small ruminant herds was 54.5% (95% CI: 47.9 -61.0) for coccidia parasite and 82.2% (95% CI: 77.0 – 86.9) for helminth parasites.

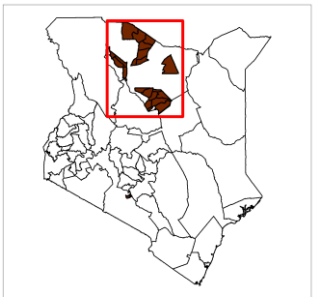
In Marsabit, the average prevalence of intestinal parasites was 48% (95% CI 42.2- 54.0) for coccidia and 30.7% (95% CI: 25.8 – 36.0) for helminths. *Haemonchus* nematode specie was the most common larvae identified after faecal culture. Co-infection prevalence for both helminth and coccidia intestinal parasite was 51.2% (95% CI: 44.6 -57.7) for Kajiado herds and 21.7% (95% CI: 17.1 -26.4) for Marsabit herds. Prevalence of helminth and coccidia parasites was not a significant risk factor for PPR seroprevalence. However, in Kajiado the 82.2% helminth prevalence was associated with the confusion of diarrhoea clinical signs with those of PPR clinical signs. Correlation analysis revealed a significant ($p<0.0001$) negative correlation between packed cell volume and FAMACHA® score. Furthermore, a positive correlation was obtained for strongyle egg count and FAMACHA® score. Indicating that the FAMACHA® score chart could be used to indicate the level of anaemia due to nematode helminth infestation in animals. Kajiado. Kajiado (68.6%) and Marsabit (82.1%) HH,

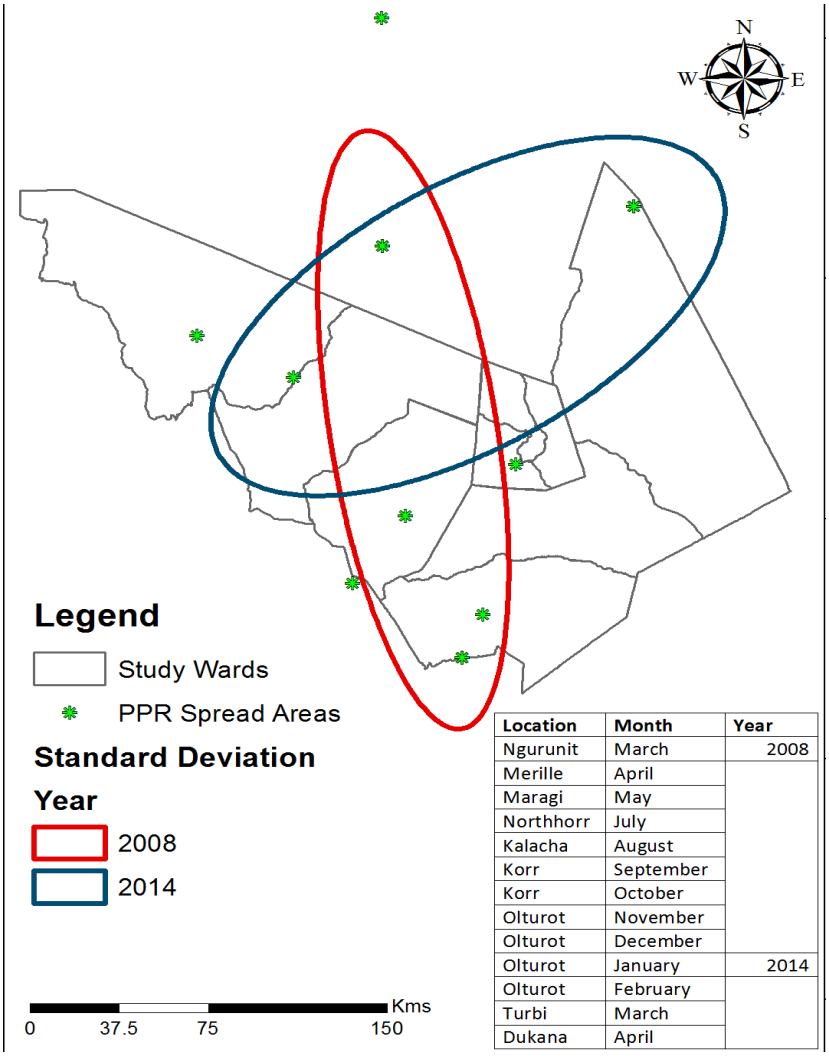
indicated that the greatest risk to PPR introduction into herds was the mixing of herds in watering areas. The main policy interventions recommended by majority of Kajiado (90.5%) and Marsabit (84.5%) livestock owners was the provision of regular and timely veterinary services. Veterinary services was defined by the livestock owners as the provision of free vaccination services, extension services and rapid response during disease outbreaks.

6.3.2 GIS analysis results

6.3.2.1 Directional trends of past PPR outbreaks

The standard deviational ellipse compactness demonstrated that there was a greater directional spread in the 2008 PPR outbreak than in the 2014 PPR outbreak (Figure 11). Based on the ellipse direction trend, the 2008 PPR outbreak had a directional trend from the South-west to the North-west while the 2014 outbreak moved from the South-west to North-east.





Location	Month	Year
Ngurunit	March	2008
Merille	April	
Maragi	May	
Northhorr	July	
Kalacha	August	
Korr	September	
Korr	October	
Olturot	November	
Olturot	December	
Olturot	January	2014
Olturot	February	
Turbi	March	
Dukana	April	

Figure 11: Standard deviational ellipse map demonstrating the compactness and directional trends of past PPR outbreak in Marsabit March 2008- April 2014.

6.3.2.2 Past PPR outbreak risk map

There were 13 PPR outbreaks reported in the drought early warning bulletins from the time period March 2008 to April 2014. The risk map below demonstrates that these outbreaks were close to points classified as permanent water sources. Overlaying past PPR outbreaks from the HH information indicated more areas that experienced PPR outbreaks but were not reported in the drought early warning bulletins (Figure 12).

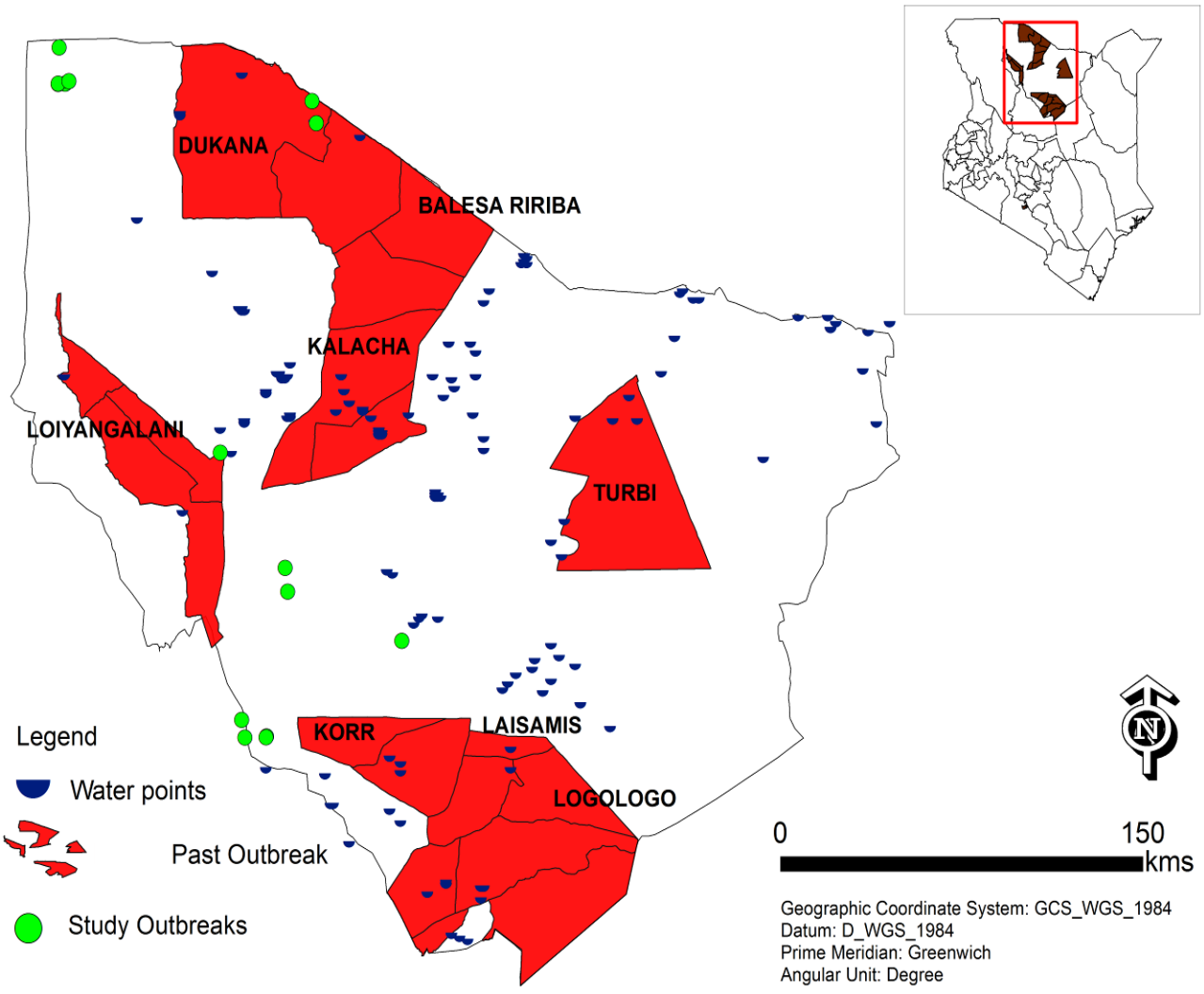


Figure 12: Map showing past PPR outbreaks with relation to permanent watering points in Marsabit County, Kenya (March 2008 – March 2015).

6.3.2.3 PPR seroprevalence choropleth maps of study areas

The maps demonstrate that Lenkisem ward in Kajiado and Loiyangalani ward in Marsabit had animals that had over 50% PPR seroprevalence (Figure 13). This was higher than the overall aggregated statistically computed means reported for Kajiado (37%) and Marsabit (22%) Counties.

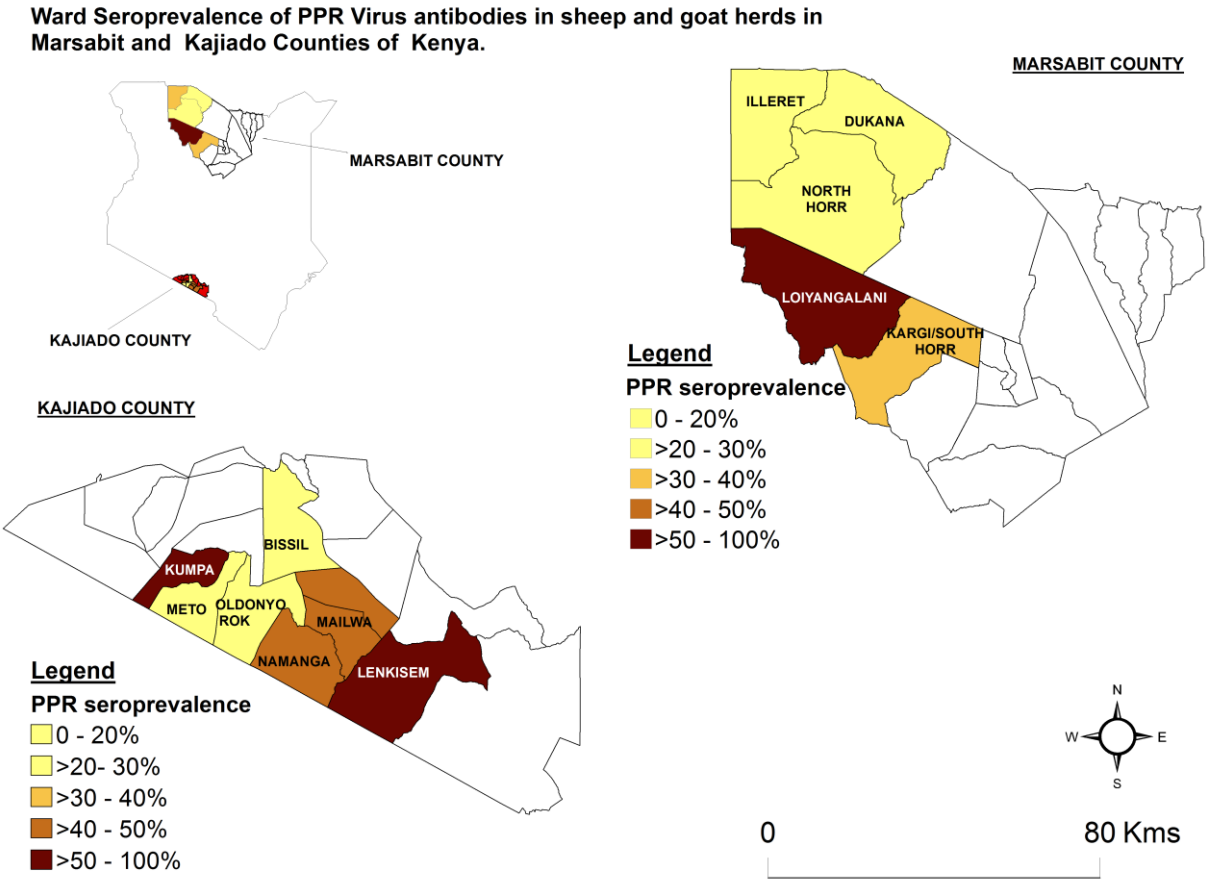


Figure 13 PPR seroprevalence levels across the administrative unit Wards in Kajiado and Marsabit (January 2014 – March 2015).

6.3.2.4 Risk mapping by attributes

Risk mapping by Boolean query revealed animals in study herds that were had may be at risk to PPR virus due to intestinal parasitism and low PPR seroprevalence levels. Risk criteria was defined as animals with FAMACHA® score of 4 or 5, PPR seroprevalence of less than 30%

presence of moderate or high oocysts as well as strongyle egg count of above 500 in Marsabit and above 1500 in Kajiado. The wards that had the highest number of herds at risk based on the set criteria were located in Illeret in Marsabit (Figure 14) and Meto in Kajiado (Figure 15).

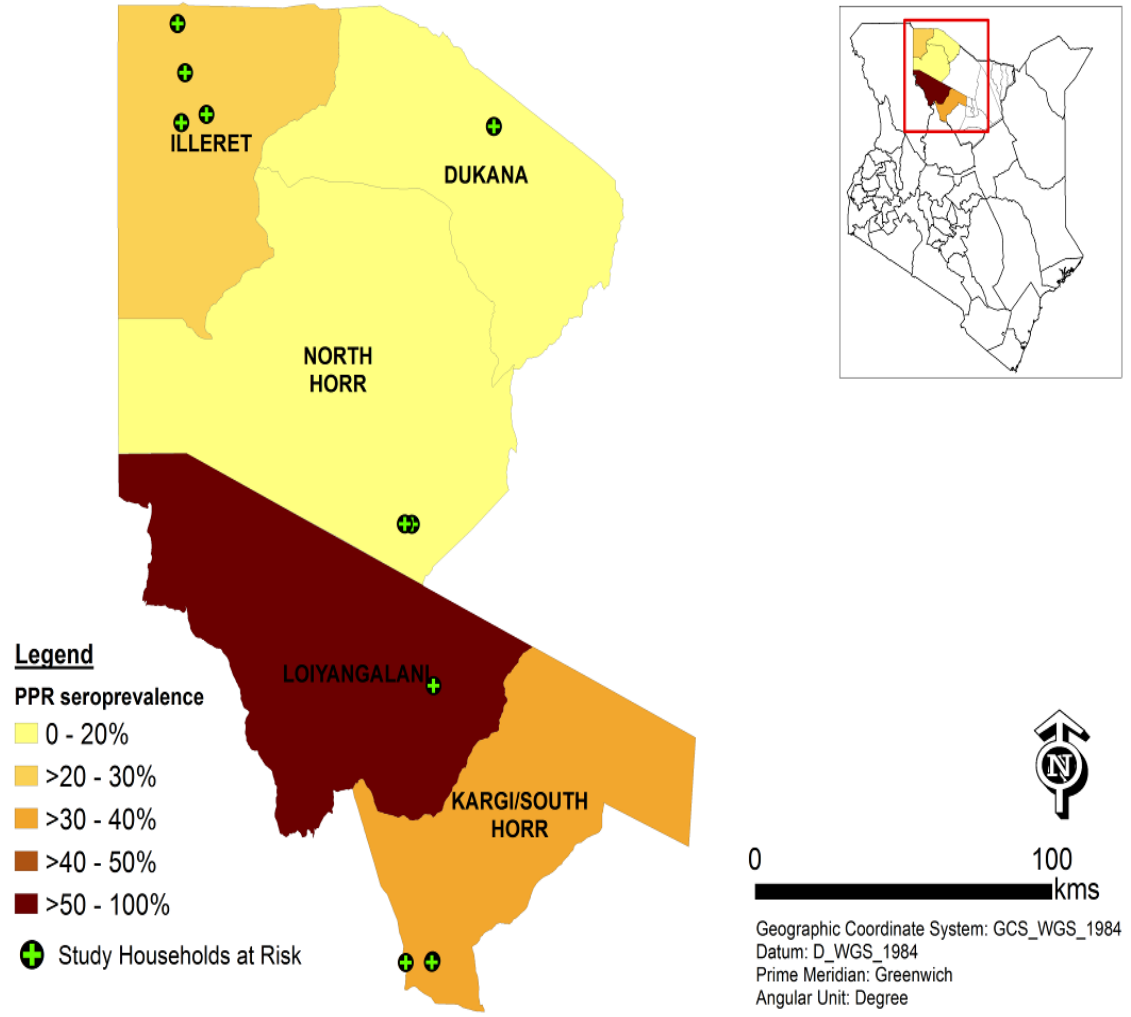


Figure 14: Risk map showing location of study herds in Marsabit at risk of PPR virus infection due to physiological stress (August 2014- March 2015)

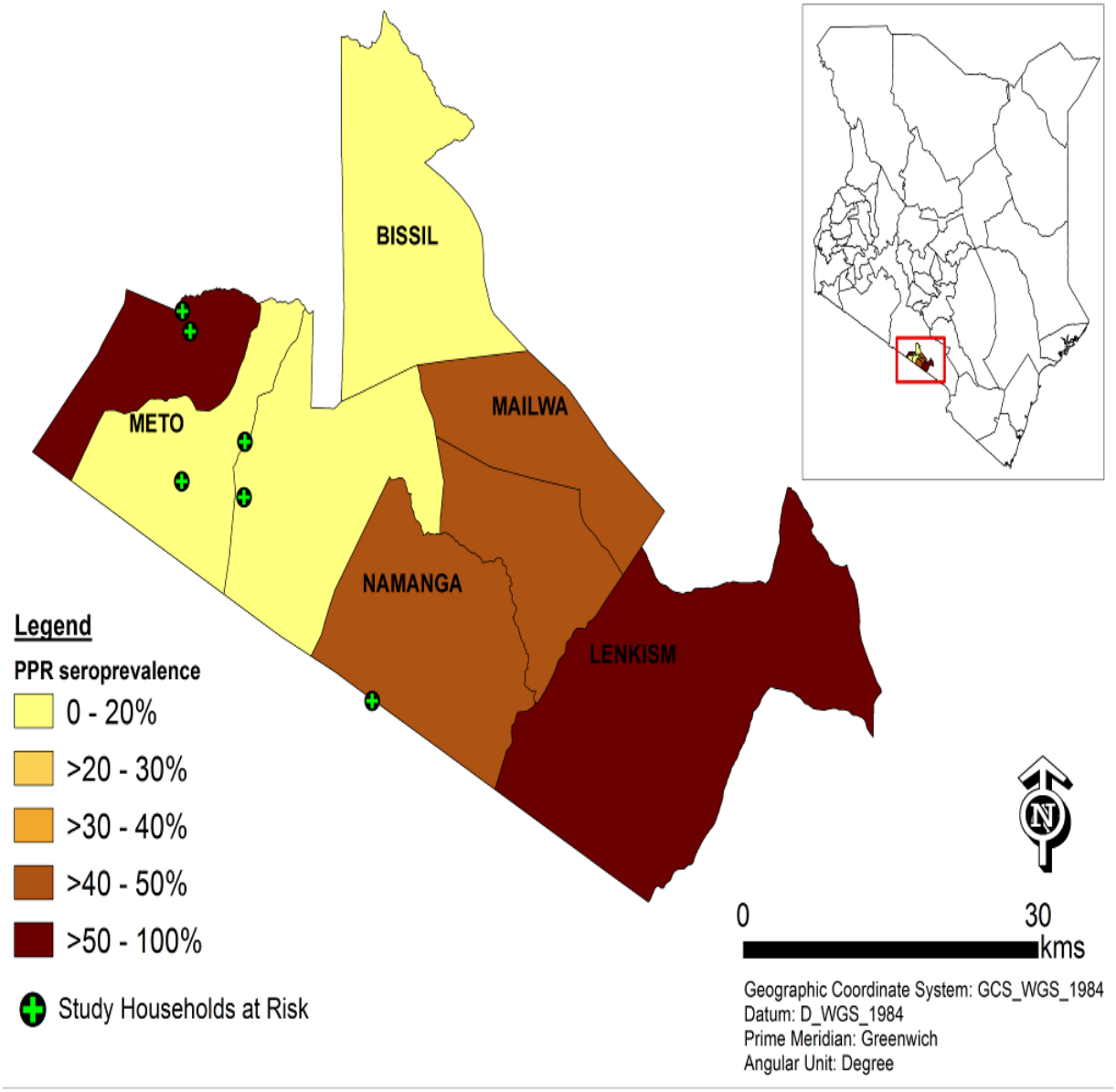
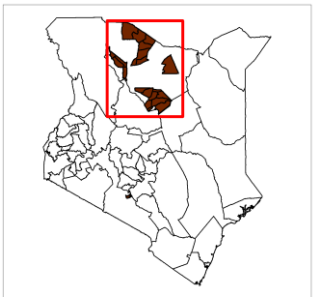
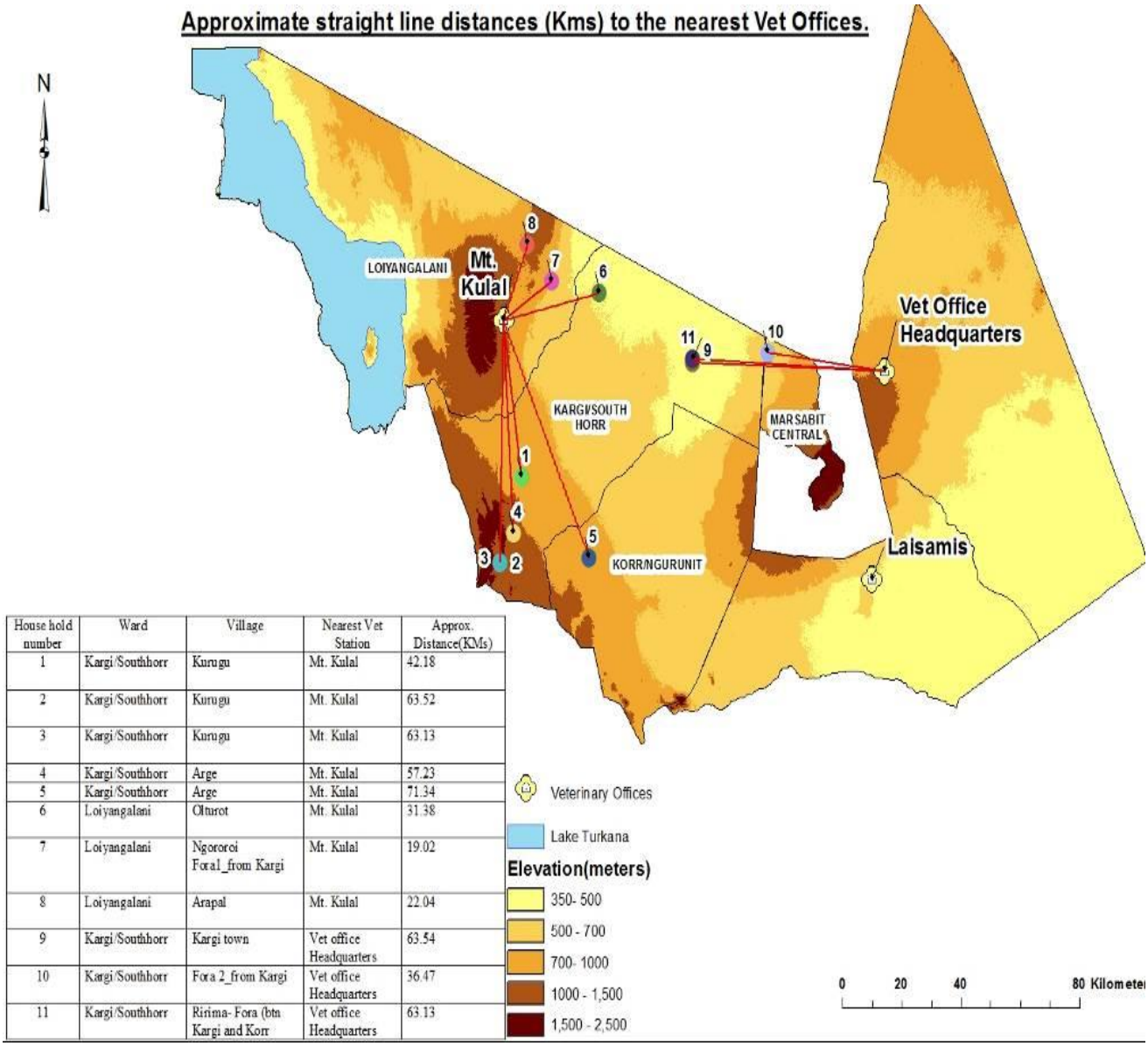


Figure 15: Risk map showing location of study herds in Kajiado at risk of PPR virus infection due to physiological stress (January 2014)

6.3.2.5 Effectiveness of veterinary service delivery

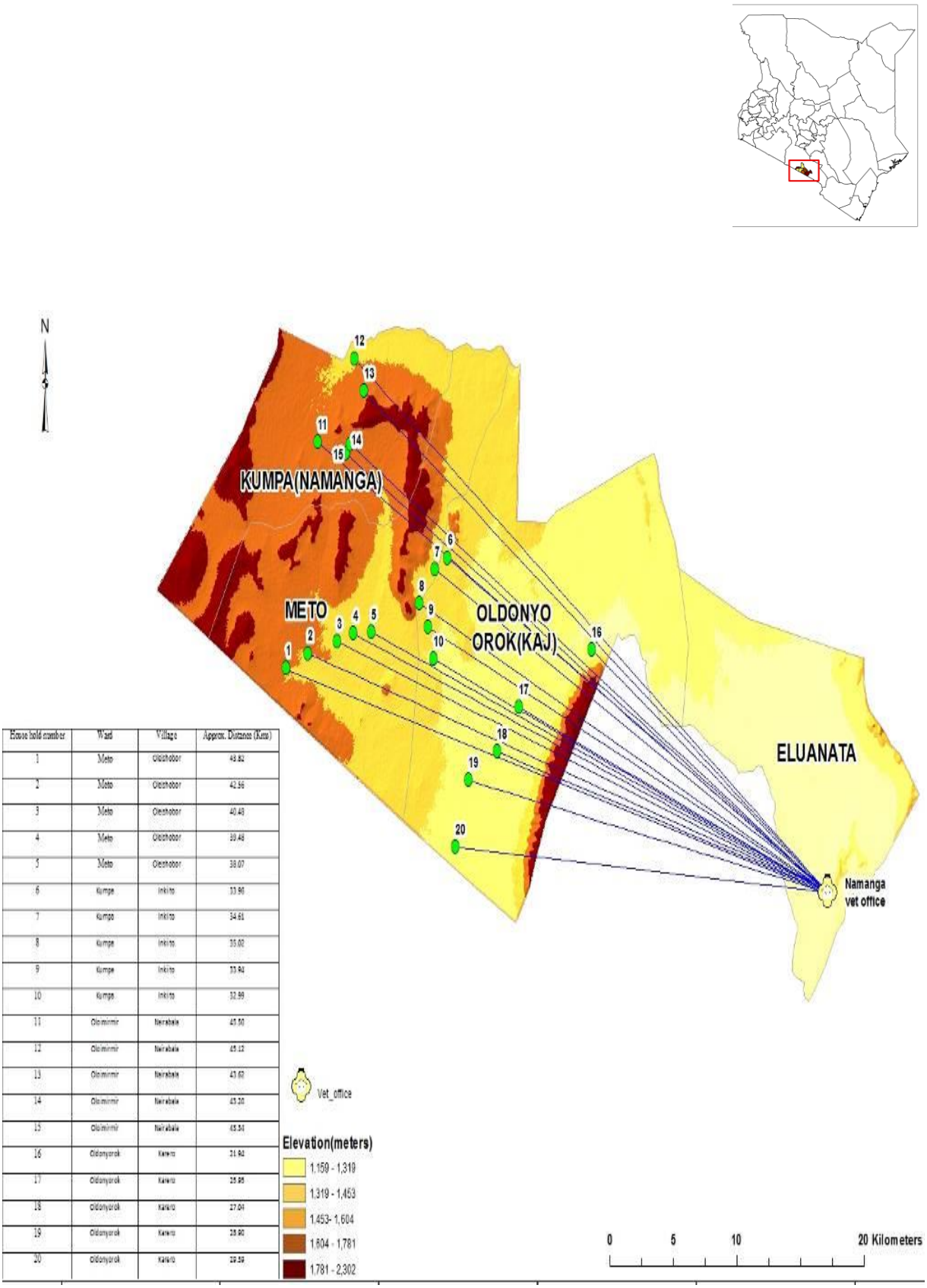
The straight line calculation (Appendix 9), revealed that in Marsabit no herd sample was allocated to the Laisamis veterinary office where all the veterinarians serving Kargi/South Horr were located during the study period in August 2014 (Figure 16). In addition, only 11 out of the 28 herds sampled were allocated a veterinary office based on the cut-off point of 100 kilometres (kms) given the motor bike mode of transport available at the time. Sampled herds were allocated the Mt. Kulal veterinary office that was closed due to lack of supplies and the Marsabit town office that served only the North Horr located herds which were not mapped as there distance was more than the set 100 kms cut off point. The one way distance to be covered by a personnel based in Mt. Kulal ranged from a minimum of 19 kms to Ngororoi in Loiyangalani to a maximum of 71 kms to Arge in Kargi/South Horr (Figure 16). The one way straight line distance to be covered in Kajiado ranged from a minimum of 21 kms to Oldonyorok to a maximum of 45 kms to Kumpa one way (Figure 17). In addition, the location of Kajiado office located in Namanga town was ideal for 20 of the 35 herds sampled (Figure17). However, the digital elevation models for both study areas revealed the great variation in the terrain in both study areas and this may prove a challenge for the provided motorbike form of transport (Figure 18).





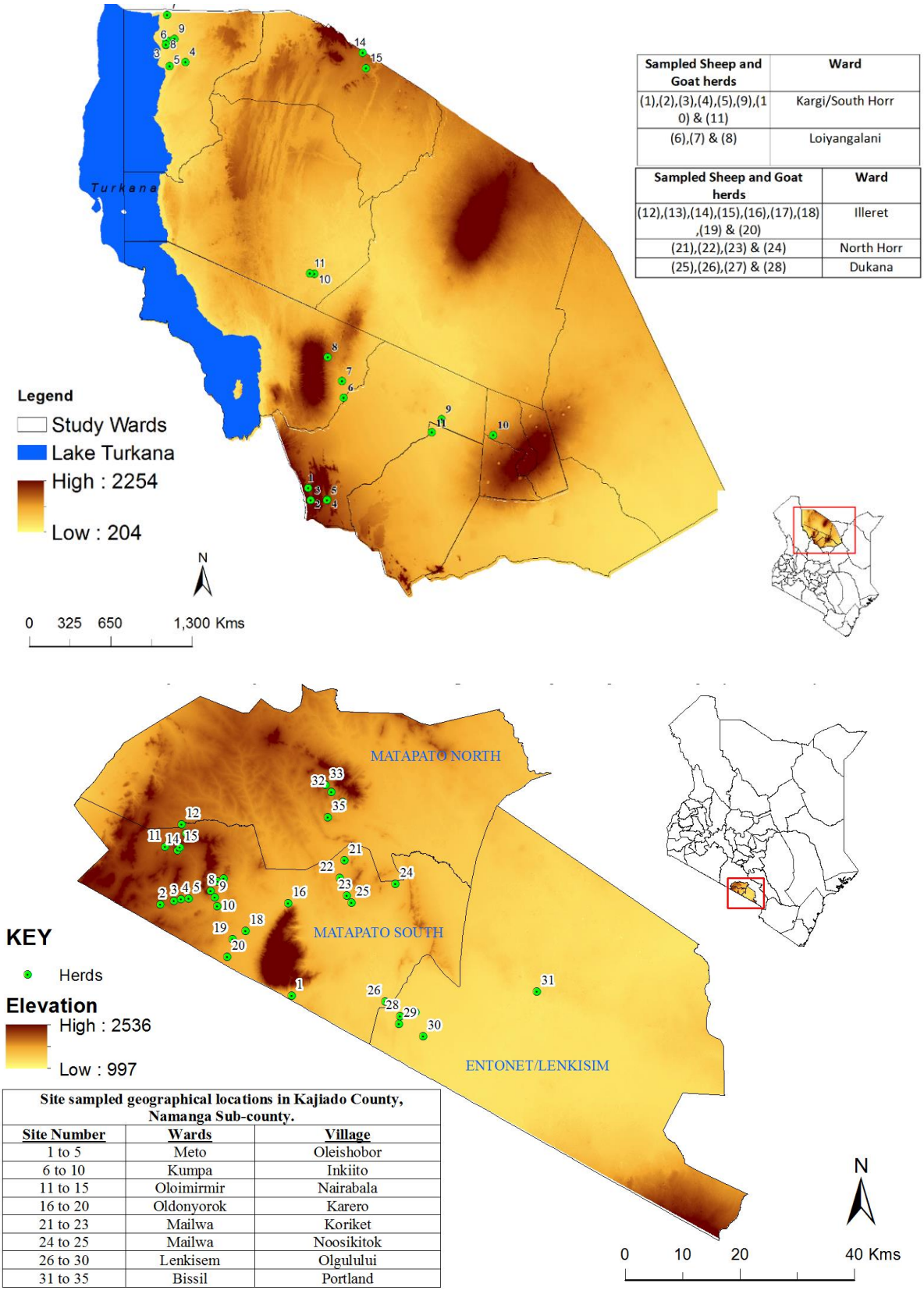
House hold number	Ward	Village	Nearest Vet Station	Approx. Distance(KMs)
1	Kargi/Southhorr	Kurugu	Mt. Kulal	42.18
2	Kargi/Southhorr	Kurugu	Mt. Kulal	63.52
3	Kargi/Southhorr	Kurugu	Mt. Kulal	63.13
4	Kargi/Southhorr	Arge	Mt. Kulal	57.23
5	Kargi/Southhorr	Arge	Mt. Kulal	71.34
6	Loiyangalani	Olturot	Mt. Kulal	31.38
7	Loiyangalani	Ngororoi Foral_from Kargi	Mt. Kulal	19.02
8	Loiyangalani	Arapal	Mt. Kulal	22.04
9	Kargi/Southhorr	Kargi town	Vet office Headquarters	63.54
10	Kargi/Southhorr	Fora 2_from Kargi	Vet office Headquarters	36.47
11	Kargi/Southhorr	Ririma- Fora (btn Kargi and Korr	Vet office Headquarters	63.13

Figure 16: Map showing allocation of sampled herds based on approximate straight line distances to the nearest veterinary office in Kargi/South Horr Marsabit County, Kenya (August 2014)



Household number	Ward	Village	Approx. Distance (Kms)
1	Meto	Olokiloboor	48.82
2	Meto	Olokiloboor	42.56
3	Meto	Olokiloboor	40.48
4	Meto	Olokiloboor	39.48
5	Meto	Olokiloboor	38.07
6	Kumpa	Inkito	33.96
7	Kumpa	Inkito	34.61
8	Kumpa	Inkito	35.02
9	Kumpa	Inkito	33.93
10	Kumpa	Inkito	32.99
11	Olaimirmir	Nairabala	45.50
12	Olaimirmir	Nairabala	45.13
13	Olaimirmir	Nairabala	43.62
14	Olaimirmir	Nairabala	43.20
15	Olaimirmir	Nairabala	43.50
16	Oldonyorok	Kariero	21.92
17	Oldonyorok	Kariero	25.95
18	Oldonyorok	Kariero	27.04
19	Oldonyorok	Kariero	28.90
20	Oldonyorok	Kariero	29.59

Figure 17: Map showing allocation of sampled herds based on approximate straight line distances to the nearest veterinary office in Namanga, Kajiado County, Kenya (January 2014).



Sampled Sheep and Goat herds	Ward
(1),(2),(3),(4),(5),(9),(10) & (11)	Kargi/South Horr
(6),(7) & (8)	Loiyangalani

Sampled Sheep and Goat herds	Ward
(12),(13),(14),(15),(16),(17),(18),(19) & (20)	Illeret
(21),(22),(23) & (24)	North Horr
(25),(26),(27) & (28)	Dukana

Site sampled geographical locations in Kajiado County, Namanga Sub-county.

Site Number	Wards	Village
1 to 5	Meto	Oleishobor
6 to 10	Kumpa	Inkiito
11 to 15	Oloimirmir	Nairabala
16 to 20	Oldonyorok	Karero
21 to 23	Mailwa	Koriket
24 to 25	Mailwa	Noosikitok
26 to 30	Lenkisem	Olgulului
31 to 35	Bissil	Portland

Figure 18: Map showing location of herds in relation to the terrain in Marsabit and Kajiado Counties, Kenya (January 2014- March 2015).

6.3.2.6 PPR vaccination planning maps

The attribute table calculation queries using small ruminant population figures from the 2009 household census determined how many days it would take to vaccinate 70% of the population so as to be able to stop the circulation of PPR virus. The PPR vaccination planning maps demonstrate that vaccination activities should target on average 600,000 animals in Korr/Ngurunit and close to 244,000 in Loglogo (Figure 19). The homestead heads information and reports from the Marsabit county veterinary offices (GOK 2009) indicated that vaccination activities campaigns run on average for 14 days. The attribute query was used to calculate how many days it would take to vaccinate the target animals given that there were 5 animal health personnel who on average vaccinated 1,000 animals a day per person making a total of 5,000 animals vaccinated in a day. The PPR planning maps demonstrated that on average 122 days would be needed for Korr/Ngurunit area and 49 days for Loglogo (Figure 20). The overlay with the Voronoi polygons also helped visualise the proposed veterinary service area of operation so as to ensure a balanced coverage of the small ruminant population. .

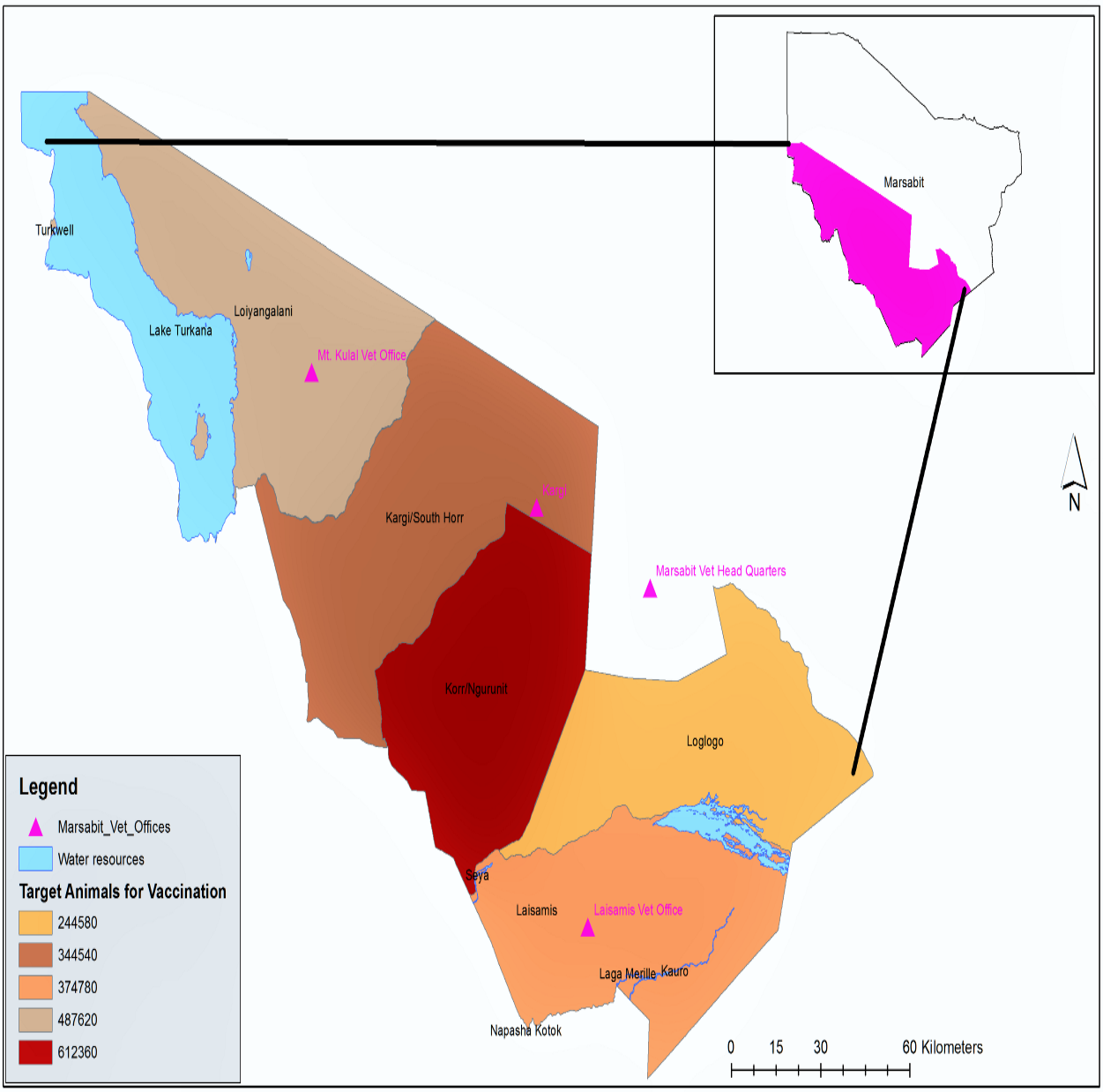
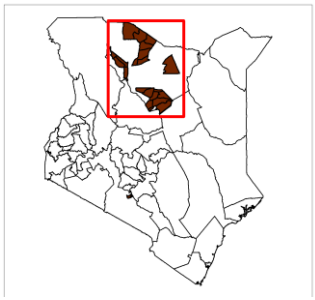


Figure 19: Map showing target number of sheep and goats in Marsabit South that require to be vaccinated so as to achieve the recommended 70% (FAO-UN/OIE 2015) PPR herd immunity that will stop the circulation of PPR virus in an endemic area (20140-2015).



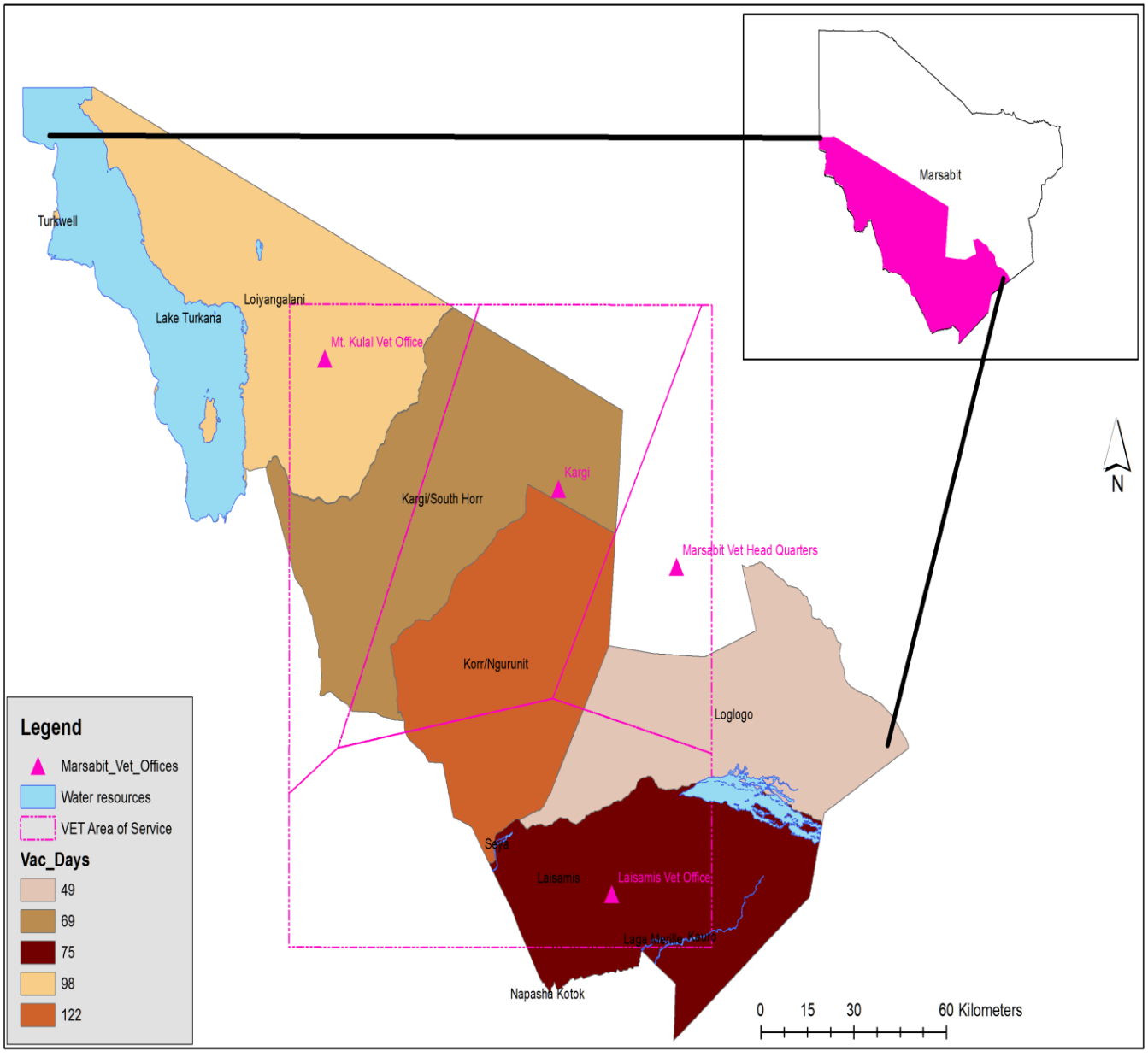


Figure 20: Map showing number of days it would take to vaccinate 70% of the small ruminant population and proposed veterinary service areas of operation (Voronoi polygons) in the Southern parts of Marsabit in Kenya (2014-2015).

6.4 Discussion

Disease surveillance information is key in managing livestock diseases (Prattley 2009). Livestock disease surveillance information in Kenya is largely lacking due to under reporting of disease incidence (FAO-UN 2011; Catley et al., 2011) and where information is available it in different formats and spread across different government and private institutions that have no sharing mechanism (FAO-UN 2011; Dhama et al., 2013). In the current study, the lack of PPR information at the director of veterinary office level, which is the official institution mandated to have notifiable disease information of the country, was largely attributed to lack of disease reporting from county level as well as lack of standardised reporting especially for laboratory samples submitted for PPR investigation, vaccination status of animals sampled was largely lacking (GoK 2015a). The new constitution devolved veterinary services to county government (GoK 2014), this resulted in a breakdown of the already weak surveillance and reporting structure (Catley et al., 2011; GoK 2014).

However the new veterinary guidelines has outlined a new institutional reporting structure that will improve disease reporting from counties, in addition, the existing mobile and web based disease information sharing platforms such as digital pen technology ARIS II will also ease and improve livestock disease information sharing (FAO-UN 2011). One of the main strength of a GIS is its ability to capture, integrate, store and analyse information from different data base sources (De Smith et al., 2015). GIS data management capability can be used in the veterinary field to capture and store an array of information from different institutions. Information such as livestock and human population demographic information, etiological factors such as watering points and laboratory records are all stored as geo-referenced attribute tables and layers thus allowing spatial epidemiology investigation (Christopher and Marusic 2013; Dharma et al., 2013; Noremark and Widgren 2014).

The integration of the drought early warning bulletins reports on PPR outbreaks in Marsabit demonstrated the usefulness of GIS as an integration tool. GIS is able to utilise data that is traditionally perceived as inadequate for epidemiological investigation (Koch 2005; Christopher and Marusic 2013). The bulletins information though not validated, allowed an analysis of past PPR outbreaks directional trend using the standard deviation ellipse, this information can then be used to target PPR disease surveillance activities (Prattley 2009).

Veterinary service delivery in pastoral areas of Kenya face numerous challenges including but not limited to lack of infrastructure, vastness and remoteness of areas (Onono et al., 2013). Human health and veterinary service location points are based on the cost containment concept that involves rationalizing healthcare service delivery through centralization of services to achieve economies of scale (Schuurman et al., 2006; Davis et al., 2012). Since pastoral areas are sparsely populated and inhabitants are highly mobile most policy makers will not invest in animal health facilities that will be underutilised (Schuurman et al., 2006). Specific literature on application of GIS spatial tools to infectious livestock disease management in Kenya is largely lacking. This study demonstrated the applicability of GIS in integrating information of various risk factors from various surveillance data sources to improve PPR disease management in pastoral areas of Kajiado and Marsabit. There are many GIS based quantitative tools that allow descriptive and inferential analysis. The descriptive statistics describe the spatial distribution patterns of disease while the inferential statistics compare the spatial distribution pattern to a theoretical hypothesis based on knowledge of risk factors such as demographic or environmental setting (Pfeiffer et al., 2008; De Smith et al., 2015). The directional distribution (Standard Deviational Ellipse) tool used to map past PPR outbreak found that the 2 outbreaks had their origin at the Southern part of Marsabit near the border with the neighbouring Samburu county, this information validated previous

government reports on the entry point of PPR into Marsabit (GoK 2008). The GIS overlay and proximity tool calculated the Euclidean distance also known as aerial or crow-fly approximate straight line distance. The proximity tool has been used to measure the accessibility of human health care facilities (Schuurman et al., 2006). The tool incorporates travel time and distance thresholds thus indicating how accessible existing health centres are in meeting the service demand of the target population around them (Davies et al., 2012). In developed countries, a criteria set by ministries of health services and health planning requires emergency service centres to be located approximately 50 kilometres (kms) that is equal to a 1 hour travel time distance from the target population. While acute inpatient services should be located 100 kms or have a 2 hour travel distance time (Schuurman et al., 2006; Davies et al., 2012). The current study calculated and allocated a straight line distance from the georeferenced existing veterinary offices in Marsabit to the sampled herds. The map was able to reveal that distance was an important hindrance to veterinary service delivery in the Marsabit. In addition, the proximity tool was able to give a policy guideline where future veterinary infrastructure should be located so as to better serve the population sampled.

However, the limitation of the straight line calculation method was highlighted when the digital elevation model was overlaid. The distance suggested to be covered given the motorcycle mode of transport and terrain of area may make surface (road) travel much longer and during rainy season impossible to use by animal health providers in Marsabit. Fortunately, GIS offers an array of tools that can be used to better describe and understand the spatial dimensions of veterinary services delivery (De Smith and Longley 2015). Voronoi (or Thiessen) polygons, partition geographic space based on the point locations of the veterinary service provider. In this method each animal health provider is represented as a point and proximity tool of GIS calculates the Euclidean distance that is used to draw a polygon around

each point (Davis et al., 2014). This tool is used to divide the area covered by the point input features into Thiessen or proximal zones. These zones represent full areas where any location within the zone is closer to its associated input point than to any other input point (Pfeiffer et al., 2008; De Smith et al., 2015). This was the method used to allocate the sampled small ruminant herds to Mt. Kulal, Kargi and Marsabit town veterinary offices. Thereby demonstrating the inability of the current veterinary office in Laisamis to serve the studied population. In addition, overlaying the Voronoi polygon map with the number of vaccination day's maps allowed visualisation of the extent of the proposed veterinary service areas of operation using a cut off distance of 100 kms. In this study, the Boolean geometrical analysis of GIS (Norstrom 2001; Pfeiffer et al., 2008) proved useful in revealing specific herds located in Kajiado and Marsabit that could be at risk for PPR outbreaks.

In addition, the overlay of past PPR outbreaks and permanent watering points demonstrated a possible link between watering areas and PPR epidemiology. This finding of watering areas as a PPR source of infection was also mentioned by livestock owners during interviews. Similarly, participatory PPR disease search studies carried out in Turkana and Baringo Counties also linked watering areas to PRR outbreaks (Kihu et al., 2012; Gitao et al., 2014). Choropleth maps also called colour shaded maps are used to demonstrate standardised data such as rates, densities or percentages. A different colour is used for each band, allowing identification of areas with high, low or middle values (Norstrom 2001; Faes et al., 2013). In this study, the advantage of the choropleth PPR seroprevalence maps was that it allowed the visualisation of specific areas that had herds with higher seroprevalence values than those reported by the statistical overall mean of Kajiado and Marsabit. This finding would aid decision makers direct vaccination activities to at risk areas instead of instituting blanket PPR vaccination campaigns (Pratley 2009; Dhama et al., 2013)

Traditional statistical analysis are inherently non-spatial. As they aggregate data to the mean, standard deviation or odds ratio to describe the central tendency of the data without regard to the relative positioning of the data in space (Pfeiffer 2008). GIS is able to integrate location and mean values. In GIS the mean value is projected as a horizontal plane hovering over the geographical area (Jeffrey et al., 2014). The points on the map are then used to determine the geographic trend in the mean data from values lower than the mean in the West toward higher values in the East thus creating a weighted mean value demonstrated by the graduated colour bands (Pfeiffer et al., 2008; Jeffery et al., 2014). The application of GIS in this study as a decision support tool for planning PPR vaccination activities was able to highlight gaps in the veterinary service delivery especially in Marsabit. GIS can be used in planning and resource allocation for example selections of suitable sites for animals health care facilities when taking into consideration the population of area, terrain and access to infrastructure like roads and electricity (Premasthira 2012; Dhama et al., 2013; Olabode et al., 2014).

6.5.1 Conclusions and Recommendations

In conclusion, GIS was found to be a useful decision support tool that can be used to plan, implement and monitor PPR vaccination activities in Kenya The study therefore recommends use of GIS as a decision support tool at county and national levels as it will increase the efficiency of veterinary services through better data capture, storage and analysis. GIS will also improve networking and communication between institutions tasked with livestock disease management (Dhama et al., 2013; FAO-UN/OIE 2015).

6.5.2 Future research areas

More researchers need to adopt the use of GIS spatial analysis techniques when designing, monitoring the impact and developing control strategies for infectious livestock diseases that do not have an intervening vector agent.

CHAPTER 7

7.0 GENERAL DISCUSSION

7.1 Discussion

The world food economy has seen a shift towards increased consumption of protein rich animal based foods, this demand has generally been driven by human population growth and increasing incomes especially in urban areas (FAO-UN 2014). The livestock sector is therefore, one of the fastest-growing sectors in agriculture especially in the developing world (Thornton 2010; FAO-UN 2014). Over 330 million livestock owners in Africa and Asia directly rely on sheep and goats for their livelihoods. In addition, out of the global 2.1 billion sheep and goats population over 80% (1.7 billion) are found in Africa and Asia. FAOSTAT projections indicate that between 2000 and 2030 the global mutton and chevon consumption will increase to 7 million tonnes per year with projections in Sub-Saharan Africa expected to reach 1.8 million tonnes most of which will be produced in pastoral production systems (FAO-UN 2014).

It is estimated that over 70% of the national livestock population and almost 90% of the small ruminant population is found in the arid and semi-arid areas of Kenya. The ASALs cover over 80% of Kenya's land mass and sustain the livelihood of close to 10 million pastoralists. In addition, the livestock sub-sector contributes to 10% of the country's Gross Domestic Product (GDP) and approximately 42% to the agricultural GDP (KNBS 2009). The endemic presence of small ruminant diseases such as *Peste des petits ruminants* (PPR) will not only affect productivity of the small ruminants but will also hinder their owners from accessing lucrative international markets that are responding to the increasing global demand for mutton and chevon (OIE 2013; FAO-UN 2015). Global estimates indicate that direct annual losses due to PPR are between 1.2 and 1.7 billion USD. Additionally, it is also estimated that the annual

PPR vaccination expenditure ranges from between 270 to 380 million USD (Elsawalhy et al., 2010; AU-IBAR 2014; FAO-UN/OIE 2015). In Kenya PPR outbreaks have resulted in the morbidity of over 5 million small ruminants and death of over 2 million animals (GoK 2008). The annual production and control costs associated with PPR outbreaks in Kenya is estimated to be 1 billion Kenya shillings (GoK 2008). However, a recent study in Turkana indicates that previous estimates due to the 2006-2008 PPR outbreak in Turkana county were grossly undervalued, with findings showing that losses stood at 19.1 million USD with mortality of small stock constituting the greatest losses valued at 16.8 million USD (Kihu et al., 2015a). Despite PPR vaccination control strategies being in place since 2008 (GOK 2008). PPR has continued to spread and is now reported in all ASAL counties of Kenya (GoK 2015a). The underlying risk factors causing the continued spread of PPR in pastoral systems of Kenya are not well understood (Gitao et al., 2014; Kihu et al., 2015b). In addition, post vaccination seromonitoring for PPR antibodies in sheep and goat herds in Kenya is not routinely done and is therefore difficult to assess the success of existing PPR control programmes (GOK 2009; Kihu et al., 2015b).

The rationale for this study was therefore threefold: The first is that Kenyan pastoral communities are differentiated by their geographical location and ethnic backgrounds (Fratkin and Roth 2005; Kaufmann et al., 2012) and although they experience similar socioeconomic disruption due to drought or livestock diseases. There exists different application in the coping and adaptive strategies thus resulting in differences in the social and economic impacts (Little 2002 and Fratkin and Roth 2005). Due to this fact, Kenyan pastoral communities are diverse and livestock disease control strategies should not be applied as blanket interventions (Kihu et al., 2015b). The study explored the distinctions in small ruminant husbandry practices amongst 5 pastoralist communities these were Maasai in Kajiado, Samburu, Rendille,

Dassanech and Gabra in Marsabit. Secondly, the prevalence of antibodies against PPR virus and prevalence of intestinal parasites so as to be able to assess the effectiveness of existing small ruminant disease control programmes at herd level and at county policy level. Thirdly, the study aimed at enhancing PPR control and surveillance programmes by demonstrating the utility of a Geographical information system (GIS) as a decision support tool. The overall study findings reveal that small ruminant production is still an important livelihood strategy for pastoral communities in Kajiado and Marsabit. However, husbandry practices and PPR seroprevalence levels differed across and within the study counties. These differences were due to external influences such as availably of animal health inputs, access to veterinary services and access to small ruminant markets.

PPR seroprevalence trends in both Kajiado and Marsabit did not have a significant upward trend as expected, given that vaccination for PPR were scheduled to occur for 5 years starting from 2008 to 2012 (GoK 2008;GoK 2009). Several factors investigated in this study may have resulted in the low PPR seroprevalence. One of which is the political setting at the time (GoK 2014). In 2010, the new constitution devolved veterinary services to counties and this may have interfered with PPR vaccination campaigns as money allocated for PPR vaccines from the national government through the director of veterinary services office was no longer available to be used at county level (GOK 2014). In addition, the initial lack of focus of vaccination campaigns in 2008 and 2009 to only PPR infected areas may have resulted in low vaccination coverage (GoK 2009). The global PPR control and eradication strategy launched in April 2015, indicates that a sustained annual PPR vaccination in endemic areas should achieve a post vaccination seroprevalence of 70% in 3 years which in turn will break the PPR virus transmission cycle in endemic areas thus resulting in significant reduction of clinical PPR cases as well as minimize the risk of spread to high risk areas (FAO-UN/OIE 2015).

This fact is further supported by a recent research carried out in Kenya. The study used participatory, serosurveillance and statistical modelling techniques and found that vaccinating 50% of the small ruminant population in Turkana county was effective in significantly reducing PPR outbreaks (Kihu et al., 2015b). Turkana county is also classified as a PPR endemic zone and was the first entry point for the disease into Kenya in 2006 (Nyamweya et al., 2009; Kihu et al., 2012). Early warning response to disease outbreaks are based on up to date surveillance information (FAO-UN 2011; Dhama et al., 2013). PPR surveillance information in pastoral systems of Kenya was found to be largely lacking due to under reporting (GoK 2014). To address this challenge, the researcher demonstrated the applicability of GIS in integrating data that is traditionally perceived as inadequate for epidemiological investigation (Koch 2005; Christopher and Marusic 2013) by using information from the monthly drought early warning bulletins and questionnaire survey information from livestock owners whose animals were sampled. The GIS overlay and Boolean geometrical functions were also used to create scenarios that demonstrated that the current set up of veterinary offices in Marsabit could not meet the demands of the small ruminant herds surveyed. This is because the animal health personnel were expected to cover long distances of over 100 kilometres to serve sampled herds. In addition, the terrain given the motorbike mode of transport at the time of the study would also prove to be a challenge.

7.2 Conclusions

The study made the following conclusions;

1. Sheep and goat production is still an important livelihood strategy for Kajiado and Marsabit pastoralist communities. However, there exists differences in small ruminant disease control practices amongst the study communities that are driven by the level of access to veterinary services, animal health inputs and livestock markets.

2. The PPR seroprevalence levels in Marsabit (22.4%) and Kajiado (37.1%) counties, were lower than the recommended 70% that prevents PPR virus circulation in endemic and high risk areas. This means that seronegative study animals and presumably many of the animals in the study area were not protected against future PPR outbreaks.
3. Post-vaccination serosurveillance was found to be an important tool that can be used to monitor the coverage and effectiveness of existing vaccination control programmes.
4. The 5 risk factors significantly associated with PPR seropositivity in the study were (i) age of animal (ii) geographical location of herds that determined accessibility to veterinary services (iii) goat herd size that determined livestock owners' willingness to invest in PPR preventive vaccines (iv) past PPR outbreak incidence and (5) PPR vaccination status.
5. The significant correlations between packed cell volume, FAMACHA© score as well as strongyle egg count means that in the absence of laboratory services as is often the case in pastoral systems of Kenya, the FAMACHA© score chart can be used to determine the helminth burden especially for *Haemonchus* nematode specie.
6. GIS was found to be a useful decision support tool that can be used to plan, implement and monitor PPR vaccination activities in Kenya.

7.3 Recommendations

In light of these study findings, the following recommendations should be considered so as to improve PPR control strategies as well as reduce disease burden and improve productivity in small ruminant pastoral production systems of Kenya;

1. PPR and other small ruminant disease control programmes should be tailored to specific geographical areas based on the social and economic settings. With this regard, Kajiado communities would be willing to pay for vaccines when compared to Marsabit communities as they are able to recover the input expense after sale of their

animals. However, for Marsabit communities, PPR vaccination programmes should continue to be offered as a public good service as their production system is still at subsistence level.

2. National and county governments should focus PPR vaccination resources and activities to PPR endemic zones like Marsabit. This support will be able to achieve a herd PPR seroprevalence of 70% that has been shown to stop PPR virus circulation resulting in a dramatic reduction of clinical PPR cases. This will in turn result in less cases spilling to high risk area like Kajiado as well as a more efficient use of the already scarce small ruminant disease control resources.
3. In addition, PPR vaccination campaigns should target young animals under 1 year and focus in areas that are far from veterinary services such as herds in satellite settlements that also often have larger small ruminant populations.
4. Policy makers in both Kajiado and Marsabit should include CCPP vaccination in goats as well as other vaccines recommended in the PPR global strategy.
5. The anthelmintic product selected during PPR or other small ruminant vaccination campaigns should first be tested for efficacy. This will be especially important for Kajiado county small ruminant herds.
6. Use of GIS as a decision support tool at county and national levels should be encouraged as it will improve the planning, implementation and monitoring of PPR and other livestock vaccination programmes.

7.4 Future Research areas

1. The current study found a significant positive correlation between strongyle egg count and FAMACHA® score. Future studies using longitudinal study designs should determine the applicability of FAMACHA® score as a biological indicator for susceptibility to important small ruminant diseases like PPR as well as determine the efficacy and resistance of anthelmintic drugs especially in Kajiado county, Kenya.

2. Research should also continue on the development of vaccines or diagnostic tests that can differentiate PPR seropositivity due to vaccination or natural infection (DIVA). This will greatly enhance the tracking of vaccinated animals in pastoral systems of Kenya.
3. More researchers need to adopt the use of GIS spatial analysis techniques when designing, monitoring the impact and developing control strategies for infectious livestock diseases that do not have an intervening vector agent.

8.0 REFERENCES

African Union- InterAfrican Bureau for Animal Resources (AU-IBAR) (2014). Standard Methods and Procedures (SMPs) for Control of *Peste des Petits Ruminants* (PPR) in the Greater Horn of Africa. Nairobi, Kenya.Pp1-24.

African Union- InterAfrican Bureau for Animal Resources (AU-IBAR) (2012). Assessing opportunities for African countries to strengthening trade in animal products in compliance with international standards through commodity based trade, zoning, improved traceability and certification Sanitary and International Standards Considerations. ISBN: 978-9966-077-09-7.Pp1-43.

African Union- InterAfrican Bureau for Animal Resources (AU-IBAR) (2010). Policy framework for pastoralism in Africa: Securing, Protecting and Improving the Lives, Livelihoods and Rights of Pastoralist Communities. Addis Ababa, Ethiopia.Pp1-38.

Aklilu Y. (2008). Livestock Marketing in Kenya and Ethiopia: a Review of Policies and Practice. Addis Ababa, Ethiopia, Feinstein International Center, Addis Ababa.Pp1-42.

Ashley, C.B., Satya, P., Carrie, B., Chris, O., Olivier, K. and Genevieve, L., (2010). Global distribution of peste des pet its ruminants virus and prospects for improved diagnosis and control', Journal of General Virology 91, 2885–2897.

Balamurugan V., Hemadri D., Gajendragad M.R., Singh R.K. and Rahman H. (2014). Diagnosis and control of peste *des petits ruminants*: a comprehensive review. Virus Diseases 25(1): 39-56.

Banyard C.A., Panda S., Batten C., Oura C., Kwiatek O. and Libeau G. (2010). Global distribution of peste des petits ruminants virus and prospects for improved diagnosis and control. Journal of General Virology 91: 2885-2897. Retrieved on October 16 2015 from http://www.microbiologyresearch.org/docserver/fulltext/jgv/91/12/2885.pdf?expires=1445892956&id=id&accname=guest&checksum=96C04506B76BC7A6B2F256AD3A198523

Barret T., Paul-Pierre P. and Taylor W.P. (2006). Rinderpest and *Peste des Petits Ruminants*: Viral plagues of large and small ruminants. Elsevier Limited, Oxford UK. ISBN-13: 978-0-12-088385-1.Pp 68-85.

Baron J., Fishbourne E., Couacy-Hyman E., Abubalar M., Jones B.A., Frost L., Herbert R., Chibsaa T.R., van't Klooster G., Afzal M., Ayebazibwe C., Toye P., Bashiruddin J. and Baron M.D. (2014). Development and testing of a field diagnostic assay for *peste des petits ruminants virus.* Transboundary and Emerging Diseases. 61(5): 390-396. DOI: 10.1111/tbed.12266.

Behnke R. and Muthama D. (2011).The Contribution of Livestock to the Kenyan Economy. Intergovernmental Authority on Development (IGAD)/ Livestock Policy Initiative (LPI). Working Paper No. 03-11. Pp 20-21, 36-40. Retrieved on October 16 2015from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.386.3966&rep=rep1&type=pdf

Bekure S., Leeuw P N., Grandin B. E. and Neate P. J. H. (1991). Maasai Herding: An Analysis of the Livestock Production System of the Maasai Pastoralists in Eastern Kajiado District, Kenya. Addis Ababa, Ethiopia: ILCA.Pp1- 154. Retrieved on October 16 2015 from http://www.ilri.org/InfoServ/Webpub/fulldocs/X5552e/X5552E00.HTM

Biernacki P. and Waldorf D. (1981). Snowball sampling: Problem and Techniques of chain referral sampling. Sociological Methods and Research. 10: 141-163.

Boone R B, Lackett J M, Galvin K A, Ojima D S and Compton J T 2007. Links and broken chains: evidence of human-caused changes in land cover in remotely sensed images. Environmental Science and Policy 10: 135-149.

Britch SC, Binepal YS, Ruder MG, Kariithi HM, Linthicum KJ, et al. (2013) Rift Valley Fever Risk Map Model and Seroprevalence in Selected Wild Ungulates and Camels from Kenya. PLoS ONE 8(6).

Catley A., Alders R.G. and Wood J.L.N (2011). Participatory epidemiology: Approaches, methods, experiences. The Veterinary Journal. DOI: 10.1016/j.tvjl.2011.03.010. Retrieved on October 16 2015 from http://origem.info/FIC/pdf/catley_participatory_epidemiology_Vet_J_2011.pdf

Cecchi G., Wint W., Shaw A., Marietta A., Mattioloi R. and Robinson T. (2010). Geographical distribution and environmental characterisation of livestock production systems in Eastern Africa. Agriculture, Ecosystems and Environment 135: 98-110.

Chantarat S., Mude A. G., Barret C. B. and Carter M. R. (2010). Designing index based livestock insurance for managing asset risk in Northern Kenya. Journal of Risk and Insurance 80(1): 2015-237.

Christoper M.M. and Marusic A. (2013). Geographic trends in research output and citations in veterinary medicine: insight into global research capacity, species specialization and interdisciplinary relationships. BMC veterinary Research 9:115.

Cinnamond-Riviere A. and Eregae M. (2003). Community-based Animal Health Workers (CAHWs). In pastoralist areas of Kenya: A study on selection processes, impact and sustainability. West Pokot, Wajir and Marsabit. London School of Hygiene and Tropical Medicine, Public Health and Policy Department .London, UK. Pp1-62.

Couacy-Hyman E. (2013). Update on PPR epidemiology, diagnosis and its control, Revue Africaine de Santé et de Productions Animales (RASPA). 11 (3-4).59-65. Retrieved on October 16 2015 from http://eismv.org/IMG/pdf/COUACY-HYMMAN_2013_RASPA_11_S_p59-65-2.pdf

Davis G.S., Sevdalis N. and Drumright L.N. (2014). Spatial and temporal analysis to Investigate infectious disease transmission within healthcare settings. Journal of Hospital Infection 86: 227-243.

Degen A.A. (2007). Sheep and goat milk in pastoral societies. Small Ruminant Research 68 (1-2): 7-19.

De Smith M., Goodchild F.M. and Longley A.P. (2015). Geospatial analysis. A comprehensive guide to principles, techniques and software tools. 5th Edition. Winchelsea Press, Winchelsea, UK.Pp1-60.

Diallo A., Barrett T., Barbras M., Shaila M.S. and Taylor W.P. (1989). Differentiation of rinderpest and peste des petits ruminants viruses using specific cDNA clones. Journal of Virological Methods. 23:127–36.

Dhama K., Verma A.K., Tiwari R., Chakraborty S., Vora K., Kapoor S., Deb R., Karthik K., Singh R., Munir M. and Natesan S (2013). A perspective on applications of geographical information system (GIS); an advanced tracking tool for disease surveillance and monitoring in veterinary epidemiology. Advances in Animal and Veterinary Sciences 1 (1): 14 – 24.

Dohoo I, Wayne M and Henrik S 2010. Sampling: In Veterinary Epidemiologic Research. 2nd Edition, VER Inc. Charlottetown Prince Edward Island Canada. Pp 48.

Dong S., Wen L., Liu S., Zhang X., Lassoie J.P., Yi S., Li X., Li J. and Li Y. (2011). Vulnerability of worldwide pastoralism to global changes and interdisciplinary strategies for sustainable pastoralism. Ecology and Society 16(2): 10.

Dundon W.G., Kihu S.M., Settypalli T.B.K., Gitao G.C., Bebora L.C., John N.M., Oyugi J.O., Silber R., Loitsch A. and Diallo A. (2014). First complete genome sequence of a lineage III *peste des petits ruminants* virus. Genome Announcements. 2(5):e01054-14. DOI:10.1128/genomeA.01054-14.

Ekaya W.N. (2005). The shift from mobile pastoralism to sedentary crop-livestock farming in the dry lands of Easter Africa: Some issues and challenges for research. African Crop Science Conference Proceedings. 7: Pp1513-1519.

Ellis J. and Swift D. (1988). Stability of African pastoral ecosystems: alternate paradigms and implications for development. Journal of Range Management. 41(6):450–458.

Elsawalhy A., Mariner J.C. Chibeu D., Wamwayi H., Wakhusama S., Olaho-Mukani W. and Toye P. (2010). Pan African Strategy for the Progressive Control of *Peste des petits ruminants* (Pan African PPR Strategy). Bulletin Animal Health Production Africa 185-193.

ESRI. (1995-2010). Directional Distribution (Standard Deviational Ellipse) (Spatial Statistics) ArcGIS Desktop Help 10.1. Available online at: http://resources.arcgis.com/EN/HELP/MAIN/10.1/index.html#//005p00000016000000

ESRI. (1995-2010).About symbolizing layers to represent quantity. ArcGIS Desktop Help 10.1. Available online at: http://resources.arcgis.com/EN/HELP/MAIN/10.1/index.html#//00s500000034000000

ESRI. (1995-2010).An overview of the Proximity toolset. ArcGIS Desktop Help 10.1. Available online at: http://resources.arcgis.com/EN/HELP/MAIN/10.1/index.html#//000800000018000000

ESRI. (1995-2010). Overlay analysis. ArcGIS Desktop Help 10.1. Available online at: http://resources.arcgis.com/en/help/main/10.1/index.html#//018p00000004000000

ESRI. (1995-2010). Iteration using a count or Boolean condition. ArcGIS Desktop Help 9.2. Available online at: http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Iteration_using_a_count_or_Boolean_condition

Faes C., Van der Stede Y., Guis H., Staubach C., Duchenye E., Hendrickx G. and Mintiens K. (2013). Factors affecting Blue tongue serotype 8 spread in Northern Europe in 2006: The geographical epidemiology. Preventive Veterinary Medicine 110 (2): 149-158.

Fenton A. (2013). Dances with worms: the ecological and evolutionary impacts of deworming on co-infecting pathogens. Parasitology 140: 1119–1132.

Ferrè C (2009). Age at first child Does education delay fertility timing? World Bank Policy Research Working paper Number 4833. Pp 47. Retrieved on October 16 2015 from https://openknowledge.worldbank.org/bitstream/handle/10986/4029/WPS4833.pdf?sequence=1

Food and Agriculture Organisation of the United Nations (FAO-UN) (1999). Manual on procedures for disease eradication by stamping out. ISBN 92-5-104585-2. Retrieved on 17th November 2015 from http://www.fao.org/docrep/004/y0660e/Y0660E00.htm#TOC

Food and Agriculture Organization of the United Nations (FAO-UN) and International Institute for Applied Systems Analysis (IIASA) (2002). Agro-Ecological Zones (AEZ) methodology. Retrieved on 17th November from http://www.fao.org/nr/gaez/en/#sthash.7njUiE7n.dpuf

Food and Agriculture Organisation of the United Nations (FAO-UN) (2009). The status of community animal health in Kenya .Pp 1-63.

Food and Agriculture Organisation of the United Nations (FAO-UN) 2011. Challenges of animal health information systems and surveillance for animal diseases and zoonoses. Proceedings international workshop organized by FAO, 23-26 November 2010, Rome, Italy. FAO Animal Production and Health Proceedings, No. 14. Rome, Italy.Pp116.

Food and Agriculture Organisation of the United Nations (FAO-UN) 2013 b. Supporting livelihoods and building resilience through *Peste des Petits Ruminants* (PPR) and small ruminant diseases control. Animal Production and Health Position Paper. Rome. Pp 16. Retrieved on October 16 2015 from http://www.fao.org/docrep/017/aq236e/aq236e.pdf

Food and Agriculture Organisation of the United Nations (FAO-UN) (2013). Supporting livelihoods and building resilience through *Peste des Petits Ruminants* (PPR) and small ruminant diseases control. Animal Production and Health Position Paper. Rome.

Food and Agriculture Organisation of the United Nations-Statistical division (FAOSTAT) (2014). FAO Statistical Year Book 2014: Africa Food and Agriculture. E-ISBN 978-92-5-108166-2.

Food and Agriculture Organisation of the United Nations (FAO-UN)/ World Organisation for Animal Health (OIE) (2015). Global Strategy for the control and eradication of PPR. OIE ISBN 978-92-9044-989-8 and FAO ISBN 978-92-5-108733-6.P. Pp13-16. Retrieved on October 16 2015 from http://www.fao.org/3/a-i4460e.pdf

Fratkin E. (2001). East African Pastoralism in Transition: Maasai, Boran and Rendille Cases. African Studies Review. 44(3):1-25. Retrieved on October 16 2015 from http://www.smith.edu/anthro/documents/FratkinASRr-2-.pdf

Fratkin, E. and Roth E.A. (2005). As Pastoralists Settle: Social, Health, and Economic Consequences of Pastoral Sedentarization in Marsabit District, Kenya. New York: KluwerAcademic Publishers.

Gatongi P.M., Prichard P.K., Ranjan S., Gathuma J.M., Munyua W.K., Cheruiyot H. and Scott M.E. (1998). Hypobiosis of Haemonchus contortus in natural infections of sheep and goats in a semi-arid area of Kenya. Veterinary Parasitology 77(1). 49-61.

Gatongi P.M., Prichard P.K., Ranjan S., Gathuma J.M., Munyua W.K., Cheruiyot H. and Scott M.E. (1998). Hypobiosis of *Haemonchus contortus* in natural infections of sheep and goats in a semi-arid area of Kenya. Veterinary Parasitology 77(1). 49-61.

Galvin K. (2009). Transitions: pastoralists living with change. Annual Review of Anthropology. 38: 185-198.

Gicheha M.G., Kosgey I.S., Bebe B.O. and Kahi A.K. (2005). Economic values for resistance to gastrointestinal helminths in meat Sheep in Kenya. Journal of Animal Breeding and Genetics. 122(3): 165-171.

Gicheha M.G., Kosgey I.S., Bebe B.O. and Kahi A.K. (2005). Economic values for resistance to gastrointestinal helminths in meat Sheep in Kenya. Journal of Animal Breeding and Genetics. 122(3): 165-171.

Gitao C G., Ithinji D G., Gitari R. and Ireri R. G. (2014). The confirmation of Peste des petit ruminants (PPR) in Kenya and perception of the disease in West Pokot. Research Opinions in Animal and Veterinary Sciences. 4(6): 312-317. Retrieved on October 16 2015 from http://www.roavs.com/pdf-files/Issue-6-2014/312-317.pdf

Government of Kenya (GoK) (2008). Situation analysis and Concept note for the Emergency project for the control of *Peste des petits ruminants* in Kenya. As of June 2008. Pp 1-19.

Government of Kenya (GoK) (2009). *Peste des petits ruminants* (PPR) post vaccination report. As of August 2009. Pp 1-27.

Government of Kenya (2012). Ministry of State for Development of Northern Kenya and other Arid Lands. National policy for the sustainable development of Northern Kenya and other arid lands "Releasing our full potential". Sessional paper No.8.

Government of Kenya (2014). Guidelines for delivery of veterinary services. As of October 2014. Pp 1-82.

Government of Kenya (2015a). Draft national Strategy for the progressive control of *Peste des Petits Ruminants* in Kenya. Zero Draft Version as of February 2015. Pp 1-65.

Government of Kenya (2015b). Kenya Veterinary Policy. As of April 2015.Pp 1-66.

Gustafson C.R., VanWormer E., Kazwala R., Makweta A., Paul G., Smith W. and Mazet J.A.K. (2015). Educating pastoralists and extension officers on diverse livestock diseases in a changing environment in Tanzania. Pastoralism: Research, Policy and Practice. 5(1). DOI 10.11.86/s13570-014-0022-5.

Hendrickx G., Biesemans J. and De Deken R. (2004). The use of GIS in Veterinary Parasitology. In : GIS and Spatial Analysis in Veterinary Science, Durr, P.A and Gatrell A.C. Editors. CABI Publishing, Wallingford, UK. Pp145-176.

Hobbs T.N., Galvin K.A., Stokes C.J., Lackett J.M., Ash J.A., Boone R.B., Reid S.R. and Thornton P.K. (2008). Fragmentation of rangelands: Implications for humans, animals and landscapes. Global Environmental Change. 18(4): 776-785.

Hussaina M.M., Ward P.M., Bodya M., Al-Rawahja A., Wadira A.A., Al-Habisa S., Saqib M., Sayed M., Mahir A. and Almaawalia G. (2013). Spatio-temporal pattern of sylvatic rabies in the Sultanate of Oman. Preventative Veterinary Medicine 110 (3-4): 281-289.

International Institute of Rural Reconstruction (IIRR) (2013). Moving herds, moving markets: making markets work for African pastoralists. Nairobi. ISBN 978-9966-754-07-3. Pp 1-185.

Intergovernmental panel on climate change (IPCC) (2014): Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea,T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken,P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and NewYork, NY, USA. Pp. 1-32.

Ithinji D.G. (2011). *Peste des petits ruminants* manifestation in sheep and goats and its prevalence in in-contact herbivores in Kenya. Master of Science Thesis. University of Nairobi.

Jeffery C., Ozonoff A.L. and Pagano M. (2014). The effect of spatial aggregation on performance when mapping a risk of disease. International Journal of Health Geographics.13(9): 1-9.

Kabaka W., Gitau G.K., Mariner J. and Abudiku N. (2012). The use of participatory epidemiology to determine the prevalence rate and economic impacts of PPR and CCPP in Turkana County of Kenya. Bulletin Animal Health Production Africa 60: 241-249.

Kajiado County Integrated Development Plan (Kajiado-CIDP) 2013-2017. Pp221. Retrieved on October 16 2015 from https://www.kajiado.go.ke/?mdocs-file=9312&mdocs-url=9311

Kasiti J.K.L., Kihara A., Oriki A.A., Okutoyi L.A., Wauna O.J., Tchouassi D.P. Tigoi C.C., Kemp S., Sang R. and Murithi M.R. (2014). Detection of Rift Valley Fever virus interepidemic activity in some hotspot areas of Kenya by sentinel animal surveillance 2009-2012. Veterinary Medicine International. Article ID 379010, 9 pages. http://dx.doi.org/10.1155/2014/379010

Kaufmann, B., Nelson, W., Gudere, R., Canger, V., Golicha, D., Frank, M., Roba, H., Mwai, O and Hülsebusch, C. (2012). Identifying local innovations in pastoral areas in Marsabit County, Kenya.German Institute for Tropical and Subtropical Agriculture (DITSL), Witzenhausen, Germany, 2012. ISBN: 978-3-9801686-9-4. Retrieved on October 16 2015 from https://cgspace.cgiar.org/bitstream/handle/10568/33281/Manual_local_innovations.pdf?sequence=1

Kaye-Zwiebel E. and King E. (2014). Kenyan pastoralist societies in transition: varying perceptions of the value of ecosystem services. Ecology and Society 19 (3): 17. http://dx.doi.org/10.5751/ES-06753-190317

Kenya National Bureau of Statistics (KNBS) 2009. National census report. Retrieved on October 16 2015 from https://www.opendata.go.ke/Agriculture/Census-Vol-II-Q-11-Livestock-population-by-type-an/qbvv-8bjk

Kenyon F., McBean D., Greer A.W., Burgess C.S.G., Morrison A.A., Bartley D.J., Bartley Y., Devin L., Nath M. and Jackson F. (2013). A comparative study of the effects of four treatment regimens on ivermectin efficacy, body weight and pasture contamination in lambs naturally infected with gastrointestinal nematodes in Scotland. International Journal for Parasitology: Drugs and Drug Resistence. 3: 77-84.

Kihu S. M., Njagi L. M., Njogu G. N., Kamande J. N. and Gitao C .G.(2012). Peste des petits ruminants in Kenya; Pastoralist knowledge of the disease in goats in Samburu and Baringo Counties. Research Opinions in Animal and Veterinary Sciences.2 (11): 544-553. Retrieved on October 16 2015 from http://www.roavs.com/pdf-files/Issue_11_2012/544-553.pdf

Kihu S.M., Njagi L.M., Njogu G.N., Kamande J.N. and Gitao C.G. (2012). *Peste des petits ruminants* in Kenya; Pastoralist knowledge of the disease in goats in Samburu and BaringoCounties. Research Opinions in Animal and Veterinary Sciences.2 (11): 544-553.

Kihu S. M., Gachohi J.M.., Gitao C.G., Bebora L.C., Njenga J.M., Wairire G.G., Maingi N. and Wahome R.G. (2013). Analysis of small ruminants' pastoral management practices as risk factors of *Peste des petits ruminants* (PPR) spread in Turkana District, Kenya. Research Opinions in Animal and Veterinary Sciences. 3(9): 303-314.

Kihu S.M., Gitao C.G., Bebora L.C., Njenga J.M., Wairire G.G., Maingi N. and Wahome R.G. (2015a). Economic losses associated with Peste des petits ruminants in Turkana County Kenya. Pastoralism: Research, Policy and Practice. 5(9). DOI 10.1186/s13570-015-0029-6. Retrieved on October 16 2015 from http://www.pastoralismjournal.com/content/pdf/s13570-015-0029-6.pdf

Kihu S. M., Gachohi M., Ndungu E. K., Gitao C. G., Bebora L. C. , Njenga J. M., Wairire G.G,Maingi N., Wahome R .G .and Ireri R.(2015b.) Sero-epidemiology of Peste des petits ruminants virus infection in Turkana County, Kenya. BMC Veterinary Research. 11:87. Retrieved on October 16 2015 from http://www.biomedcentral.com/content/pdf/s12917-015-0401-1.pdf

Kocheki A. and Gliessman R. (2005). Pastoral Nomadism: A Sustainable System for Grazing Land Management in Arid Areas. Journal of Development Agriculture 25 (4): 113-131.

König Z E, Mirkena T, Strandberg E, Audho J, Ojango J, Malmfors B, Okeyo A W and Philipson J 2015. Participatory definitions of breeding objectives for sheep breeds under pastoral systems- the case of Red Maasai and Dorper sheep in Kenya. Tropical animal health and Production. Retrieved on October 16 2015 from http://link.springer.com/article/10.1007%2Fs11250-015-0911-7

Kosgey I.S., Rowlands G.J., Van Arendonk J.A.M. and Baker R.L. (2008). Small ruminant production in small holder and pastoral/extensive farming systems in Kenya. Small Ruminant Research 77:11-24.

Kumar N., Maherchandani S., Kashyap S.K., Singh S.V., Sharma S., Chaubey K.K. and Hinn Ly. (2014). Peste des petits ruminants virus infection of small ruminants: A comprehensive review. Viruses. 6:2287-2327. DOI: 10.3390/v6062287. Retrieved on October 16 2015 from http://www.mdpi.com/1999-4915/6/6/2287

Latimer, K.S., Mahaffey, E.A. and Prasse, K.W., (2003). Veterinary Laboratory Medicine, Clinical Pathology. 4th Edition, Iowa State Press USA. ISBN 0-8138-2070-7. Pp 473.

Leta S. and Mesele F. (2014). Spatial anlaysis of cattle and shoat population in Ethiopia: growth trend, distribution and market access. Springer Plus 3:310.

Libeau G, Prehaud C, Lancelot R, Colas F, Guerre L,Bishop DHL, Diallo A (1995). Development of a competitive ELISA for detecting antibodies to the *peste des petits ruminants* virus using a recombinant nucleoprotein. Research in Veterinary Science. 58 (1): 50-55.

Libeau G. Diallo A. and Parida, S. (2014). Evolutionary genetics underlying the spread of *peste des petits ruminants* virus. Animal Frontiers.4: 14–20.

Little D.P. (2002). Rethinking interdisciplinary paradigms and the political ecology of pastoralism in East Africa. *In* African Savannas: Global Narratives and Local Knowledge of Environmental Change. Basset T. and Crummey D. Oxford UK. James Currey Publishers.Pp 1-31.

Luka P.D., Erume J., Mwiine F.J. and Ayebazibwe C. (2011). Seroprevalence of Peste des petits ruminants Antibodies in Sheep and Goats after Vaccination in Karamoja, Uganda: Implication on Control. International Journal of Animal and Veterinary Advances 3(1): 18-22.

Madder M., Walker J.G., Van Rooyen J., Knobel D., Vandamme E., Berkvens D., Vanwambeke S.O. and De Clercq E.M. (2012). e- Surveillance in Animal Health: use and evalution of moile tools. Parasitology 139(14): 1-12.

Maina S.M., Gitao C.G. and Gathumbi P.K. (2015). Clinico-pathological observations in sheep and goats exposed to lineage III *Peste des petits ruminants* virus infection in Kenya. Journal of Experimental Biology and Agricultural Sciences. 3(1). 72-80.

Marsabit County Integrated Development Plan (Marsabit-CIDP) 2013-2017. Pp1-334. Retrieved on October 16 2015 from http://marsabit.go.ke/wp-content/uploads/2015/04/County-Integrated-Development-Plan.pdf

Mbithi P.M.F., Mulei C.M. and Mogoa E.G.M (2003). Restraint of domestic, wild and laboratory animals: A manual for veterinary students, practitioners and animal handlers. University of Nairobi press. Pp 26-28.

McCabe, J. Terrence (1990), "Turkana Pastoralism: A case Against "The Tragedy of the Commons," Human Ecology. 18(1): 81-103.

McKenzie J. (1999). The use of habitat analysis in the control of wildlife tuberculosis in New Zealand. A thesis presented in partial fulfilment of the requirements of Doctor of Philosophy at Massey University New Zealand.

McNeilly T.M. and Nisbet A.J. (2014). Immune modulation by helminth parasites of ruminants: implications for vaccine development and host immune competence. Parasite 21(51): DOI: 10.1051/parasite/2014051.

Millennium Ecosystem Assessment (MEA) (2005). Ecosystems and Human Well-being: Synthesis.Island Press, Washington, DC.

Moenga B.O., Muchemi G.M., Kang'ethe E.K., Kimenju J.W., Mutiga E.R. and Matete G.O. (2013). Impact of climate change on the incidence of cattle diseases in a pastoral area of Kenya. Livestock Research for Rural Development 25:4.

Morara M K, MacOpiyo L and Kogi-Makau W 2014. Land Use, land cover cjange in urban pastoral interface. A case of Kajiado County, Kenya. Journal of Geography and Regional Planning. 7(9): 192-202. Retrieved on October 16 2015 from http://www.academicjournals.org/journal/JGRP/article-full-text-pdf/0EAE70C48265

Muse E.A, Karimuribo E D, Gitao C G, Misinzo G, Mellau L S B, Msoffe P L M, Swai E S and Albano M O 2012. Epidemiological investigation into the introduction and factors for spread of Peste des Petits Ruminants, Southern Tanzania. Onderstepoort Journal of Veterinary Research. (79): 457.Pp 1-6. Retrieved on October 16 2015 from http://www.ojvr.org/index.php/ojvr/article/viewFile/457/524

Muthee A 2006. Kenya Livestock Sector Study: an Analysis of Pastoralist Livestock Products Market Value Chains and Potential External Markets for Live Animals and Meat. Deloitte Consulting Limited, African Union- InterAfrican Bureau for Animal Resources (AU-IBAR). Retrieved on October 16 2015 from http://www.bdsknowledge.org/dyn/bds/docs/552/KenyaLivestockValueChainReport.pdf

Mwanyumba P M, Wahome R G, MacOpiyo L and Kanyari P 2015. Pastoralist livelihoods, resources and strategies in Garissa County, Kenya. Livestock Research for Rural Development 27(10). Article number 202, retrieved on October 16 2015 from http://www.lrrd.org/lrrd27/10/mwan27202.html

National Drought Monitoring Authority (NDMA). County monthly drought early warning bulletins August 2012 to February 2015). Retrieved from http://www.ndma.go.ke/

Ng'asike J. T. (2011). Turkana children's rights to education and indigenous knowledge in science teaching in Kenya. New Zealand Journal of Teachers' work 8(1): 55-67. Retrieved on October 16 2015 from http://www.teacherswork.ac.nz/journal/volume8_issue1/ngasike.pdf

Njanja J.C., Gathuma J. M. Gitau G.K. Njeruh F.M. and Kinuthia R.N. (2003). Pastoralists' perception of livestock production systems and opportunities for improvement in South-western Marsabit, Kenya. Livestock Research for Rural Development 15(7). Retrieved on 15th November 2015 from http://www.lrrd.org/lrrd15/7/njan157.htm

Njuki J. and Sanginga P.C. (2013). Women, livestock ownership and markets. Bridging the gender gap in Eastern and Southern Africa. International Livestock Research Institute (ILRI) and International Development Research Centre (IDRC). ISBN 987-0-203-08360-4. Pp 1-143.

Noremark M. and Widgren S. (2014). EpiContact Trace: an R-package for contact tracing during livestock disease outbreaks and for risk based surveillance. BMC Veterinary Research 10: 7-1.

Norstrom M. (2001). Geographical Information System (GIS) as a tool in surveillance and monitoring of animal diseases. Acta Veterinary Scandinavian. 97: 79-85.

Notenbaert M.O., Davies J., De Leeuw J., Said M., Herrero M., Manzano P., Waithaka M., Aboud and Omondi S. (2012). Policies in support of pastoralism and biodiversity in the heterogenous dry lands of East Africa.Pastoralism: Research, Policy and Practice. 2:14.

Nyamweya M., Ounga T., Regassa G. and Maloo S. (2010). Technical brief on Peste des petits ruminants ELMT (Enhanced Livelihood in the Mandera Triangle) Livestock services technical working group.

OIE/FAO-UN/WHO (2006). Global Early Warning and Response System for Major Animal Diseases, including Zoonoses (GLEWS). A tripartite agreement.

Olabode O.H., Kazeem H.M., Raji M.A., Ibrahim D.N. and Nafarnda W.D. (2014). Geo-spatial distribution of serologically detected bovine Foot and Mouth Disease (FMD) serotype outbreaks in Ilesha Baruba, Kwara State-Nigeria. Journal of Advanced Animal Research 1(3): 94-99. DOI: 10.5455/javar.2014.a20

Onono O.J., Wieland B. and Rushton J. (2013). Factors influencing choice of veterinary service provider by pastoralist in Kenya. Tropical Animal Health and Production 45:1439-1445.

Ortiz-Pelaez A., Pfeiffer D.U., Tempia S., Otieno F.M., Aden H.H. and Costagli R. (2010). Risk mapping of Rinderpest sero-prevalence in Central and Southern Somalia based on spatial and network risk factors. BMC Veterinary Research. 6:22. http://www.biomedcentral.com/1746-6148/6/22

Peacock C. (2005). Goats- A pathway out of poverty. Small Ruminant Research 60:179-186

Perry B.D., Delia G. and Sones K. (2013). Current drivers and future directions of global livestock disease dynamics. Proceedings of the National Academy of Sciences of the United States of America. 110 (52): 20871- 20877. DOI: 10.1073/pnas.1012953108.

Pfeiffer D.U., Robinson T.R., Stevenson M., Stevens K.B., Rogers D.J. and Clements A.C.A. (2008). Spatial analysis in epidemiology. Oxford University Press United Kingdom. ISBN 978–0–19–850989–9.

Perez M.A., Zeng D., Tseng C., Chen H. Whedbee Z., Paton D. and Mark C. Thurmond (2009). A web-based system for near real-time surveillance and space-time cluster analysis of foot-and-mouth disease and other animal diseases. Preventive Veterinary Medicine 91 : 39-45.

Prattley D.J. (2009). Risk based surveillance in animal health. A Doctor of Philosophy Thesis Massey University, Permerston, North New Zealand.

Premashthira S. (2012). Uses of quantitative spatial analysis and epidemiological simulation modeling for assessing control strategies for foot-and-mouth disease. Doctor of Philosophy Thesis Colorado State University

Radostits, O.M.; Gay, C.C.; Blood, D.C. and Hinchcliff, K.W. (2000). Peste des petits ruminants. In: Veterinary Medicine, 9th edition .W.B. Saunders, London. pp1077-1079.

Rutto J.K., Odhiambo M.O., Njuguna E.M, and Murithi F.M. (2013). Determinants of market participation decisions in small ruminants' market by livestock keepers in Isiolo and Marsabit Districts, Kenya. Livestock Research for Rural Development 25:3.

Salih A.H.M., Elfadi A.A.M.,Saeed K.I. and Ali Y.H. (2014). Seroprevalence and risk factors of peste des petits ruminants in sheep and goats in Sudan. Journal of Advanced Veterinary Animal Research. 1(2): 42-49. Retrieved on October 16 2015 from http://www.scopemed.org/fulltextpdf.php?mno=158717

Sanson R.I., Pfeiffer D.U. and Morris R.S. (1991). Geographic information systems: their application in animal disease control. Scientific and Technical Review of the Office International des Epizooties 10 (1): 179-195.

Schuurman N., Fielder S.R., Grzybowski S.C.W. and Grund D. (2006). Defining rational hospital catchments for non-urban areas based on travel time. International Journal of Health Geographics 5: 43. DOI: 10.1186/1476-072X-5-43.

Schwartz H.J., Shabaani S. and Walther D. (1991). Marsabit District Range Management Handbook of Kenya Volume II, pp 164. Ministry of Livestock Development, Nairobi, Kenya.

Schiling J., Opiyo F.E.O. and Scheffran J. (2012). Raiding pastoral livelihoods: motives and effects of violent conflict in North-Western Kenya. Pastoralism: Research, Policy and Practice. 2:25.

Steinfeld H., Wassennar T. and Jutzi S. (2006). Livestock Production Systems in developing countries: Status, drivers,trends. Scientific and Technical Reviews (OIE). 25 (2): 505-516.

Thornton P.K. (2010). Livestock production: recent trends, future prospects. Transactions of The Royal Society. 365: 2853-2867.

Tom Koch (2005). Cartographies of diseases: Maps, Mapping and Medicine. ESRI press, 380, New York street, Redland, California 92373-8100.

Thumbi S.M., Junga J.O., Mosi R.O. and McOdimba F.A. (2010). Spatial distribution of African Animal Trypanosomiasis in Suba and Teso districts in Western Kenya. BMC Research Notes 2010, 3:6.

Thumbi S.M., Bronsvoort B.M. De. C., Poole E. J., Kiara H., Toye P., Ndila M., Conradie I., Jennings A., Handel I.G., Coetzer J.A.W.,Hanotte O and Woolhouse M.E.J. (2013). Parasite co-infections show synergistic and antagonistic interactions on growth performance of East African zebu cattle under one year. Parasitology 140: 1789-1798.

Thumbi S.M., Bronsvoort B.M.de.C., Poole E.J., Kiara H, Toye P.G. Ndila M., Conradie I., Jennings A., Handel I.G., Coetzer J.A.W.,Hanotte O and Woolhouse M.E.J. (2014). Parasite Co-Infections and Their Impact on Survival of Indigenous Cattle. PLoS ONE 9(2): e76324. DOI:10.1371/journal.pone.0076324. Retrieved on October 16 2015 from http://www.plosone.org/article/fetchObject.action?uri=info:doi/10.1371/journal.pone.0076324&representation=PDF

Thumbi S.M., Bronsvoort B.M.de.C., Poole E.J., Kiara H, Toye P.G. Ndila M., Conradie I., Jennings A., Handel I.G., Coetzer J.A.W.,Hanotte O and Woolhouse M.E.J. (2014) Parasite Co-Infections and Their Impact on Survival of Indigenous Cattle. PLoS ONE 9(2): e76324. DOI:10.1371/journal.pone.0076324.

Vatta, A.F., Abbot, M.A., Villiers, J.F., Gumede, S.A., Harrison, L.J.S., Krecek, R.C., Letty, B.A., Mapenyi, N. and Pearson, R.A. (2006). Goat Keepers' Animal Health Care Manual. Agricultural Research Council. Onderstepoort Veterinary Institute with KwaZulu-Natal Department of Agriculture and Environment, South Africa. Pp 1-60.

Wabacha J K, Mulei C M, Gitonga N P, Njenga M J, Thaiyah A G, Nduhiu J. (2007). Atypical dermatophilosis of sheep in Kenya. Journal of the South African Veterinary Association 78(3): 178–181.

Waruiru R.M. Ngotho J.W. and Mukiri J.G. (1997). Multiple anthelmintic resistance in *Haemonchus contortus* on a sheep farm in Kenya. Veterinary Research Communications. 7:483-491.

Weiss D.J and Wardrop K.J.(2010). Schalm's Veterianry Hematology 6th Edition. Wiley-Blackwell publishers. Pp 836- 842.

Wolf C 2005. Producer Livestock Disease Management Incentives and Decisions. International Food and Agribusiness Management Review. 8(1): Pp 46-61. Retrieved on October 16 2015 from http://ageconsearch.umn.edu/bitstream/8179/1/0801wo01.pdf

World organization for animal health (OIE) 2013. Peste Des Petits Ruminants. Chapter 2.7.11:Pp1–14. Retrieved on October 16 2015 from http://www.oie.int/fileadmin/Home/fr/Health_standards/tahm/2.07.11_PPR.pdf

Young J., Kajume J. and Wanyam J. (2003). Animal health care in Kenya: The road to community-based animal health service delivery. Working paper 214. Overseas Development Institute. 111 Westminister Bridge Road SE1 7 JD. UK.

Zajac A.M and Conboy G.A. (2012). Veterinary Clinical Parasitology 8th Edition. John Wiley and Sons Incorporation. ISBN-13: 978-0-8138-2053-8. Pp 3- 39.

APPENDIX1 1: Ethical Clearance Letters

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Dr Pauline N. Gitonga,
c/o Dept of Land Resource Management & Agric. Technol.

10/07/2015

Dear Dr Gitonga,

RE: Approval of Proposal by Biosafety, Animal use and Ethics committee

Mapping risk factors associated with Pestes-des-petits-ruminantia (PPR) infections in pastoral systems of Kajiado and Marsabit, Kenya.
By Pauline Njoki Gitonga Re:A74/84381/2012

We refer to the above revised proposal that you submitted to our committee. We have now reviewed your proposal and have noted that you have satisfactorily addressed the issues that had been raised in our letter to you dated 24/02/2015.

Among these were issues regarding inclusion of methodological details in the proposal, biosafety measures to be taken when obtaining, transport and handling samples. Furthermore, you have also addressed occupational health and safe disposal of biological waste.

We hereby approve your work as per the revised proposal.

Rodi O. Ojoo BVM, M.Sc, Ph.D
Chairman, Biosafety, Animal Use and Ethics Committee,
Faculty of Vet. Medicine.

DIRECTOR OF VETERINARY SERVICES
RECEIVED
11 SEP 2013
MAIN REGISTRY
KABETE

University of Nairobi
College of agriculture and Veterinary Sciences
P.O. Box 29053, 00625
Nairobi

11th September 2013

Director of Veterinary Services
Central Veterinary Laboratories
Kabete, Nairobi Kenya

For DIRECTOR OF VETERINARY SERVICES

Dear Sir,

RE: REQUEST TO ACCESS DISEASE INCIDENCE RECORDS

I am a PhD student at the University of Nairobi developing a proposal titled: "**Comparative risk analysis of factors associated with occurrence and distribution of small ruminant diseases in Narok and Isiolo Counties of Kenya**". The study will use risk analysis tools of community participation, geographical information system and statistical modelling to identify socioeconomic, environmental, production and marketing risk factors that enhance the spread of 3 small ruminant diseases namely Peste des petits ruminants, sheep and goat pox and contagious ecthyma (orf).The study will also map the disease control and surveillance strategies that are in place in the 2 counties and evaluate their efficiency. As a preliminary preparation of my proposal I will require data on the past and current outbreaks of the 3 diseases in Kenya.

I kindly request your office to grant me access to the laboratory and epidemiological data for the 2 Counties. This will greatly facilitate the identification of study areas as well as quantification of budget lines.

Please find attached a concept note of the project.

Sincerely,

Dr. Pauline Gitonga (BVM, MSc (UON)
PhD Student: Dryland Resource Management Department of Land Resources Management and Agricultural Technology (LARMAT)
Mobile: +254-722-762910: Email: paulagitonga@yahoo.co.uk

APPENDIX 2: Livestock Owners Survey Questionnaire

Recorders name_____ Date of interview_____
Background information
County name ……..
Sub-county ……..
Wards …….
Village: …….
GPS reading of Manyatta ……..
House Hold number……..
Mobile Number……..

Section A: House hold Demography

Household head Male ( ) Female ( )
Name…….. Age……
Level of formal education: None ( ) ( ) Lower primary ( ) Upper primary ( ) High school ( ) Tertiary ( )
House hold size (a)Number of wives……..(b)Number of children…….
Under 5years……..6-18years……..>19years……..
Do they attend formal school Yes ( ) No ( )

Section B: Animal Husbandry Practices

Number of sheep?..... Number of goats…… (observation)
Breed of sheep kept?.....
Breed of Goat kept ?.....
Grazing source distance? <5Kms ( ) , <10 Kms ( ), 15-20Kms ( ), >20 Kms ( )
Watering source distance? 5Kms ( ) , <10 Kms ( ), 15-20Kms ( ), >20 Kms ( )
Where do you source your sheep and goat from?.....
Have you had of PPR disease?.....
What are the clinical signs?.....
Has it ever occurred in your flock of animals?.....
What diseases occurred in sheep last year?.....
What disease occurred in goats last year?.....
In both sheep and goats were all ages affected (explain)?.....
……
……..
Season of disease occurrence ……..…
……
……
……
Which disease had highest losses (explain)……
……..
……..
What vaccine did you give goats last year?.....
……
……
What vaccine did you give sheep last year?.....
……
When do you vaccinate?.....
……..
……
Are sheep and goat vaccines expensive…….

……
Who vaccinates your sheep and goats ……..
……..
Where do you think the above sheep and goat diseases come from …….
……
……
How do you control worms in your shoats?.....
…….
Which dewormer do you use?.....
……
Where do worms come from?.....
……
How do you control ticks/fleas and mites?.....
…….
What product do you use?.....
……..
Where do ticks/fleas/mites come from……
……
Do you think the dewormers are effective?.....
……..
Do think tick/flea/mite washes are effective?.....
…….

Section C: Household Socio- Economic practices

What is your main source of income?

Livestock keeping only ( ) Mixed- crop and livestock farming ( ) other ( )

What type of livestock species do you keep?

Cattle ( ), Sheep and Goats ( ) Donkeys ( ) Camels ( ) Poultry ( )

Who decides when to sell the small stock or purchase new stock?

Household head ( ) Wife ( ) Both ( )

What role do sheep and goats play in providing food for home consumption when compared to other livestock species? 25% ( ) 50% ( ) 75 % ( ) 100% ( )

What role do sheep and goats play in income generation when compared to other livestock species? 25% ( ) 50% ( ) 75 % ( ) 100% ( )

Which livestock specie has the highest production input cost?.....
……

Current price in the market for live sheep and goats?.....

Where do you source market for shoats and how far is it?.....
……

How do you report disease outbreaks in your livestock and to whom?.....
……..

Where do you get animal husbandry practices information…….
……..

What do you think are the challenges facing you as you try to control disease outbreaks in your herd?.....
……

What do you think can be done to control livestock diseases in your area?.....
……

APPENDIX 3: Data Collection Consent Form

English Version

Research Project Title: **Risk factors associated with occurrence and distribution of small ruminant diseases (PPR/Oludua) in pastoral production systems of Kenya.**

My name is Dr. Pauline Gitonga a PhD student from the University of Nairobi. I am conducting a study that will collect information on the risk factors causing small ruminant diseases specifically PPR/Oludua and other important diseases such as CCPP/Olkipei. I am requesting your consent to ask some personal questions concerning your animal husbandry practices. I am also requesting for consent to collect blood (10 mls) and Faecal samples from selected sheep and goats in your flock. These samples will enable me investigate if your goat and sheep flocks have protective antibody levels against PPR/Oludua as well as detect underlying parasitic conditions that may interfere with the animal's immunity.

Confidentiality Clause
Your name and personal details will be kept confidential and will not be disclosed in any publication or to third parties other than the members of this research project.

Benefits
There will be no immediate benefits to you. However, study findings will be forwarded to you through the County Veterinary Office representative. The information given will allow the Ministry of Livestock and animal health providers in your area make informed choices when designing disease control and surveillance programmes.

Withdrawal from the study
You can refuse at any point from participating in the study

Consent

I _____ Tel contact_____

Agree/ do not Agree to take part in this study and I Allow / do not Allow my animals to be sampled.

Signature of respondent:_____ Date:_____

Signature of Researcher:_____ Date: _____

Swahili Version

Utafiti wa Mradi wa : Mambo ya hatari inayohusiana na tukio na usambazaji wa magonjwa ya mbuzi na kondoo haswa (PPR / Oludua) katika mifumo ya ufugaji Kenya.

Mimi ni dakatari wa mifugo na jina langu ni Pauline Gitonga. Mimi ni mwanafunzi anayesomea shahada ya udakatari katika chuo Kikuu cha Nairobi. Ninashiriki katika utafiti wa kukusanya taarifa juu ya hatari zinazohusiana na tukio na usambazaji wa magonjwa ya kondoo na mbuzi haswa PPR / Oludua na magonjwa mengine kama CCPP/ Olkipei. Ninaomba idhini yako kuuliza maswali ya kibinafsi na inayo husu mambo ya ufugaji. Vile vile nakuomba idhini ya kukusanya damu (10 mls) na sampuli ya kinyesi kutoka kondoo na mbuzi walio katika kundi lako la wanyama. Sampuli hizi zita niwezesha mimi kuchunguza kama mbuzi na kondoo wako wana kinga ya kuwalinda kutoka ugonjwa wa PPR / Oludua. Kama vile, sampuli hizi zitabainisha kama wanyama wake wana minyoo ama vimelea ya damu ambazo sita ingilia kati ya kinga ya PPR/Oludua.

Kifungo cha Siri
Jina lako na maelezo utayonipatia itakuwa siri na haitafunuliwa katika uchapishaji yoyote au kutangazwa kwa watu wasiohusika na utafiti huu.

Faida
Hakutakuwa na faida ya haraka. Hata hivyo, matokeo ya utafiti yatatumwa kupitia mwakilishi aliye ofisi ya Wizara ya Mifugo. Habari hii itaruhusu Wizara ya Mifugo na watoa huduma za afya ya wanyama katika eneo lako kufanya maamuzi sahihi wakati wa kubuni mikakati ya kudhibiti magonjwa ya kondoo na mbuzi imeacha kuenea.

Kujitoa kutoka utafiti
Unaweza kukataa kujihusisha au Kushiriki kwa utafiti huu.

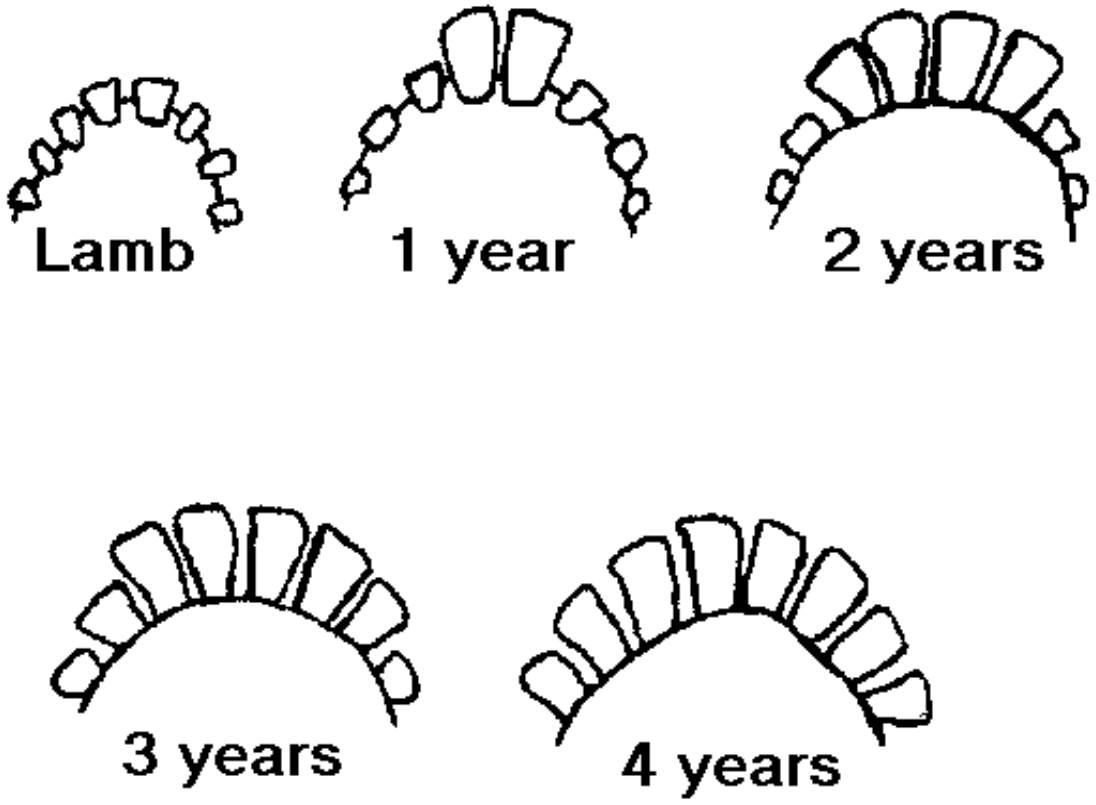
Idhini

Mimi_____Nambari ya simu _____
Nakukubali /Sikubali kuhusika na uatfiti huu. Vili vile nina ruhusu / si ruhusu wanyama wangu wachukuliwe sampuli.

Sahihi ya Mshiriki : _____ Tarehe: _____

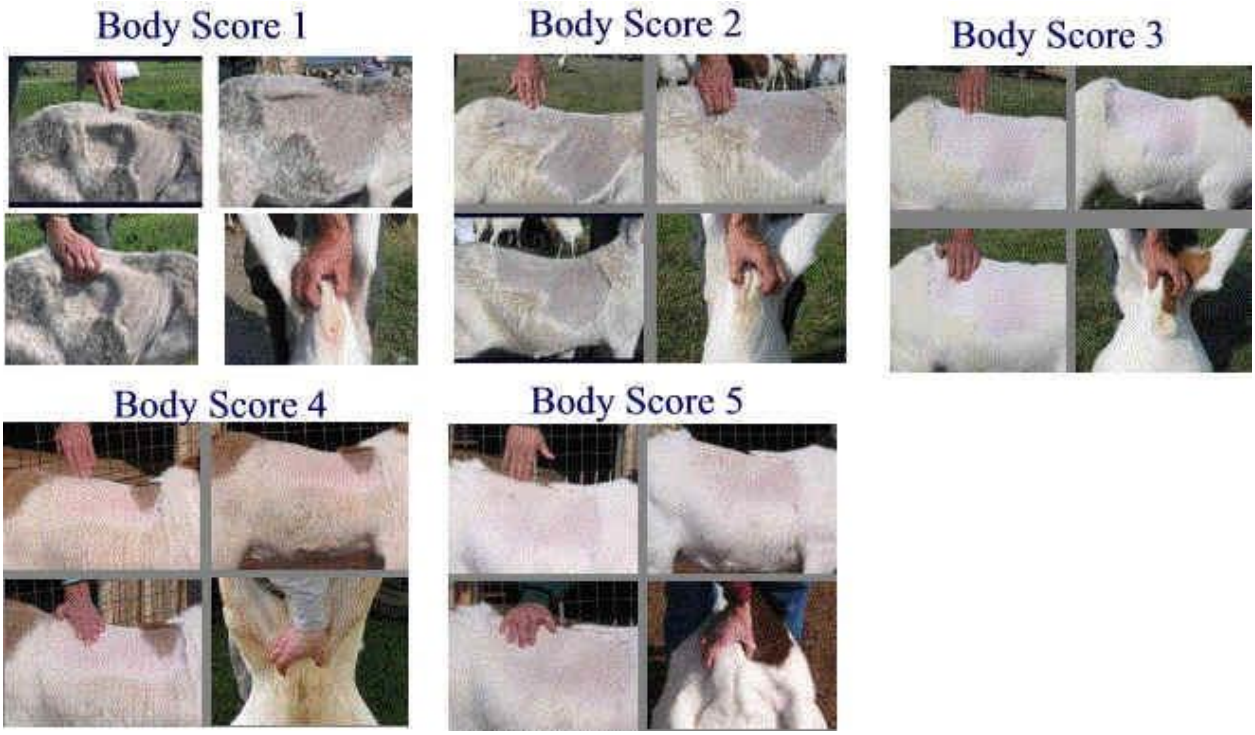
Sahihi ya Mtafiti : _____ Tarehe: _____

APPENDIX 4: Ageing Dentition Chart



Dentition showing estimated ages of sheep and goats (Adapted from Vatta et al. 2006)

APPENDIX 5: Body Condition Score Chart

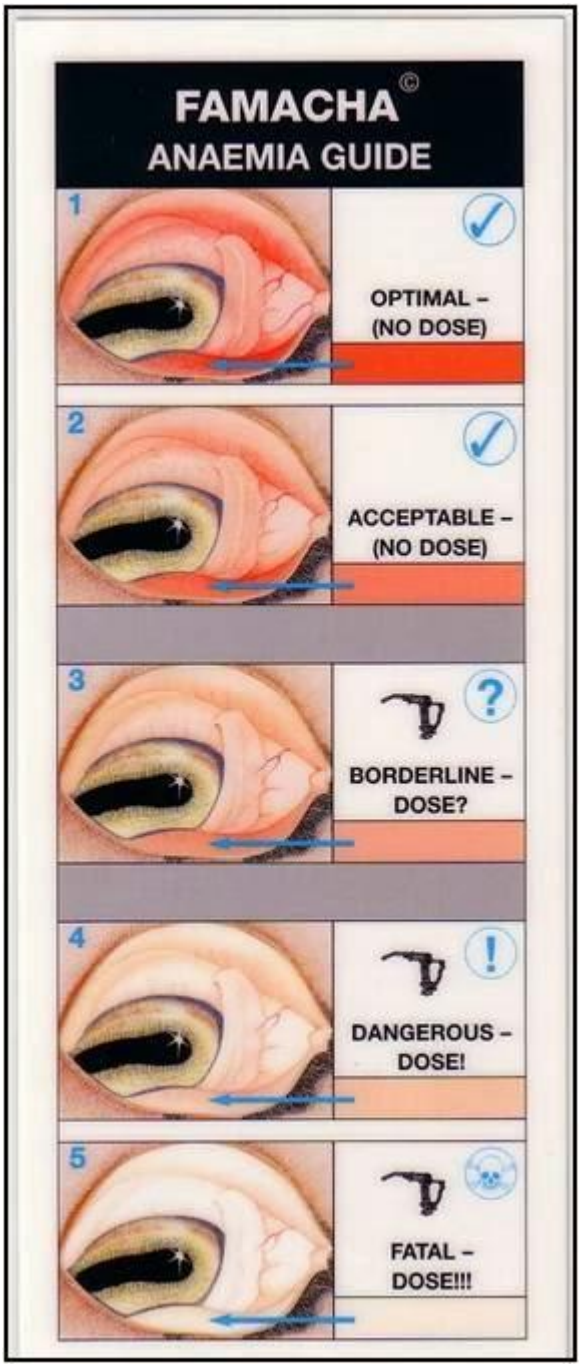


BCS	Spinous processes	Transverse Processes	Loin Muscle/Fat
1 **Emaciated**	Sharp and stick out	Sharp and finger easily pushes under ends	Loin muscle concave, no fat
2 **Thin**	Less sharp	Fingers can push under with little pressure	Loin muscle concave, no fat
3 **Optimum**	Stick up slightly. Smooth and rounded. Firm pressure	Smooth and covered., Firm pressure required	Loin muscle moderate depth, no fat

	needed to detect each one separately	to push fingers under ends	
4 **Fat**	Can be just felt. Level with flesh on either side	Ends cannot be felt	Loin muscle full and some fat cover
5 **Obese**	Cannot be felt at all. Hollows in back.	Cannot be felt	Loin muscle fully developed. Thick fat cover

Adapted from Meat Goat Production Handbook, Langston University, 2007

APPENDIX 6: FAMACHA® Score Card



FAMACHA® system for detecting the severity of anaemia (Adapted from Vatta et al., 2006)

APPENDIX 7: Approximate straight line distances

Table showing approximate line distances from Namanga veterinary office to sampled herds in Kajiado County Kenya (January – February 2014)

Homestead number	Ward	Approximate Distance in Kms
1	Meto	43.8
2	Meto	42.6
3	Meto	40.5
4	Meto	39.5
5	Meto	38.1
6	Kumpa	34.0
7	Kumpa	34.6
8	Kumpa	35.0
9	Kumpa	33.9
10	Kumpa	33.0
11	Oloimirmir	45.5
12	Oloimirmir	45.2
13	Oloimirmir	43.6
14	Oloimirmir	43.2
15	Oldonyorok	43.3
16	Oldonyorok	21.9
17	Oldonyorok	25.9
18	Oldonyorok	27.0
19	Oldonyorok	28.9
20	Oldonyorok	29.4

Table showing approximate line distances from Marsabit veterinary offices to sampled herds in Marsabit County Kenya (August 2014 – March 2015)

Homestead number	Ward	Approximate Distance in Kms
1	Kargi/South Horr, Kurugu	42.1
2	Kargi/South Horr, Kurugu	63.5
3	Kargi/South Horr, Kurugu	63.1
4	Kargi/South Horr, Arge	57.2
5	Kargi/South Horr, Arge	71.3
6	Loiyangalani/Olturot	31.4
7	Loiyangalani/ Ngororoi Fora	19.0
8	Loiyangalani/ Arapal	22.0
9	Kargi/South Horr/ Kargi town	63.5
10	Kargi/South Horr Fora	36.4
11	Kargi/South Horr/ Ririma Fora	63.1