AN INVESTIGATION OF FARM CONTACTS AND THEIR POTENTIAL IMPACT ON DISEASE TRANSMISSION IN SMALLHOLDER CATTLE PRODUCTION IN BUNGOMA COUNTY OF WESTERN KENYA

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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN VETERINARY EPIDEMIOLOGY AND ECONOMICS

DEPARTMENT OF PUBLIC HEALTH, PHARMACOLOGY AND TOXICOLOGY

FACULTY OF VETERINARY MEDICINE,

UNIVERSITY OF NAIROBI

2015

DECLARATION

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

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This research project is dedicated to my wife Sophie and children Sonia and Wallace for their emotional support throughout the period of undertaking the project.

ACKNOWLEDGEMENTS

I thank the Almighty God for giving me good health, opportunity and strength to undertake this study. For this, I glorify and honor His name. I am gratefully indebted to my supervisors, Prof. George Gitau, Prof. Eric Fevre and Dr. Gerald Muchemi, for being available for me and for providing the much needed guidance during the project and thesis writing. My thanks go to William De Glanville who was very instrumental in developing the study. He was very supportive and coordinated the study to the end even though he was outside the country.

Special thanks to International Livestock Research Institute for funding the project. My thanks are extended to Dr. Rob Christley for sharing his experiences and providing valuable input to this work. I also appreciate the support of the then Ministry of Livestock Development for granting me study approval to enable me pursue the studies.

To all the village elders who dedicated their time in helping me administer the questionnaire, I owe them a great debt of gratitude for their patient help throughout the study. I am grateful to Lawrence Opado, Guy Mumelo, Felix Makari and other staff of Veterinary office Kimilili for their logistical and emotional support during the project work.

Special thanks to my family: wife Sophie, children Sonia and Wallace for their patience, support and understanding. I am also grateful to my mother, brother and all my friends for their prayers and encouragement. Last but not the least; my thanks go to the Bungoma County livestock farmers for their warm hospitality and patience as we administered the questionnaires. They also generously supported the study by providing the necessary information. God bless them and their livestock.

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LIST OF DEFINITIONS

Nodes	Unit of interest in network analysis e.g farms.
Arcs	A directed link between two nodes.
Edges	An undirected , reciprocal link between two nodes.
Network Topology	It is the study of the arrangement or graphing of the elements(nodes, Links) of a network. Also known as network architecture.
Isolates	Unconnected nodes in the network.
Path length	The number of steps required to travel from one node to another.
Geodesic Path	The shortest path length between two nodes
Fragmentation	The proportion of pairs of farms that are unreachable in the network ; a path does not exist between them.
Clustering Coefficient	Density of the ego network after removal of the ego.
Node Centrality	The importance of the node.
Degree	The number of links incident to a node
Normalized degree	The degree of the node divided by the number of the nodes in the network.
Density	Proportion of all possible links that are actually present
Betweeness Centrality	The frequency of a node in the shortest path between pairs of nodes in the Network
Closeness Centrality	An estimate of how closely connected a node is to all other nodes of the network

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ABSTRACT

Farm animal movement usually occurs during grazing, watering, and dipping and livestock trade among others. These movements create contacts between different farms and the contacts created form networks of varying magnitude ranging from local to international depending on the scale of movement of animals. The networks are dynamic in nature and are mostly influenced by season which determines the availability of pasture and water. Contacts created act as routes through which disease pathogens may spread between farms in various geographical locations. Farms which are infected act as sources of infection to other farms when there is movement of animals from the infected farms to non-infected farms.

Limited studies have been done in Africa on contact networks between herds to give a better understanding of the spread of infectious pathogens. Most predictive models for farm animal diseases focus on gathering information and estimating transmission parameters with little attention on modeling the underlying network of contacts. These models also ignore the complex structures present at different levels including between animals, farms and the regions. Lack of accurate information on contact structures and the factors affecting them is also a challenge when complex structures are considered. Therefore understanding of the contact networks between farms is critical in instituting proper surveillance and control measures. The overall objective of the study was to determine and assess the types of contact networks between herds and the potential for transmission of diseases. The specific objectives were to determine the existing contact networks between cattle herds, to determine the frequency of the contact network between farms and to determine the factors affecting heterogeneity in contact in the study area.

The study area was in Kimilili Sub-county of Bungoma County. This was a cross sectional study involving seven villages randomly sampled. A census of all cattle keeping households in the sampled villages was undertaken. Farm contacts within these villages of Bungoma County

were explored using contact structure interview which involved a combination of photo-elicitation, structured questionnaire and a contact collection form.

In total 329 farms were included in the study. The farm contacts as a result of sharing grazing fields, water points for the four weeks during the wet season (October-December) together with breeding and ploughing contacts for the last one year of the study was reconstructed and analyzed for the seven villages. The overall farm networks for the various farm contacts in the villages were also visualized.

There was significant difference in the proportion of farmers that took their animals for grazing outside their farms daily during dry and rainy season ($z = 6.52$, $p = 0.0000$,) and the proportion of farms that took their livestock for water daily outside their homestead during dry and rainy seasons was also significantly different ($z = 2.75$, $p = 0.006$). The overall farm contacts and the distances among the farms were negatively correlated in all the villages. Contact of cattle at common water points was significantly influenced by extensive grazing management practice in the farm ($p = 0.0000$, $OR = 9.57$), number of animals kept in the farm ($p = 0.0212$, $OR = 1.23$) and presence of cross breeds in the farm ($p = 0.0044$, $OR = 0.37$). The networks in the villages resembled undirected scale free graphs with a normalized degrees; 9.6 (Namunyiri), 10.6 (Malaha), 11.5 (Sango), 11.8 (Kibunde), 12.9 (Lutonyi), 13.1 (Lurare) and 14.0 (Chebukwabi). The topology of the networks was heterogeneous with some farms exhibiting high degree of contacts compared to others.

It is observed that an introduction of some disease pathogen in the villages would lead to increased rate of spread of the disease in Chebukwabi, Lutonyi and Kibunde due to higher values of coefficient of variation which basic reproduction number (Ro) incorporates due to heterogeneous in networks. Therefore Ro will be higher in the three villages compared to the other villages. There was high rate of bull sharing in the farms both within and outside the villages and this posed a major risk to the spread of sexually transmitted infections. Extensive grazing management and the keeping of higher number of cattle in the farms were more likely to increase farm contacts in the villages. It is recommended that studies should be conducted to describe farm contacts during dry season and also contacts between the villages so as to give a better understanding of the structure of the networks which will help in the design of effective surveillance and control strategies by the veterinary department.

CHAPTER ONE

1.0 GENERAL INTRODUCTION

Movement of animals in farms usually occurs during grazing, watering and dipping etc .The movements usually link various farms to form networks which create contacts with various farms. The contacts so created act as a route through which diseases may spread between the farms. Farms which are infected act as a source of infection to other farms which are connected to them. The network created by contacts is a determinant of the pattern of spread of infection (Gupta et al., 1989). Disease and network characteristics cannot always be separated easily for example in the case of foot and mouth disease (FMD), the probability of transmission depends on both the nature of the connected nodes and links (Kao et al., 2006). Network analysis has been used extensively to study the social networks underlying the spread of various diseases (Jolly et al., 2001). The need for a clearer understanding of the contact network underlying farm populations was brought into focus by the 2001 foot-and-mouth disease (FMD) epidemic in Great Britain (GB) where lack of information on contact structure hindered the scientists from developing models to predict disease spread (Woolhouse and Donaldson, 2001). The initial spread was greatly influenced by the frequency of movement of animals around the country and their mixing in livestock markets (Ferguson et al., 2001). Gilbert et al., (2005) also assessed the role of cattle movements in the spread of bovine tuberculosis in GB using movement records.

The importance of contact networks can be quantified on their impact on the basic reproduction number, R_o (Anderson and May, 1991) which is the average number of secondary cases of infection resulting from the introduction of a single primary case in a population of previously unexposed hosts.

Interpersonal contact patterns that underlie disease transmission form a network where links join individuals who interact with each other (Bansal et al., 2010). A node in a contact

network represents individual host and an edge between two nodes represents an interaction which allows disease transmission. Livestock network is an ordinary description of the set of animal movements with nodes corresponding to livestock holding locations and links referring to livestock movements (Barabasi and Albert, (1999); Barrat et al., (2008).
Social interactions are often fluid, new interactions forms, while others dissolve, providing transient opportunities for disease transmission.

Knowledge of the structure of a network enables researchers to gain understanding on how rapidly information may spread through the network, the resilience of the network to "attack" and the social role of individuals (Webb, 2005).
The contact networks of farms consist of layers of "relations" where a relation is defined as a specific type of tie. In social networks, example of these ties includes "is a friend of" and works with" (Wasserman and Fraust, 1994). In considering disease spread between farm animals from different farms there is need to consider what ties might be associated with disease spread between farms (Webb, 2005). The ties may include grazing pastures, livestock markets, shared bulls, agricultural shows, oxen plough, water points, shared boundaries and shared equipment. The probability of disease spread from one farm to another is likely to be a function of several types of relations. By combining the set of relations contributing to disease spread to form a single network we can obtain a risk-potential network (Friedman and Aral, 2001) on which we may model disease spread.
There are a number of diseases which are transmitted directly through contacts and these include breeding diseases (sexually transmitted infections) and vector-borne infections among other diseases. When infected animals come into direct contact with healthy animals, the vectors are more likely to infect the healthy herds. These tick-borne parasitic diseases are a major challenge to livestock production in Western Kenya (Latif et al., 1995) and they include East Coast Fever, Anaplasmosis and Babesiosis. Grazing systems in Western Kenya

varies from zero grazing through semi zero grazing to free grazing/ tethering and therefore the grazing systems influences the incidence of tick borne diseases. Many smallholder farmers do not operate optimal tick control measures and therefore tick borne diseases tend to increase with increased levels of freedom of grazing (Minjauw and McLeod, 2003). Indigenous breeds are highly resistant to tick borne diseases and acquire immunity when exposed to ticks at an early stage and create “endemically stable” state and therefore losses usually occurs when there is “endemically unstable” state due to lowered tick population as a result of intensive use of acaricides. Even though vaccine for ECF is currently available the uptake is still low because they are either expensive or difficult to deliver because they contain live organism and therefore require cold chain (Minjauw and McLeod, 2003). Foot and Mouth disease (FMD) is also prevalent in this region with all the serotypes present (FMD laboratory Annual Report, 2007). This is one of the major Trans-boundary animal diseases that impact negatively on trade in livestock and livestock products in the region.

1.1 PROBLEM STATEMENT

Movement of animals usually occurs in different farms either while grazing, at watering points, during dipping, at the crush during vaccinations and during mating. These movements create contacts of animals from different farms.

These movements of cattle between farms are an important determinant of the potential spread of infectious pathogens. The extent and frequency of movement determines the rate of spread of diseases. The movement of animals could be directed or undirected where directed movements leads to introduction of pathogens to the new herds while undirected movements leads to introduction of infection on either herd.

Many predictive models for farm animal diseases focus on gathering information and estimating disease transmission parameters with relatively very little attention given to modeling the underlying network of contacts (Webb, 2005 and Waret et al., 2010).The model also ignores the complex structures present at different levels including between animals, farms and the regions. Even when such complex structures are considered they are based on crude estimates due to lack of detailed information regarding contact structures and factors affecting them.

1.2 JUSTIFICATION

Limited research has been done on contact networks of herds to give a better understanding of its risk implication to disease transmission in Africa. Most studies have been done in human diseases and therefore, this study explored contact types and the frequencies that exist between cattle farms within the region focusing on the potential routes for the spread of diseases through complex contact networks. Understanding of contact networks existing between farms is critical in disease surveillance and in instituting control and prevention measures for diseases. The networks comprise nodes with varying degrees of connections and diseases spread from one node to other nodes and therefore when the connections are fragmented then the spread of infection is controlled. Identifying highly connected nodes is important in control measures. Diseases that spread through direct contact between infected and susceptible animals can be controlled through quarantine among other measures which fragments the herd networks thereby preventing further spread of diseases. This study investigated the contact networks that existed between cattle herds and which are thought to be risk factors for the transmission of infectious diseases. It gives a better understanding of the factors affecting contact structures at the farms. The findings of this study will help in the design of surveillance and control strategies for directly transmitted infectious diseases. The results will also be compared with relevant research findings done in other geographical locations.

1.3 HYPOTHESIS

The contact network observed was random and not influenced by any factors.

1.4 OBJECTIVES

1.4.1 Overall objective

The overall objective of the study was to determine and assess the type of contact networks between herds and potential for transmission of diseases and their pathogens in Kimilili-Bungoma County of Western Kenya

1.4.2 Specific Objectives

The specific objectives were:

1. To determine the existing contact networks between cattle herds and farms in selected villages in Bungoma County in Western Kenya.
2. To determine the frequency of the contact within the network existing between farms and herds
3. To determine the factors affecting heterogeneity in contact, including factors at the animal and management level in the existing networks in Bungoma County in Western Kenya.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

The science of networks has revolutionized research into dynamics of interacting elements. There is extremely close relationship between epidemiology and network theory that dates back to the mid- 1980s. This is because the connections between individuals (or group of individuals) that allow diseases to propagate naturally define a network, while the network that is generated provides insights into the epidemiological dynamics. An understanding of the structure of the transmission network allows researchers to improve predictions of the likely distribution of infection and the early growth of infection after invasion, as well as allowing the simulation of the full dynamics (Leon et al., 2010)

The contact network structure has important effects for diseases invasion and spread (Anderson and May, 1991; Liljeros et al., 2001; May and Lloyd, 2001; Pastor-Satorras and Vespignani, 2001; Hufnagel et al., 2004; Meyers et al.,2005), and its study can provide scientific evidence for the development and implementation of effective preventive and control measures. Studies on contact structures has also been piloted in Busia Western Kenya by Glanville et al., (2012*)* and presented in the 13th Symposium of the International Society for Veterinary Epidemiology and Economics (ISVEE) in the Netherlands.

Contact network structure can have major implications for the dynamics of infections. The persistence of diseases within a social network relies on population mixing at two levels:

a) Large levels of mixing within distinct social groups (local mixing) and account for the complexity of networks which is responsible for the failure of disease control strategies.

b) The global mixing of different social groups (Bohm et al., 2009).

Effective management of livestock diseases depends on the proper understanding of networks occurring at the farm level and quantification of networks in terms of the degree of connectedness.

Studies by Lysons et al., (2007) in Britain revealed that predicting the spread of actual infections through the cattle movement network requires models that can accurately capture the epidemiology and natural history of a particular pathogen and produce results that are specific to the particular infection studied.

2.2 Network technology

A network is a collection of units of interest that may or may not be connected. The units of interest are normally called nodes or vertices in physics and mathematics and actors in the social sciences. In a population of farms, each farm would be a node in the network. Nodes may have attributes, such as type of species, geographical location, and herd size, which can be studied in the context of network analysis. Figure 2.1 shows a simple network diagram with circles as nodes and the links as arcs and edges.

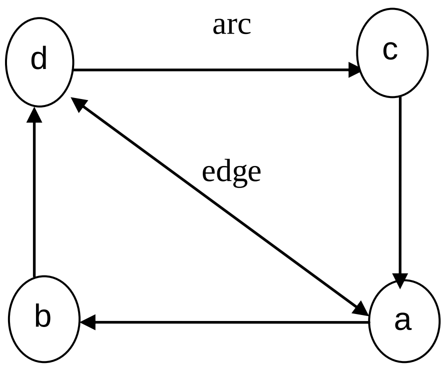


Figure 2.1: A simple network diagram with nodes, arcs and edges

Nodes are linked to each other through a relationship of some sort. For example, animal movements from farm-to-farm link farms together in a network. When these links between farms are reciprocal or undirected they are called edges and when the links are directed they are called arcs (Wasserman and Faust, 1994)

How a relationship is defined between two nodes can allow arcs to be considered as edges. For example, the movement of animals from farm to farm may be viewed as arcs (directed) if we consider the directionality from a source farm to a recipient farm. But if we consider this relationship as being a business transaction, then arcs can become edges (reciprocal) in network analysis terminology (Dube et al., 2009)

2.3 Intranetwork metrics and nomenclature

A subset of the network where any two nodes i and j are reachable from each other by following a path is referred to as a strong component of the network. Identifying strong components of a network is important because introduction of disease into a node of a strong component may likely result in the spread of the disease to other nodes within the strong component.

2.4 Network analysis and livestock movement studies and implications for disease control

Studying animal movements using network analysis techniques enables researchers to explore relationships among livestock farms. The number of movement from a farm is not just an isolated attribute; instead, the relationship created between a source farm and its recipient farms becomes part of a complex web of connections. This approach allows epidemiologist to identify nodes in the web that are at risk of being infected and transmitting infection to other operations (Dube et al., 2009). The first appearance of the use of network analysis in veterinary epidemiology was in 2002 at a conference where a study of the contact structure of the British sheep population was presented (Webb and Sauter-Louis, 2002). In 2003, the first two published studies using network analysis in veterinary epidemiology appeared in the literature. Corner et al., (2003) used social network analysis to characterize the networks of possums sharing dens to support the development of tuberculosis vaccine trials in captive brush tail possums (*Trichosurus vulpecula*) in New Zealand. Christley and French, (2003) also explored the contact networks among race horse trainers in Great Britain. Since then, the number of publications has increased.

Similar studies on contact structures were also explored by use of structured questionnaire on social network analysis in highlands of Ethiopia by Waret et al., (2010). This study revealed greater variability in contact structures at the grazing points than watering points which is contrary to the believe that watering points are critical in the potential spread of infections and therefore interventions at grazing points is key on the contact structure and control of diseases among herds in Highland Ethiopia (Waret et al., 2010). The challenge to this study was that developing countries do not have registered animal movement and therefore characterization of networks of animal contacts is difficult in field data collection.

Network analysis studies have been used in:

(1) Descriptive studies of the contact structure of livestock movements (Webb and Sauter-Louis, 2002; Christley et al., 2005; Webb, 2005, 2006; Bigras-Poulin et al., 2006, 2007; Robinson and Christley, 2007),

(2) Understanding of past epidemics using network analysis (Shirley and Rushton, 2005; Ortiz-Pelaez et al., 2006),

(3) Assessing the impact of livestock movement regulations using network analysis (Green et al., 2006; Kao et al., 2006; Robinson et al., 2007) and

(4) Characterizing the impact of the livestock contact structure on the spread of diseases, predicting epidemic size and developing network models for testing the validity of network concepts (May and Lloyd, 2001; Kiss et al., 2005, 2006; Saramaki and Kaski, 2005; Shirley and Rushton, 2005; Woolhouse et al., 2005; Green et al., 2006; Kao et al., 2006, 2007)

These studies have provided valuable information on the characteristics of some livestock contact structures, the types and uses of network analysis measures and the impact that the network structure has on modeling and controlling livestock diseases.

2.5 Types of network structures

2.5.1 The ideal network

This network allows complete description of the spread of infectious pathogens. It considers the strength of all potential transmission routes from individual to individual at a time. It also captures all possible transmission networks and quantifies the strength of contacts. Transmission dynamics is far from this ideal as information on the potential transmission routes within a population tend to be limited in a number of ways;

a) Difficulties in gathering information on the entire population.
b) Information is usually captured on a single transmission route either as presence or absence of contact without quantifying the strength or frequency of contact.
c) Data on contact networks are usually dynamic but what is usually recorded is whether a contact was present during a particular period with little attention given to how this pattern may change over time (Leon et al., 2010)

2.5.2 Random networks

The spatial position of individuals is not important and connections are formed at random (Bollobas 1985). In most cases each individual has a fixed number of contacts through which infections can spread and the network is characterized by absence of clustering and by homogeneity of individual-level network properties. The dynamics of diseases on random networks can be studied as a simple branching process (Diekmann et al., 1998), from which both the initial growth rate of the disease and the final epidemic size are reduced when compared with the random- mixing model.

2.5.3 Scale free networks

This is a network whose degree distribution follows a power law. Many networks are conjectured to be scale-free, including World Wide Web links, biological networks, and social networks.

The most common characteristic in a scale-free network is the relative commonness of vertices with a degree that greatly exceeds the average. The highest-degree nodes are often called "hubs", and are thought to serve specific purposes in their networks. The scale-free property strongly correlates with the network's robustness to failure. The major hubs are closely followed by smaller ones. These in turn, are followed by other nodes with an even smaller degree and so on. This hierarchy allows for a fault tolerant behavior. If failures occur at random and the vast majority of nodes are those with small degree, the likelihood that a hub would be affected is almost negligible. Even if a hub-failure occurs, the network will generally not lose its connectedness due to the remaining hubs. On the other hand, if a few major hubs are chosen and taken out of the network, the network is turned into a set of rather isolated graphs. Thus, hubs are both strength and a weakness of scale-free networks (Cohen et al., 2001 and Callaway et al., 2000). Another important characteristic of scale-free networks is the clustering coefficient distribution, which decreases as the node degree increases and also follows a power law. Figure 2.2 show a random network and scale free network with the hubs highlighted.

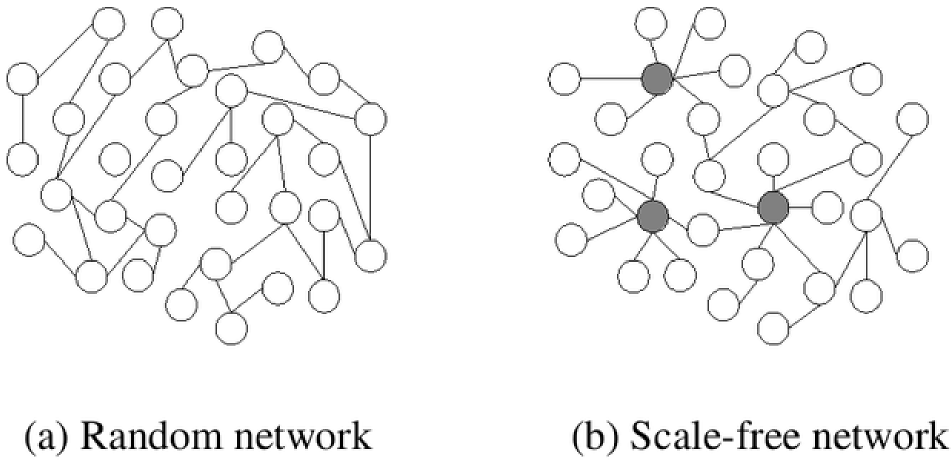


Figure 2.2: Random network and scale-free network.

2.5.4 Small world networks

Lattices display high clustering but long path lengths, that is, it takes many steps to move between two randomly selected individuals, where as random networks have short path lengths, since there are many long-range links, but low clustering. Small-world networks, described in the work of Watts and Strogatz (1998), offer a means of moving between the rigid arrangement of lattices and the unstructured connections of random networks. Small world networks improve upon the rigid structure of the lattice by allowing a low number of random contacts across the entire space. Small world networks provide a step towards reality by capturing the local nature of transmission and the potential for long range contacts but they have a weakness of neglecting heterogeneity in the number of contacts and the tight clustering of contacts within households or social setting (Leon et al., 2010). Figure 2.3 show an example of small world network with the two hubs represented by bigger nodes.

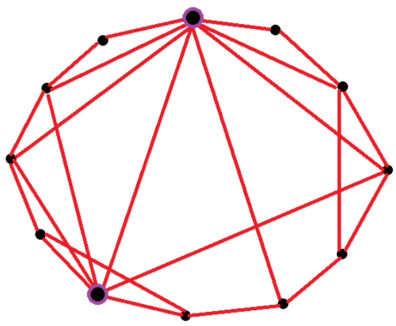


Figure 2.3: Small world network

2.5.5 Spatial Networks

They are generated using the spatial location of all individuals in the population. Therefore lattices and small worlds are a particular form of spatial network. The method positions each individual at a specific location which is chosen at random. Two individuals (say I and J) are then probabilistically connected based upon the distance between them; the probability is given by connection kernel which decreases with distance, such that connections are predominantly localized. (Leon et al., 2010).

2.5.6 Movement networks

An alternative source of network information comes from the recorded movements of individuals. Such data frequently describes a relatively large network as information on movements is often collected by national or international bodies. The network of movements has nodes representing locations (rather than individuals) and an edge to capture the number of movements from one location to another- as such the network is rarely symmetric (Leon et al., 2010).

2.5.7 Contact tracing networks

The networks generated by this method can take two distinct forms.

a) When contact-tracing is used to initiate proactive control. This is often the case for sexually transmitted infections (STIs), where the identified cases are asked about their recent sexual partners, and these individuals are traced and tested; if found to be infected , then contact tracing is repeated for their secondary cases (Wikipedia).

b) Contact tracing for the early stages of an airborne epidemic as was seen for the 2009 H1N1 pandemic (Wikipedia).

2.6 Techniques for gathering contact information

2.6.1 Infection tracing

After an epidemic, field epidemiologists put a lot of effort on determining the source of infection for each case (Haydon et al., 2003; Riley et al., 2003). In this regard, each infected individual is linked to one another from whom they got the infection, and additionally, to others whom they transmitted the disease, therefore providing a transmission network consisting of all the links through which infection spread in a single outbreak. The tool provides information about the individuals most involved in diseases transmission (Riley et al., 2003)

2.6.2 Contact tracing

It aims at identifying all potential transmission contacts from a source index case revealing a new set of individuals who might be infected and who can be the subject of further tracing (Klovdahl, 1985; Ghani et al., 1997; Ghani and Garnett, 1998; Muller et al., 2000; Wylie and Jolly, 2001; Potterat et al., 2002; Eames and Keeling, 2003; Fraser et al., 2004). Because it aims to identify potential transmission routes, contact tracing suffers from network definition issues and it is also time consuming and relies on individuals providing complete and accurate data about personal relationships.

During an epidemic, contact tracing is an important means of disease control that seeks to quickly remove infected livestock herds (Kiss et al., 2006).

2.6.3 Diary based studies

Because determination of networks through tracing is highly labor intensive and relies on the subject individuals being able to recall and willing to recount their contacts, diary based studies subjects record of contact as or shortly after they occur, shifting the workload from the researcher to the subject and allowing a larger number of individuals to be sampled in detail (Edmunds et al., 1997).The challenge with this approach include;

a) Since data collection is at the discretion of the researchers, the definition of a close contact may not be the same for all individuals.
b) Since this method gathers detailed individual-level data, it may be difficult for the co-coordinating researcher to link this information into a comprehensive network, as the names or identifiers of contacts may not be accurately or uniquely recorded. Therefore, unless the subject individuals come from the same group, it is likely that the study will result in a large number of fragmented sub-networks, each one representing a network of a few individuals (Klovdahl, 1985; Scott, 1991; Wasserman and Faust, 1994)

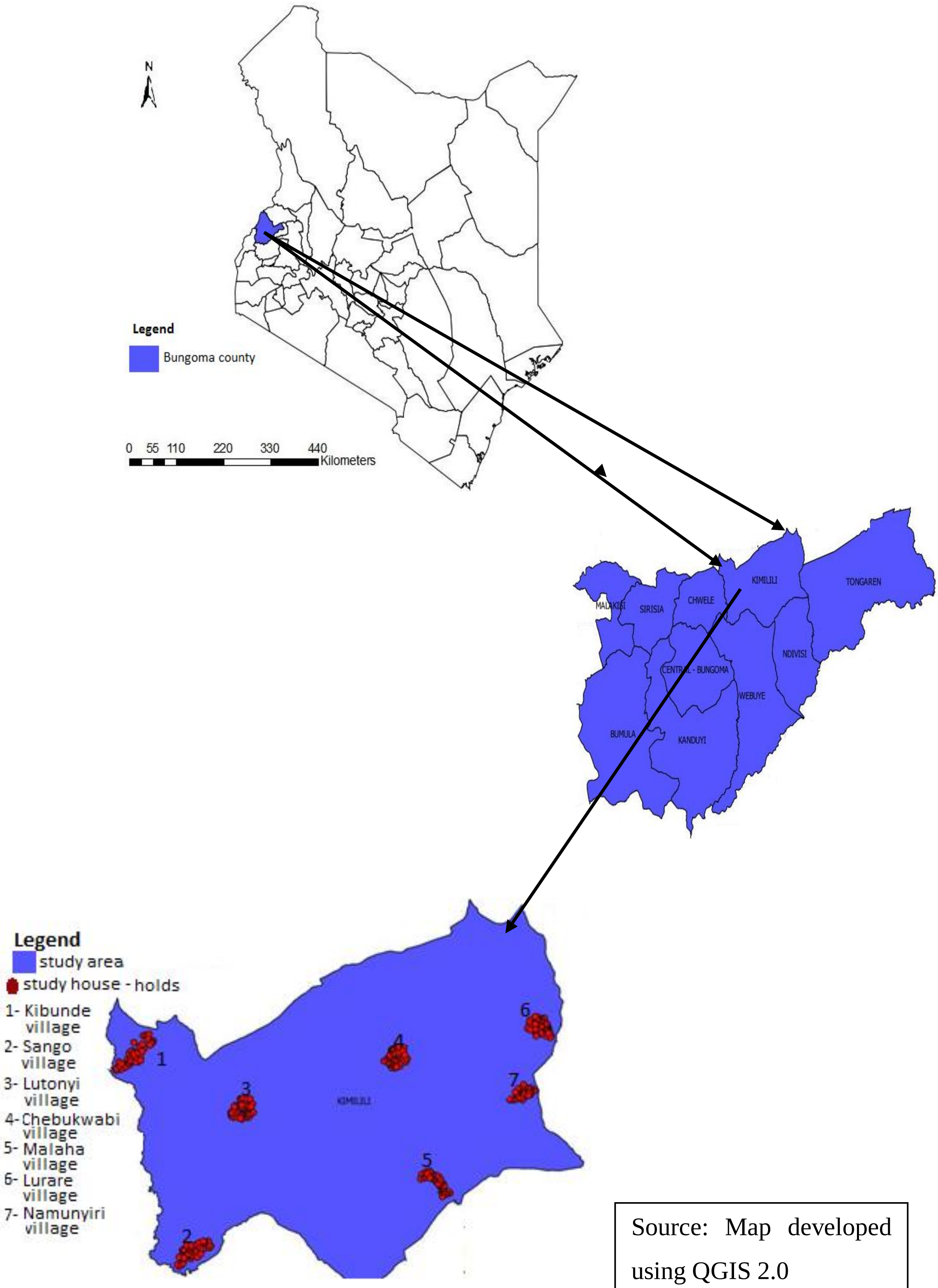
The main advantage of this network is that the responsibility for collecting the data lies with the individual rather than the research

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study site

The study was carried out in Kimilili district in Bungoma County. Kimilili district was conveniently selected because the study was part of the “People, Animals and their Zoonoses”(PAZ) project; a research project carried out jointly by the University of Edinburgh, UK and the International livestock Research Institute(ILRI) to investigate the epidemiology of zoonotic diseases in western Kenya since 2010 (Doble and Fèvre , 2010). Bungoma county has a population of 333,532 heads of cattle and 1,076,367 households (Kenya National Bureau of Statistics, 2009). Cattle production systems in the county can be classified broadly as small scale dairy production systems, small scale dairy/ meat production systems and small scale dairy/ meat/ traction production systems. There are three different breeds of cattle within these production systems namely; pure breeds (graded cattle), cross breeds and local zebu cattle. The population of zebu cattle is high as a result of the socio-cultural roles (dowry payments, prestige and sales for income) and resistance to diseases. These cattle are reared under free grazing/ tethering, semi-zero grazing or zero grazing systems and they depend on natural pastures/ forage, fodder crops and agricultural by-products as their main feed source (Mudavadi et al., 2001). The agro-ecological zones of Bungoma County range from Upper Midland Zone 1 to Lower Midland Zone 4 with a total of 1684 sq Km. Mixed crop farming activities also takes place in the area including maize, sugarcane, vegetable and horticultural farming.



Source: Map developed using QGIS 2.0

Figure 3.1: The map of Kenya showing Bungoma County and Kimilili

3.2 Study design

This study was a cross sectional survey for all the network members of cattle herds that had come into contact.

3.3 Sampling design

A full list of all the villages in Kimilili district was obtained from the office of local administrators (District offices). Seven villages were randomly selected using systematic random sampling. The villages were selected from the data set describing all the villages in the district using random number generation. Recruitment of villages involved a visit to the assistant chief for the sub-location in which the village falls where the study approach and its expected outcomes were explained and permission to work within those areas was sought.

Data collection within the villages involved three stages;

3.3.1 Recruitment of Villages and census

A census of all cattle keeping households within the villages was undertaken with the help of village elder. This involved a visit to all homesteads within the village and seeking information regarding cattle keeping. For households keeping cattle, the study was explained and their participation was sought. Consenting farmers had their full names collected and a face-forward portrait photograph of the head of the household (or individual with responsibility for cattle if head was not available) was captured using digital camera. Farmers who were not willing to have their photo taken had their full names were recorded. The portrait photograph was used to help ease identification of all herds that had come into contact with the herds of the person on the photo during questionnaire interview in the village. A meeting date and time with those individuals within the home who had general responsibility for cattle and for those persons who had been involved in taking cattle to grazing, watering points in the past four weeks was arranged. The four weeks duration was mainly to minimize recall bias since there was no documentation of movements of animals and therefore farmers were likely not to remember all the contacts.

3.3.2 Interview and photo-elicitation

On a subsequent day, consenting cattle-keeping household were re-visited and the contact structure interview (Appendix 1) was performed as shown in figure 4.1. This interview involved a combination of photo-elicitation, structured questionnaire and a data collection form for capturing the existing contacts (Appendix 2). For the photo-elicitation, the homestead head and anyone else in the household involved in cattle management (i.e those people who take cattle out for grazing or to watering points) were shown a slide containing the photos of the heads of cattle keeping households within the village using camera, together with the homestead head's name in text. The name was said out loud by the enumerator, and the participants were asked to report on any contact of animals during grazing, watering, mating and ploughing that they could recall between their own cattle and cattle owned by the individual in the photograph in the past 4 weeks. For reports of contact, the location of contacts (e.g whilst at grazing, at the water point, in the homestead etc) was captured. Farmers were also asked to verbally recall between herd contacts that involved the use of shared bulls and between farm movements of animals (i.e trade) from within and outside the village in the past 12 months. For those contacts that had occurred between cattle herds from outside the village, only the name of the village was captured.

3.3.3 Geographic Mapping of the Study Site

Using a Global Positioning System (GPS) hand held receiver (GARMIN® international Inc. 1200 East 151st street, Olathe, Kansas, USA.), an accurate location for each of the homestead (farms) visited was recorded. The geo-reference data was recorded in terms of waypoint, latitude and longitude and saved in the GPS hand held receiver. The spatial proximity of farms was explored to see how they influenced the contact structures.

3.4 Data management and analysis

The information from the questionnaires was entered into Microsoft Excel® 2003 (Microsoft Corporation, USA). Descriptive statistics and tests for univariate and multivariate associations between various contacts and independent variables: herd size, land size, grazing management (dry versus rainy season), and breeds in the farm were analyzed using R-PROJECT (www.R project.org). Grazing management was divided into three levels; zero grazing, semi intensive and extensive. Zero grazing was dropped hence it was not included in the analysis because of very low cell value that could make the model unstable (only one farm reported zero grazing). Farms were categorized into four levels: farms with exotic breeds only, farms with cross breeds only, farms with indigenous breeds only and the last category were farms with mixed breeds (farms rearing a mixture of any of the three breeds).

Grazing contact was defined as farms that practiced either semi intensive or extensive grazing management during the four weeks duration of the study and grazed their animals outside their farms with animals coming into direct contact (physical mixing) or indirect contact (grazing in the same field though animals did not have physical body contact). Grazing contact was categorized into presence of grazing contact (1) and absence of grazing contact (0). Grazing contacts was classified into two with one contact captured when farmers graze their cattle outside the homestead (open grazing fields) and another when cattle in neighboring homesteads cross the boundaries and graze in the neighbor's farm. Breeding contact was binarized (presence/absence) and bull breeding contact was defined as the number of farms with mature non castrated males where the owners were aware of their bulls having sexual contacts with mature cows from other farms outside the homestead (another farm in the village, another village in the sub-location, another sub-location) in the past one year of the study and cow breeding contact as the number of farms with mature cows in calf in the past one year having been served by a bull from outside the farm either within the village or outside the village. Breeding contact was therefore defined as presence of either bull breeding or cow breeding contacts after excluding farms which did not have mature cows and intact bulls. Statistical significance for comparisons used $\alpha=0.05$.

Network data were entered into Microsoft Excel where several symmetric (undirected links) binary networks were built with farms as nodes and links being sharing of grazing points, water points, breeding bulls and ploughing bulls. Network analysis was explored using UCINET 6.182 (Borgatti et al., 2002).

Network density (proportion of all possible links that are actually present), number of isolates (nodes not connected to any other) were calculated for each network. The degree for each node which is the number of links incident to a given node was normalized (degree of the node divided by the number of the nodes in the network) to allow for comparison with other networks. The mean normalized degree and average geodesic distance (mean number of links in the shortest path between all reachable pairs of the nodes) was also determined. Clustering coefficient (density of the ego network after removal of the ego), network centrality which is the measure of variability of centrality of the individual nodes was also calculated. Other centrality measures that were determined included betweeness centrality which is the frequency with which node k falls between pair of other nodes on the geodesic path connecting them and closeness centrality which is the distance from one node to all others in the network. The relative betweeness (RBc*i*) and relative closeness which allowed for comparison of values of nodes from different networks (Gould, 1987) was also extracted.

Bootstrap paired t-test was used to test for differences in densities of two networks using 5000 random permutation per test so that assumptions of independence and random sampling are not required (Hanneman and Riddle, 2005). Dyadic quadratic assignment procedure (QAP) correlation was used to calculate the correlation between two matrices using Pearson coefficient based on 10000 random permutations. Farms were mapped with geographic information system and influence of spatial location on contact structures analyzed. The proximity between homesteads was therefore explored to find how they affect their degree of contact.

CHAPTER FOUR

4.0 RESULTS

4.1 Household demographics

The study was carried out in seven villages (6 locations) in Kimilili Bungoma County and a total of 329 farms were visited and questionnaire administered as shown in figure 4.1. The overall proportion of farms headed by males was 83.3%.

Figure 4.1: A farmer being interviewed during field data collection in Chebukwabi village

The breed composition and number of farms keeping cattle were as shown in Table 4.1. The overall mean size of the land in the farms was 3.23 acres.

Table 4.1: Breed composition and number of farms keeping cattle in the villages

Village Name	No. of farms keeping cattle(n)	Indigenous Breed (%)	Cross Breed (%)	Exotic Breed (%)
Chebukwabi B (Cheb)	44	80.15	19.85	0.00
Malaha A (Mal)	53	57.46	42.54	0.00
Kibunde (Kib)	48	74.83	21.09	4.08
Namunyiri (Nam)	43	71.77	28.23	0.00
Lutonyi (Lut)	45	74.03	25.97	0.00
Lurare (Lur)	48	71.01	28.99	0.00
Sango	48	91.26	8.74	0.00

4.2 General farm and livestock management

The proportion of farms that practiced extensive grazing management during dry the season was 14.3% and the number dropped to 12.8% during the rainy season as shown in Table 4.2 (a) and (b) respectively. The proportion of farms that reported taking their animals outside their farms for watering was 38.9% during the rainy season with 94.44% indicating river as the source of water .The number of farms increased to 42.9% during the dry season. The proportion of farmers that reported taking their animals outside their farms for pastures during the rainy season was 53.2% and the number increased to 61.7% during the dry season. Figure 4.2 show photograph of cattle from two different farms grazing together after crossing the farm boundary into the neighbor’s farm.

Figure 4.2: Cattle from two different farms grazing together (Cattle on the right have crossed the fence to join the neighbor's cattle on the left- an example of neighbor's boundary grazing contact.

The proportion of farmers that brought new animals to their farms during the last one year of the study was 31.3% with the range of animals being 1-9 cattle. The proportion of farmers that reported to have brought several animals (ten and above) into their farms was 2.1%. Only 3.3% of farms that brought new animals into their farm reported acquiring them from within the villages with the rest getting them from the market.

The proportion of farms which gave out/ sold cattle in the last one year of the study was 35.9% with the range being 1-9 cattle and 2.1% selling several (10 and above) and this was for livestock traders. The number of farmers who reported selling/giving their cattle within the villages was only 5.3%.

Table 4.2 (a): Proportion of farms practicing various grazing management methods during dry season

Village	Zero grazing (%)	Semi-intensive grazing Management (%)	Extensive grazing management (%)
Chebukwabi B	2.3	88.6	9.1
Malaha A	0	84.9	14.1
Kibunde	0	95.8	4.2
Namunyiri	0	95.3	4.7
Lutonyi	0	82.2	17.8
Lurare	0	83.3	16.7
Sango	0	68.8	31.2
Overall	0.3	85.4	14.3

Table 4.2 (b): Proportion of farms practicing various grazing management methods during rainy season

Village	Zero grazing (%)	Semi-intensive grazing Management (%)	Extensive grazing management (%)
Chebukwabi B	0	93.2	6.8
Malaha A	0	90.6	9.4
Kibunde	0	100	0
Namunyiri	0	95.3	4.7
Lutonyi	0	82.2	17.8
Lurare	0	81.3	18.8
Sango	0	68.8	31.3
Overall	0	87.2	12.8

4.3 Sources of bulls for ploughing of farms in the selected villages in Kimilili-Bungoma County

The overall number of farms that sourced bulls from outside their farms for ploughing was 59.6% as shown in Figure 4.3 with Sango village which had the highest proportion (79.2%) and Namunyiri village the least proportion (25.6%).The farms that reported sourcing bulls for ploughing, 68.34% used bulls from within the villages and Chebukwabi had the highest (76.7%) and Sango lowest proportion (56.8%) as shown in Figure 4.4.

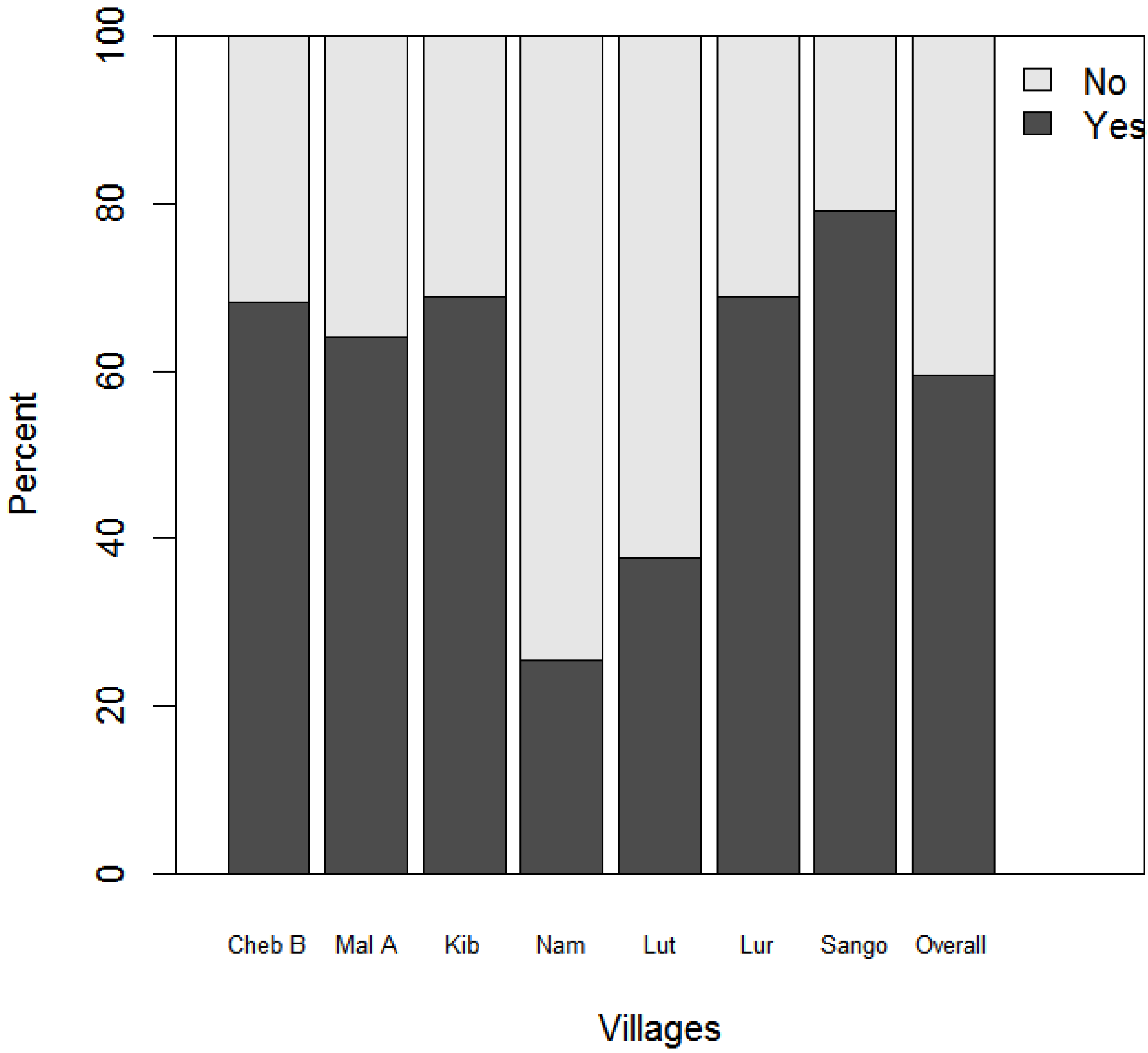


Figure 4.3: Proportion of farms that hired bulls into their farms for ploughing in Kimilili-Bungoma County.

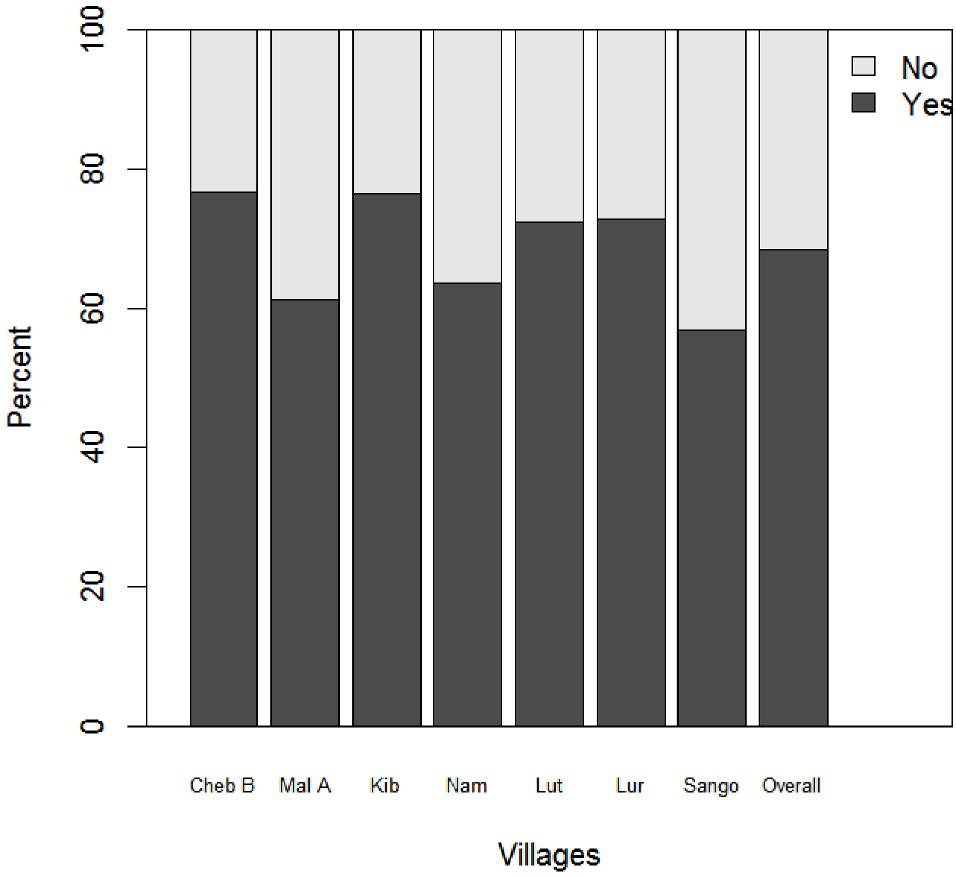


Figure 4.4: Proportion of farms that hired bulls from within the villages for ploughing in Kimilili-Bungoma County

4.4 Frequency of grazing off the farm

The overall proportion of farmers that took their animals outside their homestead for pastures daily during the dry season was 49.9% with the highest village Sango (72.9%) and lowest Kibunde (22.9%). During rainy season the number dropped to 25.2% with Sango village having the highest proportion of 39.6% and both Kibunde and Lurare (18.8%).The number of farms that reported never to have taken their cattle off the farm during dry season was 30.7% and the number increased to 42.9% during rainy season. Table 4.3 and 4.4 shows the frequency of grazing animals off the farms during dry and rainy seasons in Kimilili Sub County respectively.

Table 4.3: Frequency of grazing animals off the farm during dry season in Kimilili-Bungoma County.

Village	Every day (%)	Once/twice a week (%)	Once/ twice a month (%)	Only a couple of times (%)	Never (%)
Chebukwabi	59.1	15.9	0	2.3	22.7
Malaha	35.8	20.8	7.5	0	35.8
Kibunde	22.9	29.2	0	0	47.9
Namunyiri	44.2	20.9	0	0	34.9
Lutonyi	68.9	11.1	0	0	20.0
Lurare	47.9	14.6	0	0	37.5
Sango	72.9	8.3	2.1	2.1	14.6
Overall	49.8	17.3	1.5	0.6	30.7

Table 4.4: Frequency of grazing off the farm during rainy season in Kimilili-Bungoma County.

Village	Every day (%)	Once/twice a week (%)	Once/ twice a month (%)	Only a couple of times (%)	Never (%)
Chebukwabi	22.7	29.5	2.3	0	45.5
Malaha A	26.4	24.5	1.9	1.9	45.3
Kibunde	18.8	20.8	2.1	2.1	56.3
Namunyiri	23.3	30.2	0	0	46.5
Lutonyi	26.7	46.7	0	0	26.7
Lurare	18.8	31.3	2.1	2.1	45.8
Sango	39.6	27.1	0	0	33.3
Overall	25.2	29.8	1.2	0.9	42.9

4.5 Frequency of watering off the farm during the dry and wet seasons

The overall proportion of farms that took their animals outside their farms for water daily during dry period was 41.6% with the highest village being Lutonyi (75.6%) and lowest village being Namunyiri (14.0%). During wet season the overall proportion went down to 31.3% with Lutonyi still the highest (64.4%) and Malaha lowest (7.6%). Farms that never took their animals off their farms for watering during dry and wet seasons were 52.6% and 57.44% respectively.

4.6 Contacts of animals during breeding among the farms.

The proportion of farms that reported having post pubertal bulls not castrated was 17.6%. Chebukwabi village had the highest proportion of bulls (31.8%) and Lurare had the least proportion (10.4%). The proportion of farms that reported their bulls serving other cows was 75.9%. The overall proportion of bull contact was 63.8%. The overall proportion of farms that had mature cows was 93.0% with a range 1-5 cows. Table 4.5 shows the proportion of farms with mature cows and cow breeding contacts

Table 4.5: Proportion of mature cows and presence of cow mating contacts in the farms

Name of Village	Presence of a cow (%)	Presence of breeding contact (%)
Chebukwabi	91.0	77.5
Malaha	96.2	78.4
Kibunde	96.7	68.1
Namunyiri	90.7	61.5
Lutonyi	88.9	70.0
Lurare	93.8	82.2
Sango	97.9	87.2
Overall	90.5	75.3

The overall proportion of farms that reported their cows being served by a bull was 90.5% (Both within the farm and outside the farm). Out of this proportion, 75.5% of the farms reported presence of cow breeding contact (mating contact outside the farms).

The overall breeding contacts for both males and females was 80.1% with Sango (89.6%) highest and Namunyiri (65.9%).

4.7 Use of cattle dips and veterinary services by the study farms

All the study farms reported applying tick control measures in their farms during the previous one year of the study. The proportion of farms that reported spraying their animals at home was 97.9% (95.6%- 99.0%) while those which attended crush pens (community dips) was 1.8%. 0.3% reported using pour on as a means of tick control. The proportion of farms that applied tick control every week was 73.3% while 20.4% applied tick control every two weeks. The proportion of farms that reported accessing veterinary services from private vets was 80.2%, from government veterinarians was 16.11% and 1.22% of respondents reported to never having accessed the service in the previous one year of the study with the remaining proportion accessing the service from neighbors/agrovet shops. Farms that reported deworming their cattle during the previous one year was 67.8% with 98.7% reported drenching as a means of worm control. The proportion of farms that reported deworming when cattle show clinical signs was 60.4%, farms deworming after getting professional advice was 12.0% and farms deworming after every three months was 11.1%. The proportion of farmers that reported periods of ill health during the previous one year of the study was 61.1%.

4.8 Associations between the frequency of grazing and watering off-farm during dry and rainy seasons

During the study period, the proportion of farms that took their animals for water outside their farms during the dry season was 42.9% and it dropped to 38.9% during the rainy season but the difference was not significant (z= -1.03, p>0.05,). The proportion of farmers that took their animals off their farms for water daily during the last dry period (June to September) was 41.6% and the proportion dropped to 31.3% during the rainy season (October to December).The difference in the proportions was significantly different (z =2.75, p= 0.006 **)**. The proportion of farmers that took their animals off the farm for pasture daily during the dry season was 49.9% and the proportion dropped to 25.2% during the rainy season. The difference in proportion was significantly different (z= 6.52, p=0.0000,). The probable grazing contact for rainy season was 53.2% and for dry season it increased to 61.7% and this was significantly different (z = 2.21, p=0.027,).

4.9 Factors associated with contacts in the study farms.

4.9.1 Factors associated with presence of breeding contact in Kimilili-Bungoma County.

Testing for association between presence of breeding contacts (outcome variable) and the farm level factors: land size, number of animals in a farm, presence of a mature bull (non castrated), presence of a reproductively mature female cattle, breed and grazing management during dry and wet season. Table 4.6 shows the results for testing significance on a univariate binary logistic regression.

Table 4.6: Farm level factors associated with breeding contact on univariate analysis

No	Variables	OR (95% C.I)	P-Values
	Grazing management during rainy season		
1	Extensive (Semi intensive= Ref)	0.28(0.07-0.82)	0.0413 *
	Grazing management during dry season		
2	Extensive (Semi intensive= Ref)	0.34 (0.09-0.88)	0.0472*
3	Land size	1.02 (0.91- 1.13)	0.683
4	Number of animals in the farm	0.86(0.72- 1.01)	0.0776
5	Presence of a bull (Non castrated)	0.81 (0.37-1.65)	0.578
6	Presence of mature female	1.24 (0.20-24.08)	0.843
	Breeds		
	Cross (Indigenous=Ref)	1.39 (0.71-2.64)	0.322
7	Mixed	1.82 (0.78-4.03)	0.148

*significant at 0.05 level

Both extensive grazing managements were significantly associated with presence of breeding contact at 95% confidence interval. Farms practicing extensive grazing management during rainy season (OR=0.28, p=0.413) and during dry season (OR=0.34, p=0.472) were significantly associated with presence of breeding contact. This means that extensive grazing management decreased the odds of breeding contact.

All predictors were put into multivariate regression model for analysis as shown in Table 4.7. The results indicated that all the variables were not significantly associated with presence of breeding contact.

Table 4.7: Factors associated with breeding contact on multivariate analysis

No	Variables	OR (95% C.I)	P-Values
1	Grazing management during rainy season		
	Extensive (Semi intensive= Ref)	0.50(0.06 - 4.21)	0.5073
2	Grazing management during dry season		
	Extensive (Semi intensive= Ref)	0.81(0.10 - 4.37)	0.8213
3	Land size	1.08 (0.94 - 1.23)	0.2663
4	Number of animals in the farm	0.82(0.65 - 1.01)	0.0718
5	Presence of a bull (Non castrated)	1.02 (0.43 - 2.25)	0.9577
6	Presence of mature female	1.18(0.16 -24.36)	0.8897
7	Breeds		
	Cross (Indigenous=Ref)	1.21(0.60 - 2.35)	0.5880
	Mixed	2.10(0.82- 5.12)	0.1091

*significant at 0.05 level

4.9.2 Farm factors associated with presence of watering contacts during rainy season

The results for univariate association between the presence of watering contacts during the rainy season and explanatory variables are shown in Table 4.8

Table 4.8: Farm factors associated with the presence of watering contact during the rainy season on univariate analysis.

No	Variables	OR (95% C.I)	P-Values
1	Grazing management during rainy season		
	Extensive (Semi intensive=Ref)	15.94(6.61- 47.52)	0.0000 *
2	Land size	1.16(1.06-1.29)	0.0030 *
3	Number of animals in the farm	1.47(1.29-1.70)	0.0000 *
4	Breeds		
	Cross (Indigenous=Ref)	0.30(0.15-0.55)	0.0002 *
	Mixed	1.64(0.81-3.37)	0.1744

*significant at 0.05 level

The analysis showed that four variables were significant in explaining the presence of watering contact during rainy season. Farms practicing extensive grazing management during the rainy season was significant (OR=15.94, p=0.0000), land size (OR=1.16, p=0.003), number of animals in the farm (OR=1.47, p=0.0000) and presence of cross breeds in a farm (OR=0.3, p=0.0002)

All predictors were put into multivariate logistic regression model and the output is shown in Table 4.9. In the logistic regression analysis three variables were significant at 95% confidence interval. Farms practicing extensive grazing management (OR=9.57, p=0.0000), number of animals in the farm (OR=1.23, p=0.0212) and presence of cross breeds (OR=0.37, p=0.0044). Both land size and farms with mixed breeds (indigenous and cross breeds) were not significantly associated with watering contact.

Table 4.9: Farm factors associated with presence of watering contact during rainy season on multivariate analysis.

No	Variables	OR (95% C.I)	P-Values
1	Grazing management during rainy season		
	Extensive (Semi intensive=Ref)	9.57(3.72-29.78)	0.0000 *
2	Land size	1.04(0.92-1.18)	0.5413
3	Number of animals in the farm	1.23(1.03-1.48)	0.0212 *
4	Breeds		
	Cross (Indigenous=Ref)	0.37(0.18-0.71)	0.0044 *
	Mixed	1.16(0.51-2.63)	0.7182

*significant at 0.05 level

4.9.3 Farm factors associated with presence of watering contacts during the dry season

The results for univariate association between presence of watering contacts during dry season and explanatory variables are shown in Table 4.10. All the variables were significant at 95% confidence level. Farms practicing extensive grazing management during the dry season (OR=15.69, p=0.0000), land size (OR=1.18, p=0.0018) number of animals in the farm (OR=1.49, p=0.000), presence of cross breeds in a farm (OR=0.31, p=0.0002) and presence of mixed breed in a farm (OR=2.30, p=0.0281) were significantly associated with presence of watering contact during dry season.

Table 4.10: Farm factors associated with presence of watering contact during the dry season on univariate analysis

No	Variables	OR (95% C.I)	P-Values
1	Grazing management during dry season		
	Extensive (Semi intensive= Ref)	15.69(6.57-46.52)	0.0000 *
2	Land size	1.18(1.07-1.31)	0.0018 *
3	Number of animals in the farm	1.49(1.30-1.73)	0.0000 *
4	Breeds		
	Cross (Indigenous=Ref)	0.31(0.16-0.55)	0.0002 *
	Mixed	2.30(1.11-4.97)	0.0281 *

*significant at 0.05 level

When all the predictors were put into a multivariate logistic regression, only three variables were significantly associated with presence of watering contact during dry season. These were grazing management during the dry season (OR=10.07, p=0.0000), number of animals (OR=1.23, p=0.0238) and cross breed (OR=0.38, p=0.0044) as shown in Table 4.11.

Table 4.11: Farm factors associated with presence of watering contact during the dry season on multivariate analysis

No	Variables	OR (95% C.I)	P-Values
1	Grazing management during dry season		
	Extensive (semi intensive= ref)	10.07(3.98-31.05)	0.0000 *
2	Land size	1.04(0.92-1.19)	0.5069
3	Number of animals in the farm	1.23(1.03-1.47)	0.0238 *
4	Breeds		
	Cross (Indigenous=Ref)	0.38(0.19- 0.73)	0.0044 *
	Mixed	1.69(0.74-3.97)	0.2165

*significant at 0.05 level

4.9.4 Farm factors associated with presence of grazing contacts during the rainy season

The association between presence of grazing contacts during the rainy season and farm variables; land size, number of animals and breed was tested for their significance at 95% confidence interval. On univariate analysis only farms with mixed breeds was significant (OR=2.21, p=0.0401) as shown in Table 4.12.

Table 4.12: Grazing contact during the rainy season and independent variables on univariate analysis

No	Variables	OR (95% C.I)	P-Values
1	Land size	0.96(0.88-1.05)	0.3450
2	Number of animals in the farm	1.30(1.14-1.49)	0.0001 ***
3	Breeds		
	Cross (Indigenous= Ref)	1.08(0.64-1.83)	0.7709
	Mixed	2.21(1.06-4.89)	0.0401 *

*significant at 0.05 level

All the predictors were analyzed together in multivariate logistic analysis for their association with presence of grazing contact during rainy season and the result is shown in Table. 4.13. None of the predictors were significant at 95% confidence interval.

Table 4.13: Grazing contact during rainy season and independent variables on multivariate analysis

No	Variables	OR (95% C.I)	P-Values
1	Land size	0.78 (0.67-0.90)	0.0001***
2	Number of animals in the farm	1.30(1.08-1.57)	0.0000***
3	Breeds		
	Cross (Indigenous=Ref)	1.45(0.83-2.53)	0.5667
	Mixed	3.25(1.31-8.72)	0.0643

*significant at 0.05 level

4.9.5 Farm factors associated with presence of grazing contacts during the dry season

The association between presence of grazing contacts during the rainy season and the variables; land size, number of animals and breed was tested for their association with presence of grazing contacts during dry season. Two variables were significant at 95% confidence interval; the number of animals in the farm (OR=1.9, p=0.0105) and presence of mixed breed in a farm (OR=2.3, p=0.0282) and they increased the odds of grazing contacts during dry season as shown in Table 4.14

Table 4.14: Grazing contact during dry season and independent variables on univariate analysis

No	Variables	OR (95% C.I)	P-Values
1	Land size	0.95(0.87-1.04)	0.2865
2	Number of animals in the farm	1.19(1.05-1.36)	0.0105 *
3	Breeds		
	Cross (Indigenous=Ref)	0.31(0.16-0.55)	0.0002 ***
	Mixed	2.30(1.11-4.97)	0.0282 *

*significant at 0.05 level

All the predictors were then put in a multivariate logistic regression model and the results are as shown in Table 4.15.Only farms with mixed breed was significant at 95% confident interval (OR=2.64, p=0.0407).

Table 4.15: Grazing contact during dry season and independent variables on multivariate analysis

No	Variables	OR (95% C.I)	P-Values
1	Land size	0.82(0.72- 0.92)	0.0012**
2	Number of animals in the farm	1.31 (1.13-1.54)	0.0007***
3	Breeds		
	Cross(Indigenous= Ref)	1.00 (0.58-1.73)	0.9975
	Mixed	2.64 (1.09 - 7.16)	0.0407*

*significant at 0.05 level

4.10 Network analysis in selected Villages during October/November rainy season in Kimilili-Bungoma County

Description of the various network measures in the villages

4.10.1 Description of the farm networks due to breeding and ploughing during the year of the study

The mean normalized degree for the farms was highest in Lurare village (3.3) and this was followed closely by Chebukwabi village (3.0).This indicates the average number of farm contacts as a result of breeding network. Lutonyi and Malaha villages had the least mean normalized degree. The maximum possible links in Lurare village was 1128 and the present links was 37. Malaha and Lutonyi had the least network density of 2.0% and 1.9%

respectively. Network centralization which is a measure of the variability of centrality was highest in Namunyiri (42.2%) and Sango (42.0%). This indicates that some farms in these two villages had more degrees than other farms in the same villages. Kibunde village had a network centralization value of 8.8% and this indicates there was little variation in centrality. The number of isolates (unreachable nodes) was highest in Lutonyi and Malaha villages and this was an indicator of high fragmentation in the network. There was no clustering in the breeding network except in Namunyiri and Lurare which had a low clustering coefficient. Table 4.16 show the network measures for breeding network in the villages.

Table 4.16: Average normalized degree, isolates, network centralization and size of components of breeding networks in selected villages in Kimilili-Bungoma County in the year 2013.

Villages	No. of nodes	Average normalized degree	Network Centralization (%)	No. of isolates	No. of Components	Size of Components	Clust. Coef
Chebukwabi	44	3.0	35.9	14	3	17,10,4	0.0
Kibunde	48	2.2	8.8	17	6	9,8,6,3,3,2	0.0
Lutonyi	45	1.9	12.3	22	4	11,5,5,2	0.0
Malaha	53	2.0	12.0	20	6	10,10,6,3,2,2	0.0
Namunyiri	43	2.7	42.2	16	3	23,3,2	0.1
Lurare	48	3.3	25.4	11	1	37	0.2
Sango	48	2.3	42.0	16	6	21,3,2,2,2,2	0.0

The mean density for ploughing networks was highest in Chebukwabi (2.5%), Kibunde (2.5%) and Malaha (2.5%). This indicates that out of the maximum possible undirected links in Chebukwabi (946), Kibunde (1128) and Malaha (1378) there were only 24, 28 and 34 links present in those villages respectively. Namunyiri village had the least density with only 7 undirected links present. The mean normalized degree was highest in the three villages and the network centralization was highest in Malaha (27.4%), an indication of variability in the network centrality among the nodes with one node (MarSim) having a normalized degree of 28.85 followed by two farms with a normalized degree of 9.62. There are many isolates with Namunyiri having the highest number and the clustering coefficient is 0 in almost all the networks which is an indication of randomness of the networks. Table 4.17 shows the network measures for ploughing in the villages.

Table 4.17: Average normalized degree, isolates, network centralization and size of components of ploughing networks in selected villages in Kimilili-Bungoma County in the year 2013.

Villages	No. of nodes	Average normalized degree	Network Centralization (%)	No. of isolates	No. of Components	Size of Components	Clust. Coef
Chebukwabi	44	2.5	14.4	12	8	9,6,4,4,3,2,2,2	0.0
Kibunde	48	2.5	13	13	8	13,6,5,3,2,2,2,2	0.0
Lutonyi	45	1.3	13	29	3	8,6,2	0.0
Malaha	53	2.5	27.4	20	1	33	0.1
Namunyiri	43	0.8	6.7	35	2	5,4	0.0
Lurare	48	1.9	6.9	20	7	5,5,5,5,4,2,2	0.0
Sango	48	1.7	13.8	22	7	8,4,4,4,2,2,2	0.0

The graphs in Figure 4.5 (a,b,c) show network structure of farms represented by nodes and the accompanying contacts (links). Nodes incident too many edges represents source farms for bulls either for breeding or ploughing in the respective villages. The graphs have been plotted using geographic coordinates (longitudes and latitudes) to represent the actual location of the farms. Few graphs have been selected to aid in visualizing the contact networks that existed in the farms in the year 2013.

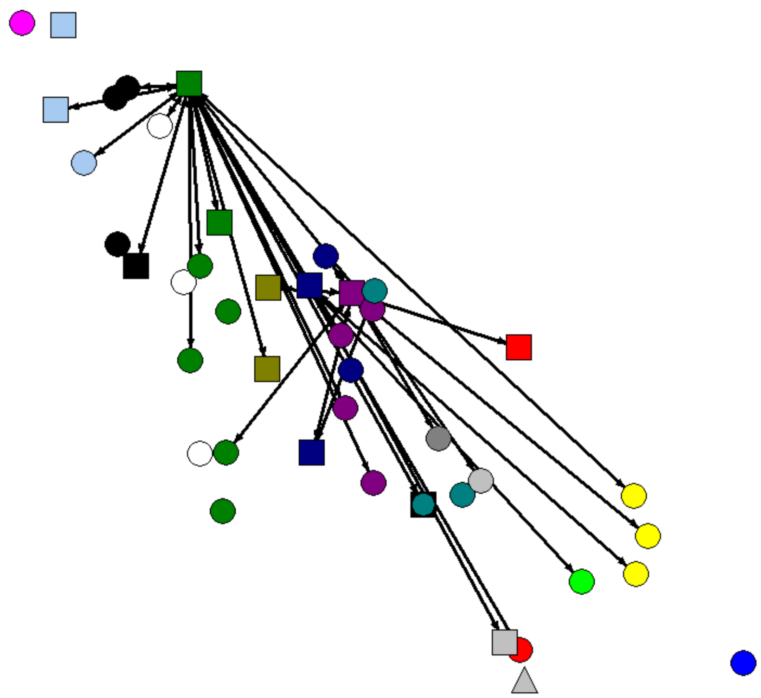


Figure 4.5 (a): Breeding network for Chebukwabi village in 2013.

Legend

○ = Farms with no bulls

□ = One bull

△ = Two bulls

⧇ = Three bulls

Different colors = Geographic locations

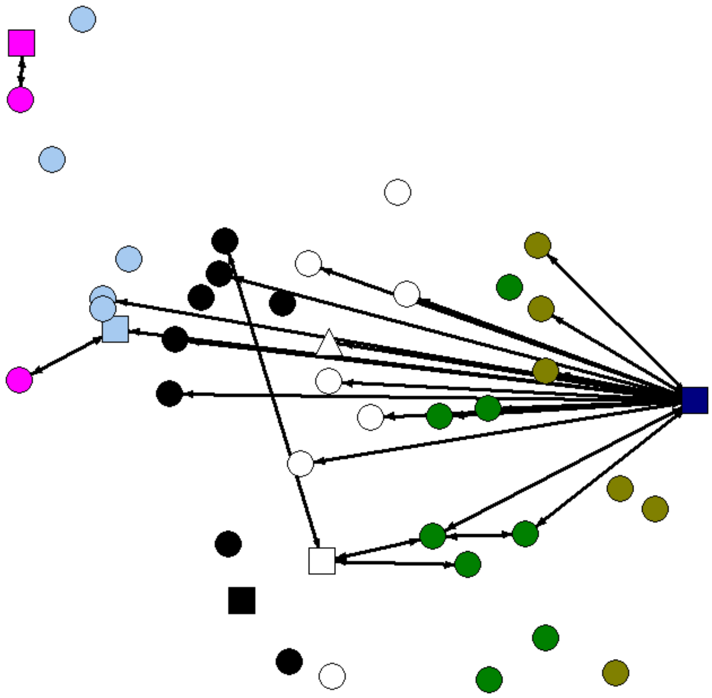


Figure 4.5 (b): Breeding network for Namunyiri village in 2013

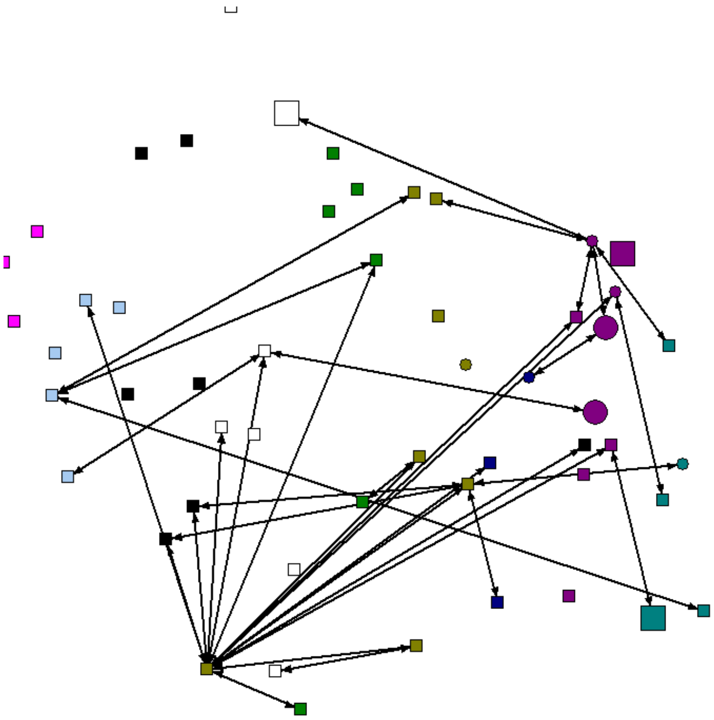


Figure 4.5 (c): Ploughing network for Malaha village in 2013.

Legend

Colors = Different geographic locations

○ = Farms where animals are watered outside homestead

□ = Farms where animals are watered at home

○ □ = Farms practicing semi intensive management

◯ ☐ = Farms practicing extensive grazing management

4.10.2: Description of farm networks due to common watering points and grazing contacts during the wet season (October/November) in selected villages in Bungoma County

The average normalized degree was highest in Lutonyi (8.3) and lowest in Malaha and Namunyiri. This indicates that there were more farm contacts as a result of common water points in Lutonyi and very few contacts in Malaha and Namunyiri. Average network density was equally high in Lutonyi (8.3%) an indication that out of the maximum possible undirected links (990), there was 82 undirected links. There was slight variability in network centrality in Chebukwabi and Lurare. The number of isolates was also highest in Malaha and Namunyiri. The results for common water point networks are shown in Table 4.18

Table 4.18: Average normalized degree, isolates, reciprocity, network centralization and size of components of common water point networks in selected villages in Kimilili-Bungoma County in October/November 2013.

Water point network								
Villages	No. of nodes	Average normalized degree	Network Centralization (%)	No. isolates	No. Components	Size Components	Reciprocity	Clust. Coef f
Chebukwabi	44	4.4	19.7	20	3	13,8,3	1.0	0.6
Kibunde	48	2.7	15.0	24	3	20,2,2	1.0	0.5
Lutonyi	45	8.3	10.4	10	4	24,7,2,2	0.6	0.6
Malaha	53	0.5	5.5	43	3	6,2,2	1.0	0.0
Namunyiri	43	0.7	11.8	35	2	6,2	1.0	0.0
Lurare	48	4.7	15.1	24	1	24	0.7	0.4
Sango	48	4.5	10.8	15	3	22,7,4	1.0	0.5

Figure 4.6 show a visual presentation of graph for Lutonyi water contact network plotted with the geographic coordinates of the farms.

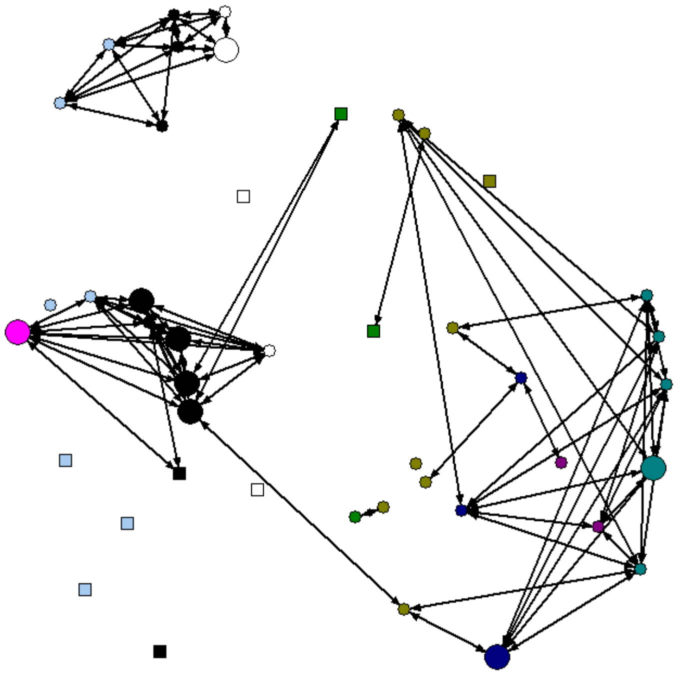


Figure 4.6: Farm contact networks due to sharing of common water points.

Legend

Colors = Different geographic locations

○ = Farms where animals are watered outside homestead

□ = Farms where animals are watered at home

○ □ = Farms practicing semi intensive management

○ □ = Farms practicing extensive grazing management

The average normalized degree of the open field grazing was highest in Lutonyi (7.0) and Sango (5.6) and lowest in Kibunde (1.3) and Chebukwabi (2.0). The network densities was relatively high in the Lutonyi (7.0%) and Sango (5.6%) compared to the other villages and Kibunde had the lowest density network of 1.3% and the largest number of isolates (32).

The number of network components was highest in Lutonyi (5) and Sango (4) with high clustering coefficient. The results for extensive field grazing contacts are shown in table 4.19.

Table 4.19: Average normalized degree, isolates, reciprocity, network centralization and size of components of extensive grazing networks in selected villages in Kimilili-Bungoma County in October/November 2013.

Open field grazing contact								
Villages	No. of nodes	Average normalized degree	Network Centralization (%)	No. of isolates	No. of Components	Size of Components	Reciprocity	Clust. Coef
Chebukwabi	44	2.0	10.1	24	4	9,6,3,3	0.9	0.2
Kibunde	48	1.3	5.3	32	3	10,4,2	0.7	0.4
Lutonyi	45	7.0	11.7	7	5	22,7,4,3,2	1.0	0.6
Malaha	53	4.2	7.6	10	4	20,18,3,2	0.8	0.2
Namunyir	43	2.4	9.9	20	3	14,7,2	1.0	0.3
Lurare	48	3.8	13.8	21	2	25,2	1.0	0.6
Sango	48	5.6	14.2	6	4	27,8,4,3	0.9	0.4

The average normalized degree for grazing network as a result of neighbors grazing into their neighbors homestead(s) / (farm) or animals crossing the farm boundaries and grazing together with neighbors animals was high in Chebukwabi (6.6), Kibunde (5.9) and Namunyiri (5.1) and their network densities were also relatively high compared to the other networks. The variability in the network degree was low in Sango (14.2%) which is an indication of slight skewness in distribution in individual degrees. The number of isolates was higher in Sango, Lutonyi and Lurare as shown in Table 4.20. Kibunde and chebukwabi had the largest component size with high clustering coefficient. Figure 4.7 (a) and (b) shows a visual presentation of the selected networks plotted with the actual coordinates of the farms.

Table 4.20: Average normalized degree, isolates, reciprocity, network centralization and size of components of neighbors farm(s)/boundary grazing networks in selected villages in Kimilili-Bungoma County in October/November 2013.

Neighbors' farm/border grazing contact								
Villages	No. of nodes	Average normalized degree	Network Centralization (%)	No. of isolates	No. of Components	Size of Components	Reciprocity	Clust. Coef
Chebukwabi	44	6.6	12.6	5	6	13,9,8,6,2,2	1.0	0.6
Kibunde	48	5.9	11.7	7	3	15,14,12	0.9	0.4
Lutonyi	45	2.3	7.1	19	6	8,5,5,3,3,2	1.0	0.5
Malaha	53	3.8	8.0	11	4	24,12,2,2,2	1.0	0.3
Namunyiri	43	5.1	12.1	9	4	24,6,2,2	0.9	0.5
Lurare	48	3.0	10.2	15	9	8,7,4,3,3,2,2,2,2	0.9	0.5
Sango	48	3.5	14.2	21	3	21,3,3	0.9	0.5

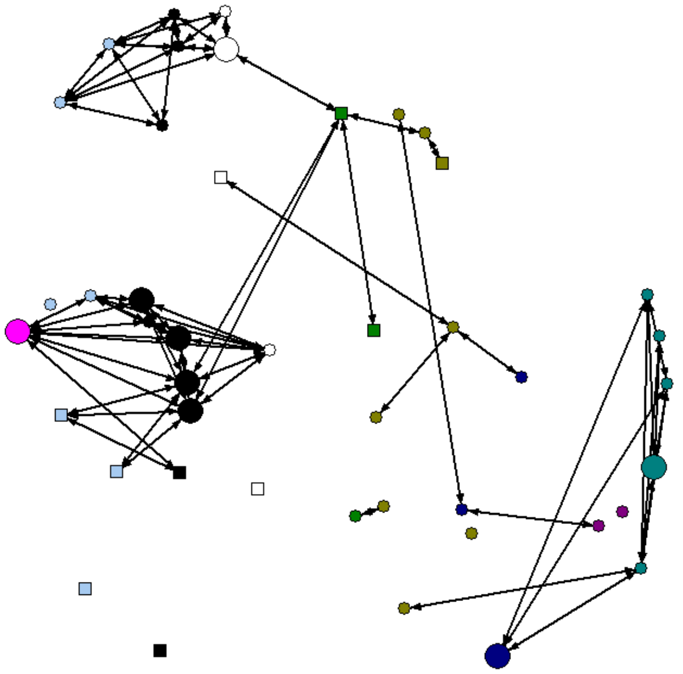


Figure 4.7(a): Lutonyi farm contact networks due to open field grazing.

Legend

Colors = Different geographic locations

= Farms where animals are watered outside homestead

= Farms where animals are watered at home

= Farms practicing semi intensive management

= Farms practicing extensive grazing management

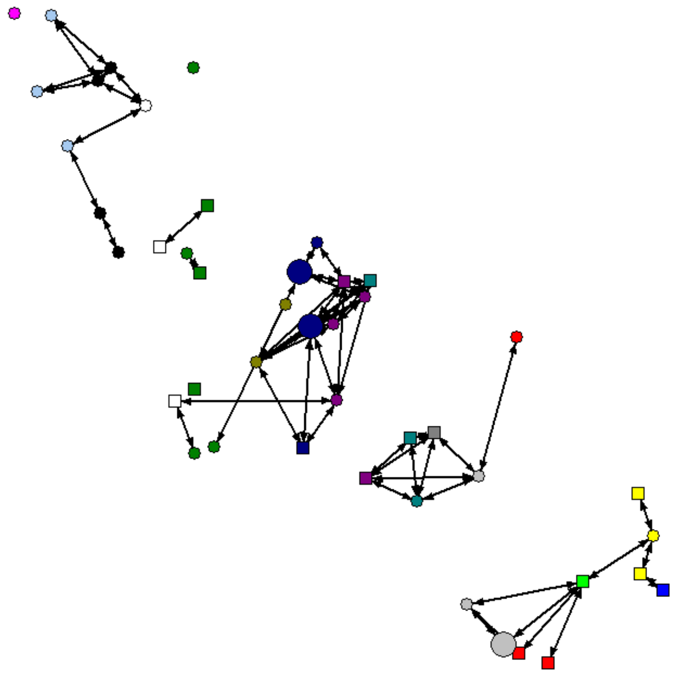


Figure 4.7 (b): Chebukwabi village farm grazing contacts at the neighbors farm(s)/ common boundary points

4.10.3 Comparing the mean densities of common water points contact networks and open field grazing contact networks (extensive)

Using bootstrap paired t-test the densities for the two networks were compared in every village. In four villages (Chebukwabi, Namunyiri, Malaha and Sango) the densities were significantly different as shown in Table 4.21.

Table 4.21: Comparing mean densities for common water points and open grazing field networks in the villages

Name of villages	Density of Water network (%)	Density of extensive grazing network (%)	95% bootstrap CI for the difference (paired sample)	P-value
Chebukwabi	4.4	2.0	[0.0003, 0.0484]	0.0488
Kibunde	2.7	1.3	[-0.0055, 0.0321]	0.1594
Lutonyi	8.3	7.0	[-0.0033, 0.0296]	0.1204
Malaha	0.5	4.2	[-0.0501, -0.0239]	0.0002
Namunyiri	0.7	2.4	[-0.0331, -0.0023]	0.0272
Lurare	4.7	3.8	[-0.0054, 0.0232]	0.2212
Sango	4.52	5.6	[-0.0203, -0.0010]	0.0284

*significant at 0.05 level

4.10.4 Comparing the densities of farm water contact networks and farm boundaries grazing networks.

The difference in the densities for the two networks were significantly different in Malaha, Namunyiri, Lutonyi and Kibunde (p-value<0.05).This was also consistent with 95% bootstrap CI for the difference as shown in Table 4.22.

Table 4.22: Comparing mean densities for farm water points and farm boundary grazing networks in the villages.

Villages	Water Density (%)	Farm boundary grazing network (%)	95% bootstrap CI for the difference (paired sample)	P-value
Chebukwabi	4.4	6.6	[-0.0468, 0.0045]	0.1052
Kibunde	2.7	5.9	[-0.0571, -0.0067]	0.0148
Lutonyi	8.3	2.3	[0.0298, 0.0894]	0.0006
Malaha	0.5	3.9	[-0.0461, -0.0206]	0.0002
Namunyiri	0.7	5.1	[-0.0642, -0.0244]	0.0002
Lurare	4.7	3.0	[-0.0096, 0.0433]	0.2034
Sango	4.5	3.5	[-0.0182, 0.0395]	0.4789

4.11 Testing for the associations between: breeding and ploughing networks, water and extensive grazing networks, water and farm boundary grazing contact networks.

Results for correlation test indicated that breeding and ploughing networks were correlated in Kibunde, Lutonyi, Malaha and Sango with Pearson coefficient of 0.2, 0.1,0.1 and 0.4 respectively with ($p<0.05$). Pearson correlation test indicated that water and extensive grazing networks were correlated in 5 villages (Chebukwabi,Lutonyi,Malaha,Lurare,Sango) as shown in Table 4.23. Water and farm boundaries grazing networks were also correlated in 5 villages (Chebukwabi,Kibunde,Lutonyi, Lurare and Namunyiri). Therefore knowing the density of one network helps in predicting the density of the other in those villages.

Table 4.23: Correlation tests between: breeding and ploughing networks, water and extensive grazing network, water and farm boundaries grazing networks in villages in Kimilili-Bungoma County.

Name of the village	Breeding and ploughing networks		Water and extensive grazing networks		Water and farm boundaries grazing networks	
	Pearson cor. coef	p-value	Pearson cor. coef	p-value	Pearson cor. coef	p-value
Chebkwabi	-0.0	0.486	0.2	0.001	0.3	0.000
Kibunde	0.2	0.001	0.1	0.060	0.1	0.009
Lutonyi	0.1	0.031	0.7	0.000	0.1	0.000
Malaha	0.1	0.009	0.1	0.003	0.0	0.237
Namunyiri	0.1	0.151	0.1	0.140	0.2	0.004
Lurare	0.1	0.149	0.6	0.000	0.1	0.028
Sango	0.4	0.000	0.8	0.000	0.0	0.522

Quadratic Assignment procedures (QAP) regression for common water point's ties on extensive grazing ties and farm boundary ties was done. The hypothesis was that existence of an extensive contact tie between two farms or farm boundary tie between two farms increases likelihood of common water point tie. Table 4.24 shows the results for the "full partialling" method.

Table 4.24: QAP regression of water ties in extensive grazing ties and farm boundary ties by full partialling method.

Village	Independent predictor	Unstdized coef.	Std coef.	P-value	R-Square	Model Fit P-value
Chebukwabi	Intercept	0.024	0.000		0.121	0.000
	Boundary cont	0.246	0.295	0.000		
	Extensive cont	0.214	0.146	0.0030		
Kibunde	Intercept	0.022	0.000		0.014	0.005
	Boundary cont	0.062	0.091	0.0110		
	Extensive cont	0.091	0.065	0.0680		
Lurare	Intercept	0.019	0.000		0.403	0.000
	Boundary cont	0.046	0.037	0.0960		
	Extensive cont	0.698	0.631	0.0000		
Lutonyi	Intercept	0.028	0.000		0.505	0.000
	Boundary cont	0.089	0.048	0.0720		
	Extensive cont	0.760	0.702	0.000		
Malaha	Intercept	0.003	0.000		0.019	0.002
	Boundary cont	0.008	0.022	0.2240		
	Extensive cont	0.048	0.135	0.0010		
Namunyiri	Intercept	0.003	0.000		0.030	0.002
	Boundary cont	0.059	0.158	0.0030		
	Extensive cont	0.024	0.045	0.1340		
Sango	Intercept	0.004			0.644	0.000
	Boundary cont	0.029	0.026	0.2630		
	Extensive cont	0.726	0.802	0.000		

Only in three villages (Sango, Lurare and Lutonyi) that knowing whether a tie exists between a pair of two farms due to extensive grazing contact and whether a tie exists between two farms due to farm boundary contact reduces the uncertainty in predicting water tie by value greater than 40%. The intercept indicates the probability of water tie if there is no extensive grazing contact and no farm boundary contact between two farms.

4.12 The effects of distance and management practices on farm contacts

Correlation test between a pair of farmers practicing similar activity was undertaken in the villages. The hypothesis was that pair of farmers taking their livestock outside their farms for water was likely to be connected. Chebukwabi, Lutonyi and Sango were significantly correlated ($p<0.05$ and Pearson correlation coefficient 0.1 to 0.2). The correlation between farm distances and overall farm contacts was negatively correlated ($p=0.0000$, Pearson correlation between -0.2 to -0.4) while distances and breeding contacts were negatively correlated in Kibunde (Pearson corr. -0.2), Lutonyi (Pearson corr. -0.1) and malaha (Pearson corr. -0.1) as shown in Table 4.25

Table 4.25: Association between pair of farmers taking their livestock for water outside their farms and influence of distance on contact.

Farms taking their animals to common water points			Distance between farms on breeding contacts		Distance between farms on overall contacts	
Village	Pearson Correlation	P-value	Pearson Correlation	P-value	Pearson Correlation	P-value
Chebukwabi	0.1	0.008	-0.0	0.311	-0.4	0.000
Kibunde	0.0	0.423	-0.2	0.000	-0.3	0.000
Lutonyi	0.2	0.000	-0.1	0.009	-0.4	0.000
Malaha	0.0	0.531	-0.1	0.002	-0.3	0.000
Namunyiri	-0.1	0.165	-0.1	0.134	-0.3	0.000
Lurare	0.0	0.37	0.1	0.022	-0.2	0.000
Sango	0.1	0.027	-0.1	0.072	-0.3	0.000

4.13 Comparing the mean normalized degree tie and the farm attributes: grazing management and source of water for the cattle

The mean degree tie for farms taking their cattle for water outside the homestead was compared to those watering their cattle at home using t-test. There were significant differences ($p < 0.05$) in four villages (Chebukwabi, Lurare, Lutonyi and Sango). Table 4.26 (a) shows the results for the comparison of the mean normalized degree ties for the two different sources of water for livestock in the villages.

Table 4.26 (a): Comparison of the mean normalized degree for the sources of water for livestock in the villages.

Village	Mean 1	Mean 2	Difference in Mean normalized degree	One-Tailed Tests		Two-Tailed
				Group 1 > 2	Group 2 > 1	Group 1 > 2
Chebukwabi	16.3	10.3	6.0	0.007	0.994	0.0156
Kibunde	14.0	10.6	3.4	0.049	0.954	0.0852
Lurare	20.7	10.0	10.7	0.0	1.0	0.0001
Lutonyi	14.8	7.0	7.8	0.001	0.999	0.0018
Malaha	14.3	10.0	4.3	0.067	0.937	0.1196
Namunyiri	12.7	9.4	3.3	0.205	0.795	0.4242
Sango	13.2	9.3	3.9	0.019	0.982	0.0458

Legend

Mean 1 = mean normalized degree for farmers taking their livestock for water outside their homes.

Mean 2 = mean normalized degree for farmers watering their livestock at home.

The difference in mean normalized degree for farms practicing semi intensive and extensive grazing management was also compared using t-test and the results are as shown in Table 4.26 (b). There was significant difference in mean normalized degree for the two grazing management practices in Lurare, Lutonyi and Sango ($p<0.05$). Kibunde village had all the farms practicing semi intensive grazing management.

Table 4.26 (b): Comparison of the mean normalized degree for the grazing management in the villages.

Village	Mean 1	Mean 2	Difference in Mean normalized degree	One-Tailed Tests		Two-Tailed
				Group 1 > 2	Group 2 > 1	Group 1 > 2
Chebukwabi	13.5	20.2	-6.7	0.903	0.102	0.1869
Kibunde						
Lurare	11.5	20.1	-8.6	0.996	0.004	0.0054
Lutonyi	10.9	22.2	-11.2	1.000	0.000	0.0001
Malaha	10.5	11.2	-0.6	0.616	0.402	0.8677
Namunyiri	9.6	10.7	-1.1	0.608	0.392	0.8189
Sango	9.6	15.7	-6.1	0.998	0.002	0.0026

Legend

Mean 1 = mean normalized degree for farms where semi intensive management is practiced.

Mean 2 = mean normalized degree for farms where extensive grazing management is practiced.

4.14 The overall farm contacts in the selected villages in Kimilili-Bungoma County

The average density of the overall farm networks was highest in Chebukwabi (14%) followed by Lurare (13.1%) and Lutonyi (12.9%) as shown in table 4.27. This indicates that out of the maximum possible undirected ties in Chebukwabi, Lurare and Lutonyi of 968, 1152 and 1013 there were actually 136,150 and 131 undirected links present respectively in those villages. The network density was low in Namunyiri (9.6%) with only 89 undirected ties out of 925, the maximum possible undirected links. Network variability was high in Sango (36.8) and Namunyiri (34.8) and this indicates that there were few nodes which dominated the network (higher centrality). All the networks had one component with slightly varying sizes and Chebukwabi, Sango and Kibunde completely connected (no isolates) and few isolates in other villages.

Table 4.27: Overall contact measures for the villages

Overall Farm contacts						
Villages	No. of nodes	Average normalized degree	Network Centralization (%)	No. of isolates	No. of Components	Size of Components
Chebukwabi	44	14.0	29.2	0	1	44
Kibunde	48	11.8	21.0	0	1	48
Lutonyi	45	12.9	17.4	2	1	43
Malaha	53	10.6	25.0	3	1	50
Namunyiri	43	9.6	34.8	1	1	42
Lurare	48	13.1	21.8	1	1	47
Sango	48	11.5	36.8	0	1	48

Figure 4.8 show the frequencies of the degree in the three villages which had the highest (Chebukwabi and Lurare) and lowest (Namunyiri) average normalized degrees. In Chebukwabi village most farms (18) had a normalized degree greater than 14 and in Lurare village, most farms (13) had a normalized degree >14. In Namunyiri, ten farms had a degree of 5 and there were only two farms with normalized degree of 14.

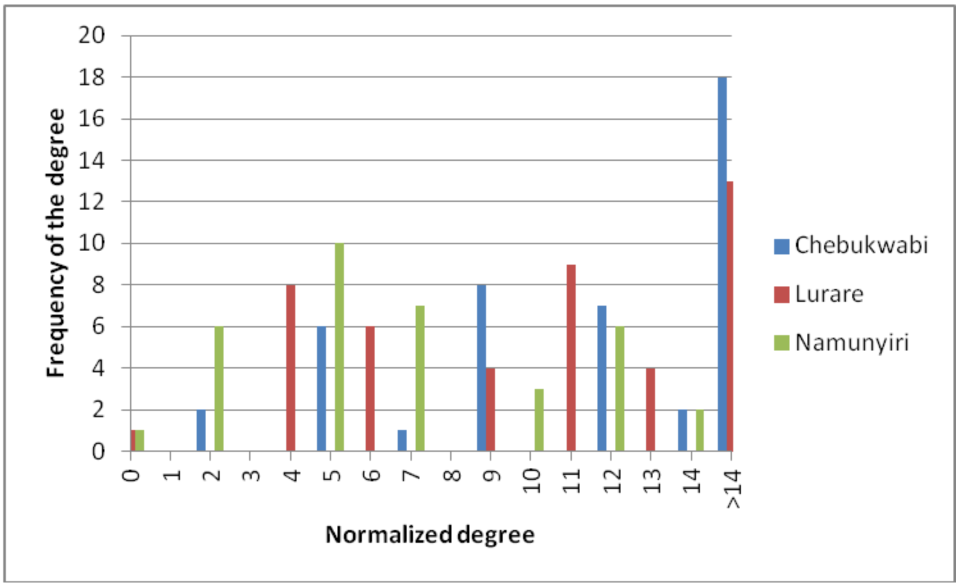


Figure 4.8: The frequencies of the farm normalized degrees in Chebukwabi, Namunyiri and Lurare.

4.15 The path length between the farms and the flow in the networks within the villages

The average normalized betweeness centrality also called Relative Betweeness centrality (RBc) was highest in Namunyiri village (5.67) as shown in Table 4.28 and lowest in Lurare.

Table 4.28: Flow between the farms and the shortest distances within the villages

Overall Farm contacts						
Village	No.nodes	CV	Average Ncloseness	Average Nbetweeness	Geodesic distance	Clust. Coefficient
Chebkwabi	44	1.7	41.7	3.5	2.5	0.5
Kibunde	48	1.8	38.8	3.5	2.6	0.5
Lutonyi	45	1.8	21.8	3.6	2.7	0.5
Malaha	53	1.6	17.9	3.0	2.7	0.3
Namunyiri	43	1.3	23.8	5.7	3.4	0.4
Lurare	48	1.6	29.8	3.0	2.4	0.4
Sango	48	1.6	39.6	3.4	2.6	0.5

Legend

Ncloseness = Normalized closeness

Nbetweeness = Normalized betweeness

CV = Coefficient of variation

Three farms in Namunyiri (AmoWaf, PeWan and FitWany) had a high RBc's of 54.6, 29.8 and 19.0 and this indicates the importance of these nodes because they lie in the geodesic path. There were 33 farms in the shortest path between any pair of nodes in Namunyiri (non zero betweeness) and 11 farms had RBc greater than the average RBC (5.7). Two of these farms also had high normalized degrees. Malaha village has the lowest RBC (3.0) and the three farms with the highest values (25.8, 13.6 and 11.8) as shown in Table 4.29 were MarSim, EvSim and JudWany respectively and the first two equally have the highest normalized degree in that village. There were 46 farms in the shortest path between any pair of farms in Malaha and 15 farms had RBc greater than the average RBC (3.00)

Table 4.29: Relative betweenness centrality (RBC) of the first top three in every village

Nodes in Namunyiri	RBC	Nodes Lutonyi	RBC	Nodes in Lurare	RBC	Nodes in Malaha	RBC
Amowaf	54.6	FreSia	16.3	JaWe	23.4	MarSim	25.8
PeWan	29.8	DisMak	13.7	IsMu	20.1	EvSim	13.6
FitWany	19.0	JoWaMa	12.8	JoPa	13.0	JudWany	11.8
Nodes in Kibunde	RBC	Nodes in Chebukwabi	RBC	Nodes in Sango	RBC		
AnMa	19.6	BenSim	40.2	MoWwa	50.6		
TuMu	18	BenWa	14.4	JaMak	10.8		
JaNWa	16.2	DicNdal	12.6	BenKha	9.5		

Closeness centrality which focuses on the distance of an actor to all others in the network was calculated as shown in Table 4.27. The average normalized clossness was high in Chebukwabi (41.7), Sango (39.6) and Kibunde (38.8) and the higher values are indicative of greater centrality (importance). The number of farms which had normalized clossness greater than 40 were; Chebukwabi (29 farms), Sango (23 farms) and Kibunde (21farms).

The average geodesic distance was highest in Namunyiri (3.4) , Lutonyi and Malaha (2.7) and lowest in Lurare (2.4) as shown in Table 4.28. In Namunyiri, Chebukwabi and Lurare the geodesic distance with the highest frequency was 2 while it was 3 in the others as shown in table 4.30.

Table 4.30: Frequencies of geodesic distances among the villages

No. of geodesic distance	Lutonyi	Malaha	Namunyiri	Sango	Kibunde	Lurare	Chebukwabi
1	228	146	82	130	133	148	132
2	261	405	212	412	379	442	367
3	321	418	194	419	412	381	346
4	156	179	160	143	181	101	88
5	30	65	101	22	22	9	12
6	7	12	54	2	1		1
7			34				
8			14				
9			5				
10			1				

A summary of the significant findings in the villages are shown in Table 4.31.

Table 4.31: Summary of overall parameters of the matrices in the selected villages

Villages	**Cheb**	**Kib**	**Lut**	**Mal**	**Nam**	**Lur**	**Sango**
No. nodes	44	48	45	53	43	48	48
Density (undirected) (%)	14.0	11.8	12.9	10.6	9.6	13.1	11.5
No. undirected links	132	133	128	146	87	148	130
Average Normalized degree	14.0	11.8	12.9	10.6	9.6	13.1	11.5
Degree Centralization (%)	29.2	21.0	17.4	25.0	34.8	21.8	36.8
Diameter	6	6	6	6	10	5	6
No.reachable pairs	946	1128	903	1225	861	1081	1128
% reachable pairs	100	100	91.2	88.9	95.3	95.8	100
Average geodesic distance	2.5	2.6	2.7	2.7	3.4	2.4	2.6
Geodesic distribution (mode)	2	3	3	3	2	2	3
Clustering coefficient	0.5	0.5	0.5	0.3	0.4	0.4	0.5
Relative closeness	41.7	38.8	21.8	17.9	23.8	29.8	39.6
Relative betweeness	3.5	3.5	3.6	3.0	5.7	3.0	3.4

Legend

Cheb- Chebukwabi

Kib- Kibunde

Lut- Lutonyi

Mal- Malaha

Sang- Sango

Nam- Namunyiri

Lur- Lurare

The graph in figure 4.9 (a, b) indicates the overall contacts that existed in Chebukwabi and Lutonyi in Bungoma County during the study period.

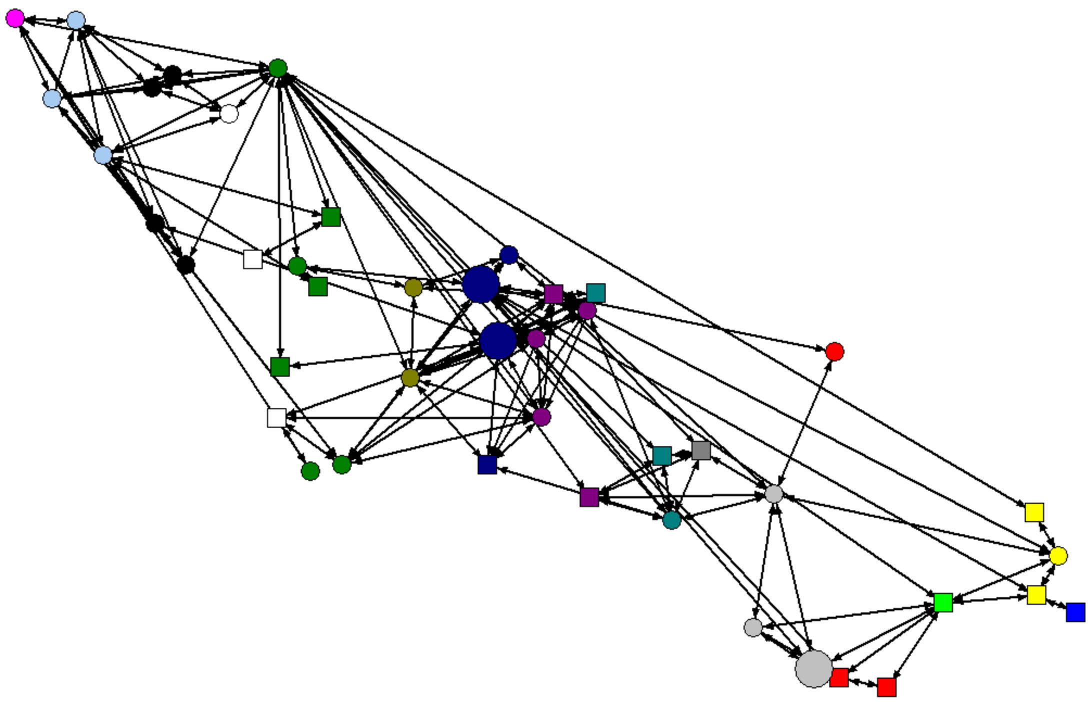


Figure 4.9 (a) : Overall contact for Chebukwabi

Legend

Colors = Different geographic locations

○ = Farms where animals are watered outside homestead

□ = Farms where animals are watered at home

○ □ = Farms practicing semi intensive management

◯ ☐ = Farms practicing extensive grazing management

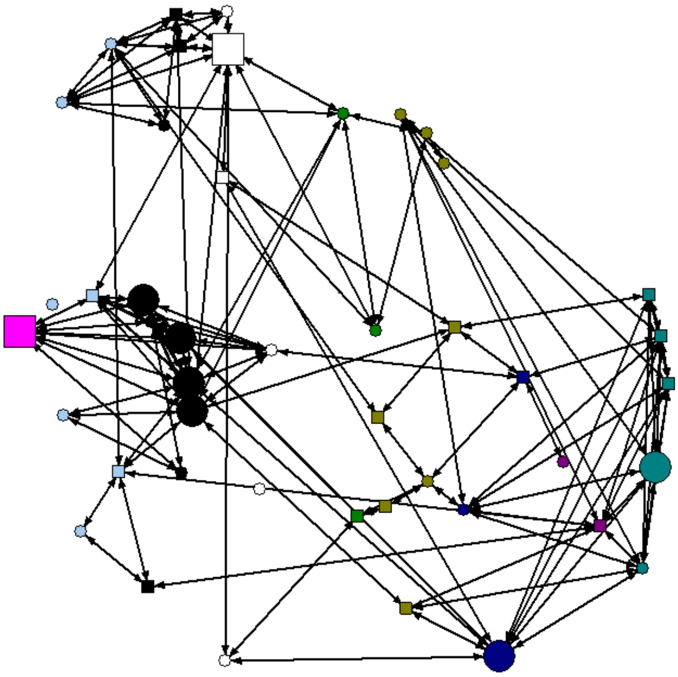


Figure 4.9 (b) : Overall contact for Lutonyi

CHAPTER FIVE

5.0 DISCUSSION

The aim of this study was to assess the types of contacts between farms and the implication for disease transmission. The networks that were identified included; breeding networks, ploughing networks, common water points networks, open field grazing networks (extensive grazing) and common boundary grazing networks. Both the relationships between the attributes of the nodes and the associations between the individual nodes in the villages were explored to gain a better understanding of the topology of existing networks during the wet season.

5.1 Network attributes

Most of the farmers practiced extensive grazing management during the dry season compared to wet season and therefore more farm contacts as a result of grazing was likely to occur during the dry season. Most farmers also increased their daily frequency by which they took their animals outside their homes in search of pastures and water during the dry season compared to the wet season. This is because during the dry season most farmers have exhausted their feed reserves for their livestock and therefore pastures and water become scarce hence the need to move livestock in different areas in search of pastures and water. This finding indicates that the probability of contacts was significantly increased during the dry season.

Most of the farms which acquired new animals into their farms bought them from the livestock markets and this was a potential risk of introducing new diseases such as foot and disease (FMD) into the herds since livestock markets acts as hubs (Natale et al., 2009, Fèvre et al., 2006 and Dube et al., 2010). Livestock are moved from various locations into the livestock market and therefore when there is weak surveillance in the markets, disease spread into the herds is likely to occur upon introduction of sick or animals incubating disease into the farm. McLaws and Ribble (2007) characterized the impact that markets play as hubs in a network of livestock movement to the spread of FMD. They concluded that movement of infected animals through a market was the activity with highest risk of leading to very large FMD outbreaks. Most of the farms in the villages indicated high rate of bull sharing within and outside the villages. This practice was common because most farms had castrated bulls and there were only a few intact bulls that were available for breeding. The practice of bull sharing was a major risk to the spread of sexually transmitted infections in the farms. All the variables for breeding contacts that were tested on multivariate analysis were not explaining the outcome. This could be explained by the fact that farmers were choosing specific farms which had bulls with specific attributes like bull size and therefore they took their cows to such bulls regardless of distance. This could be the reason why in a given village only specific farms with bulls had their bulls mating many cows within the village and outside the village yet there were other bulls in the same villages.

Farms which had more animals had increased probability of making contacts at the common water points both during dry and wet season. This is because the larger the number of livestock in a farm, the higher the amount of water consumption and this makes it more likely for farmers to take their animals to the water source outside their farms. Farms which had cross breeds were less likely to take their cattle to the common water points outside their farms mainly because these farms were mostly practicing semi intensive management and they also kept fewer numbers of animals which they could give water at home.

5.2 Network analysis

There were more breeding contact opportunities for animals within Chebukwabi and Lurare villages as shown by the lower number of isolates and high average normalized degrees compared to other villages. There was greater variability in breeding contacts in Namunyiri and Sango due to very few farms with bulls allowing their bulls to mate several cows within and outside the villages. Hiring of bulls for ploughing where farmers combine their oxen to drive ox plough makes some villages at a greater risk of introducing diseases into their farms. There were more watering point contacts in Lutonyi as shown by the high average normalized degree and low isolates compared to other villages. This is because there is a river that passes through the village and therefore most farmers are able to take their animals to the river easily. It is only Namunyiri and Malaha which didn’t have a river source going through the village and therefore they had fewer watering point contacts as most farmers relied on water from the wells for their livestock. Open field grazing contacts was also highest in Lutonyi and Sango compared to other villages and the contacts were randomly distributed in the villages. Lutonyi also had the lowest number of farm boundary contacts due to animals crossing the farm boundaries and grazing together with the neighbors’ animals. This is due to the availability of grazing land for livestock compared to other villages.

In Chebukwabi, most farms were connected through common water points’ contact while in Malaha, Namunyiri and Sango most farms were connected through open field grazing networks. This is because most farmers were practicing semi intensive grazing management in Chebukwabi while in the other villages’ larger proportion of farmers practiced extensive grazing management. There was also no river passing through the two villages (Malaha and Namunyiri).

Farms which took their animals for pastures outside their homesteads were more likely to take them to the river for water in Chebukwabi, Lutonyi, Sango, Malaha and Lurare. Therefore these farms which had contacts during grazing were also likely to have contacts at water points. Knowing whether a contact existed between two farms due to open field grazing reduced the uncertainty of predicting common water points tie by value greater than

40% in Sango, Lurare and Lutonyi. As expected farms which practiced extensive grazing management in Lurare, Lutonyi and Sango had more contacts compared to the farms that practiced semi intensive management.

5.3 Overall farm contacts

The overall connections in the villages were highest in Chebukwabi, Lurare and Lutonyi and all the villages had one component with few isolates. Namunyiri showed the least connectivity but had few farms which were more central and they laid in the geodesic path between other farms and therefore to reach other farms you had to go through these central farms which is evident in the high relative betweeness. Therefore removal of these central nodes could easily disintegrate or weaken the network. The average geodesic distance was highest in Namunyiri, Lutonyi and Malaha and therefore it took more steps to reach a farm from any other in these villages. According to the values of geodesic distances and proportions of reachable pairs in chebukwabi, Kibunde and Sango, these villages were considered to be at a higher risk of disease transmission compared to the others. As expected contacts in the villages were negatively correlated with distances therefore farms that were close were more likely to be linked compared to farms that were far. This was because during the wet season pastures are available and therefore livestock are not moved far away from homesteads.

5.4 Implication of the networks for the spread of disease in the villages

The degree of networks is important in identifying highly connected individuals hence predicting the risk of infection. There was heterogeneity in contacts with few nodes which monopolized the contacts while most nodes had few contacts and this greatly influences disease behavior (Christley et al., 2005; Bigras-Poulin et al., 2007). Epidemics can spread faster on scale free networks because of existence of hubs as compared with random networks of equivalent size (Kiss et al., 2006). Therefore, disease control strategies that target the most highly connected nodes (hubs) in a scale-free network will be more effective than those used on randomly selected nodes (May and Lloyd 2001; Kiss et al 2006). Because of heterogeneous mixing leading to heterogeneous degree of the contacts, basic reproduction number (Ro) will incorporate heterogeneous mixing by including coefficient of variation of the degree (Christley et al., 2005). Therefore contact networks where few farms have extraordinary large number of contacts will result in higher Ro compared to networks with uniform degree distribution (Albert et al., 2000 and Smith et al., 2005). Thus, same disease will exhibit different epidemic patterns taking into account differences in degree distribution (Salathe and Jones, 2010). Introduction of the same pathogen in the villages will result into higher Ro in Chebukwabi, Lutonyi and Kibunde because of greater values of coefficient of variations compared to other villages. Therefore higher values of Ro will dictate the behavior of the disease in these villages. Network topology also plays a significant role in the spread of diseases. The rate of spread of diseases would have been slowed down in Namunyiri because of the average distance between the farms which was larger and low coefficient of variation. This suggests that pathogens could not transmit from one farm to all others except by passing through other farms and this will slow down the rate of spread in the village thus giving time for control measures to be instituted. Depending on the point of introduction of the pathogen particularly for directly transmitted infections, farms with higher degree will have increased risk potential for the spread of the pathogens in the network. Therefore the appropriate approach of control is to prevent the types of contacts that lead to transmission (Fèvre et al., 2006) and in the event of epidemic outbreak, contact tracing is the most important means of disease control as it seeks to quickly remove infected livestock from further spreading of infection (Kiss et al., 2006). Nodes with very high degrees will act as “super spreaders” in the spread of diseases. The component structures of networks act to limit transmission within a population. Clustering of the networks also mitigates the effect of R_o in the networks (Molina and Stone, 2012) and in particular during the later stages of disease spread. High clustering coefficient is related to diminish number of nodes because more connections lead to the same farms (May and Lloyd, 2001). When more nodes are infected the susceptible nodes become depleted and the correlation in infection becomes a limiting factor and slows down the rate of spread (Kiss et al., 2006) and hence local extinction of infection.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

From the study the following conclusions can be made:-

1) Most of the farms practice semi-intensive grazing management with only a small proportion practicing extensive grazing management.

2) There was a significant difference in the daily frequency of grazing and watering off the farm during rainy and dry seasons. More farmers took their animals to graze and to the river outside their farms daily during dry season compared to the wet season. The river was the common water point in most villages.

3) Most of the farms acquire new animals from livestock markets and this could be a risk to introduction of diseases in the villages. There was also high a rate of communal bull sharing and this could be a potential route for disease transmission.

4) Contacts in the villages were mainly influenced by the distances between the farms. Farms that were close to each other were more likely to come into direct contacts compared to farms that were far apart except for breeding contacts which were independent of distance in the villages.

5) The networks in the villages resemble a free scale networks with varying degree of contacts. Some farms are more connected than others and therefore this heterogeneity in contact can be a risk to the spread of diseases once there is an introduction to those highly connected nodes.

6.2 Recommendations

1) Network approach is the most appropriate tool for strategic disease control because it handles heterogeneity in contacts. When farms which are highly connected are identified in the networks, they become the critical points for disease surveillance by the Veterinary department. These highly connected nodes are particularly important in targeted prevention programs because interventions aimed at the highly connected farms disrupt the networks and cuts off the spread of infections. Network analysis should play a key role in disease control program and during epidemic eradication (Birgas-Poulin et al 2006)

2) Understanding the network topology in the villages has implication on the cost of control strategy. Targeting only highly connected farms has the effect of disrupting the networks into fragmentation and this slows down the rate of spread of disease in the network and this is at a less cost compared to random vaccination which is likely to miss a number of highly connected nodes and at a high cost (Barabasi and Bonabeau 2003). Random vaccinations will require a larger coverage and this increases cost.

3) Design of transmission models which are useful decision making tools when looking at different control strategies, can be improved by taking into account this network study if the transmission probability is low (Smieszek et al., 2009) as well as the frequency of contact and the random mixing hypothesis cannot be assumed (Eames et al., 2003, Shirley and Rushton, 2005)

4) Studies should be conducted to describe contacts during dry seasons within the villages and comparisons made with the wet seasons since many farms indicated that they were likely to have more contacts during dry season. This will help in the design of accurate transmission models based on the seasonal variation of network topology. Also contacts

between the villages should be explored to provide a better understanding of the risk of the spread of diseases.

5) Veterinary extension awareness should be up scaled to educate farmers on the risk of communal bull sharing. Bull sharing in the villages and between the villages is likely to spread sexually transmitted infections in the farms.

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APPENDICES

Appendix 1: Contact structure interview

AN INVESTIGATION OF FARM CONTACTS AND THEIR POTENTIAL IMPACT ON DISEASE TRANSMISSION IN SMALLHOLDER CATTLE PRODUCTION IN BUNGOMA COUNTY OF WESTERN KENYA

A : GENERAL INFORMATION

(A 1) Date of interview …………………………

(A 2) Name of interviewer………………………

(A 3) Location…………………….. (A 4) Village…………………………

(A5) GPS reading ………………………………..

(A6) Waypoint ID……………………………………

(A6) Name of household head ……………………………….

(A7) Sex of household head……………………………………

1=Male 2=Female

(A 7) Respondent relationship (Person with responsibility for cattle management)

1= Household head 4= Relative

2=Spouse 5= Worker

3 = Son/daughter 6= other

(A8) Gender of a person being interviewed

1=Male 2= Female

(A9) Age

1-18 years= Young

Above 18 years = adult

(A10) Reason for keeping cattle (Select all that apply)

1. Milk for home (Yes/No) 2. Milk for sale (Yes/No)

3. Meat for home (Yes/No)   4. Meat for sale (Yes/No)

5. Selling calves (Yes/No)   6. Selling adults (Yes/No)

7. Ploughing (Yes/No)   8. Dowry (Yes/No)

9. Other (Describe)…………………………..

B: LIVESTOCK NUMBERS AND COMPOSITION

(B1) What is the total number of cattle currently in your farm……………….

(B2) Breed (1=Exotic   No……………

2=Crosses   No……………

3=Indigenous No……………

(B3) Sex (Males ……..   Females……………)

(B4) Adults (over 3 years)………………

(B5) Heifers/ Bullocks (2-3 years)…………….

(B6) Calves (<2years)

(B7) No. of Shoats (Goats/Sheep)

(B8) Adults (>1year)

(B9) Kids/Lambs (< 1year)

C: LIVESTOCK MOVEMENT / MANAGEMENT

(C1) What grazing management do you practice in the past four weeks during rainy season

1=Zero grazing

2= Semi intensive

3= Extensive

(C2) Where do you take your cattle for pastures during rainy seasons in the past four weeks?

……………………….

………………………..

…………………………

………………………..

(C3) What grazing management do you practice during dry season (Christmas to Easter)?

1=Zero grazing

2 = Semi intensive

3= Extensive

(C4) Where do you take your cattle for pastures during dry seasons (Christmas to Easter)?

……………………….

………………………..

…………………………

……………………….

(C5) Which grazing system are you using during rainy season (September to December)?

1=Individual herd grazing

2=Community free grazing

3=Grazing with neighbor alone

4=Other (specify)…………………………

(C6) Are your cattle taken outside of the home for water during rainy season(September to December)?

1=Yes

2=No

(C7) If your answer is YES in the above, what is the source of water for your cattle?

1=River

2=Borehole

3=Dam

4=Spring

(C8) Can you name the watering point(s) during this rainy season (September to December)?

….……………………………

…………………………………

………………………………..

(C9) Are your cattle taken outside of the home for water during dry season(June to September) ?

1=Yes

2=No

(C10) If your answer is YES in the above, what is the source of water for your cattle?

1=River

2=Borehole

3=Dam

4=Spring

(C11) Can you name the watering point(s) during dry season (June to September)?

….……………………………

…………………………………

………………………………..

(C12) How many cattle have been brought into the farm (new) over the past 1 year? All cattle including those that are not present on the farm currently ……………………

(C13) Did any of these cattle come from a farm in this village?

1=Yes

2=No

(C14) If yes, what is the name of the farmer where the cattle originated from?

…………………………………..

(C15) How many cattle have been given out/ sold in the past 1 year from the farm?

………………………………..

(C16) Did any of the cattle you have given out go to a farmer in this village?

1=Yes

2=No

(C17) If yes, what is the name of the farmer? ....

(C18) Have you hired any bulls for ploughing in the last 12 months?

1=Yes

2=No

(C19) If your answer is YES in the above, is the person you hired his bulls comes from this village?

1=Yes

2=No

(C20) If your answer is YES in the above, can you name the person(s)?

………………………………

……………………………

(C21)During the last dry periods (June to September), how often did you take your animals OFF YOUR FARM for grazing?"

1=Every day

2=Once or twice per week

3=Once or twice per month

4=Only a couple of times

5=Never

(C22) During the last four weeks (rainy season), how often did you take your cattle OFF YOUR FARM for grazing?"

1=every day

2=Once or twice per week

3=Once or twice per month

4=only a couple of times

5=Never

(C23) During the last dry period (June toSeptember), how often did you take your animals OFF YOUR FARM for water?

1=Every day

2=Once or twice per week

3=Once or twice per month

4=Only a couple of times

5=Never

(C24) During the last four weeks (rainy season), how often did you take your animals OFF YOUR FARM for water?

1=Every day

2=Once or twice per week

3=Once or twice per month

4=Only a couple of times

5=Never

D. BREEDING AND FERTILITY PROBLEMS

(D1) What is the total number of bulls that has been in the farm for the last ONE year (post pubertal bulls not castrated) …………………………

(D2) Are you aware of any of your bulls serving any cows? (Your own cows or anyone else's including non- planned services e.g whilst grazing)

1=Yes

2=No

(D3) If YES, what was the origin of the cow that your bull served? (select all that apply including non-planned service during grazing)

1= This farm

2= Another farm in this village

3=Another village in this sub-location

4= Another sub-location

5=Don't know

(D4) In the last one year, what is the total number of reproductively mature females that have been on this farm? (i.e post pubertal female animals: first time heifers and cows)………………………

(D5) Over the past 1 YEAR, have any of these cows been served by a bull? (Including non-planned service on or off this farm)"

1=Yes

2=No

(D6). Have there been any cow’s in calf on this farm in the past 1 year? (Including introduced in calf heifers)

1=Yes

2=No

(D7) If YES, Where did the bull that served these animals come from?

1=My own bull

2=A farm in this village

3=A village in this sub-location

4=Outside this sub-location

5=Artificial insemination

6=Bought when pregnant

7=Don't know

(D8) In the last 12 months have any animals on this farm experienced any periods of ill health?

1=Yes

2=No

(D9) If YES, what signs did you observe?

1=Diarrhoea 2=Hard faeces 3=Staring Coat 4=Lack of appetite 5=Weight loss

6=Skin problems 7=Swollen lymph nodes 8=Coughing 9=Abortion/Still births

10=Metritis 11=RFM 12=Infertility 13=Mastitis 14=Lameness

11=Others (Specify)………………………

E: LIVESTOCK MOVEMENT DURING VACCINATION AND DIPPING

(E1) Have you attended a crush pen in the past 4 weeks?

1=Yes

2=No

(E6) What is the name of the crush pen ?........................

(E7) How many times have you attended that crush pen in the past 4 weeks?

1=1 time

2=2 times

3=3 times

4=4 times

(E8) Any others in the past 4 weeks?

1=Yes

2=No

(E9) What is the name of the crush pen (s)?......................

(E10) How many times have you attended that crush pen(s) in the past 4 weeks

1=1 time

2=2 times

3=3 times

4=4 times

(E11) What is the total acreage of this farm?...

F. VETERINARY INPUT

(F1) Where do you access Veterinary services

1=Government vet 2=Private vet 3= Agrovet 4= Family

5=Neighbor 6=Never accessed 7=Other(specify)……………

(F2) In the last 12 months,did you perform worm control?

1=Yes 2=No

(F3) In the last 12 months, what did you use to control worms?

1= Drench 2=Tablets/bolus 3=Pour on 4=Injection

5Traditional medicinal 6=Others (Specify)………………………………

(F4) In the last 12 months, how often did you deworm your cattle?

1=Every month 2=Every three months 3=Every four months

4= When cattle show symptoms (thin, staring coat etc)

5= When money available 6= Professional advice 7=Season ally (Before onset of rain)

(F5) In the last 12 months, did you control ticks in your farm?

1=Yes 2=No

(F6) What did you use for tick control?

1=Pour on 2=Injection 3=Spray 5=Dip

6=Traditional 7=Any other (specify)

(F7) In the last 12 months, how often do you use tick control?

1= at least once a week 2=Once after every two weeks 3=at least once a month

4=every 2 months 5 = every 3 months 6=every 6 months

7=Cattle with symptoms 8=When money is available 9=Professional advice

10=season 11=Others(specify)……………………….

G. SOCIOECONOMIC STATUS

(G1) The number of houses in the farm (compound)

1=one to two houses

2=three to five houses

3=six to nine houses

4= ten and above

(G2) The proportion of houses with grass thatched roof

1=All

2=Quarter

3= Half

4= Three quarter

5=None

(G3) The proportion of houses with iron sheet roof

1=All

2=Quarter

3= Half

4= Three quarter

5=None

(G4) The proportion of houses with mud walls

1=All 2=Quarter 3= Half

4= Three quarter

5=None

(G5) The proportion of houses with bricks/stone walls(permanent houses)

1=All

2=Quarter

3= Half

4= Three quarter 5=None

Appendix 2: Contact Collection Tool and photo interview questions

Photo-interview template

1) In the past 4 weeks, can you recall this person bringing their animals to graze on your farm, or in the area immediately surrounding your homestead? **Yes/No**

[include plough teams]

How often has that been in the last 4 weeks? Daily; weekly; Once or twice

2) In the past 4 weeks, can you recall having taken your cattle to graze on this person's farm, or in the area immediately surrounding their homestead? **Yes/No**

[include plough teams]

How often has that been in the last 4 weeks? Daily; weekly; Once or twice

3) In the past 4 weeks, when you have taken you animals out for grazing (off your farm), do you recall seeing this person also grazing their animals? **Yes/No**

How often has that been in the last 4 weeks? Daily; weekly; Once or twice

In that time, have your animals come into direct mixing contact (as example in photo)? **Yes/No**

4) When you have taken your animals to the water point in the past 4 weeks, have you seen this person with their cattle at the same water point? **Yes/No/Not sure**

How often has that been in the last 4 weeks? Daily; weekly; Once or twice

In that time, have your animals come into direct mixing contact (as example in photo)? **Yes/No**

5) This person has a bull, or has had a bull in the past. Are you aware of the farmer's bull serving any of your cattle (including planned and non-planned service) in the past 1 year? **Yes/No**

Can you recall the number of occasions?

Contact collection tool

The first column indicate farms and first row indicates type of contact

Name of the farmer…………………………………..

Names	Graze in your farm	Graze in their farm	Meet whilst grazing	Meet at water points	breeding contact	ploughing contact

LEVELS FOR CONTACT DURING GRAZING AND WATER POINTS IN THE VILLAGES

1= Every day

2=Once or twice per week

3=Once or twice per month

4=Only a couple of times

Appendix 3: Overall farm contact networks in the villages

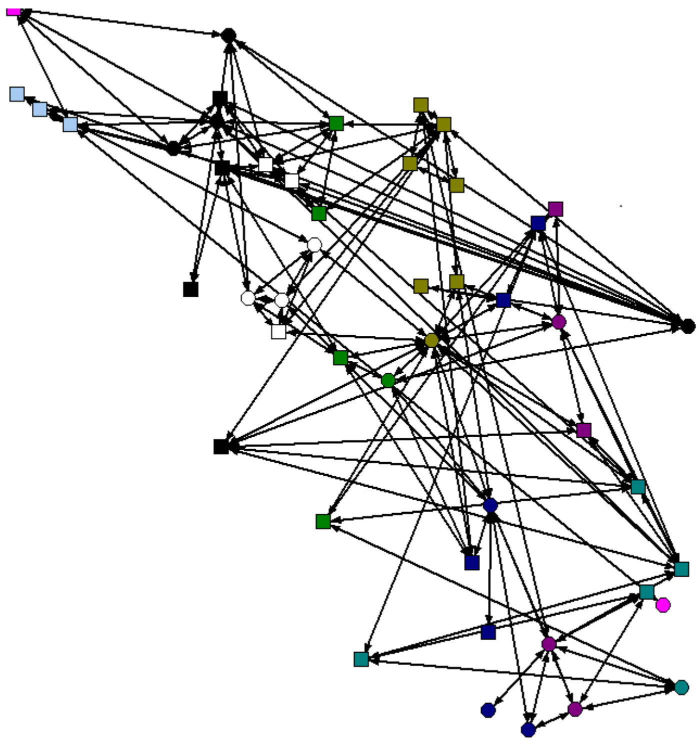

Figure 4.10 (a): Kibunde village:

Legend

Different colors = Different geographic locations

Circle = Farms where animals are watered outside homestead

Square = Farms where animals are watered at home

Small nodes = Farms practicing semi intensive management

Big nodes = Farms practicing extensive grazing management

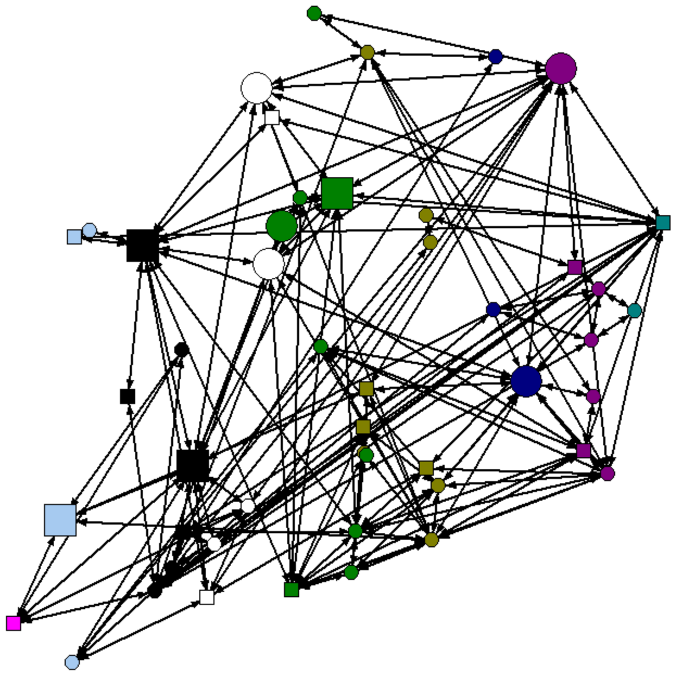

Figure 4.10 (b): Lurare village

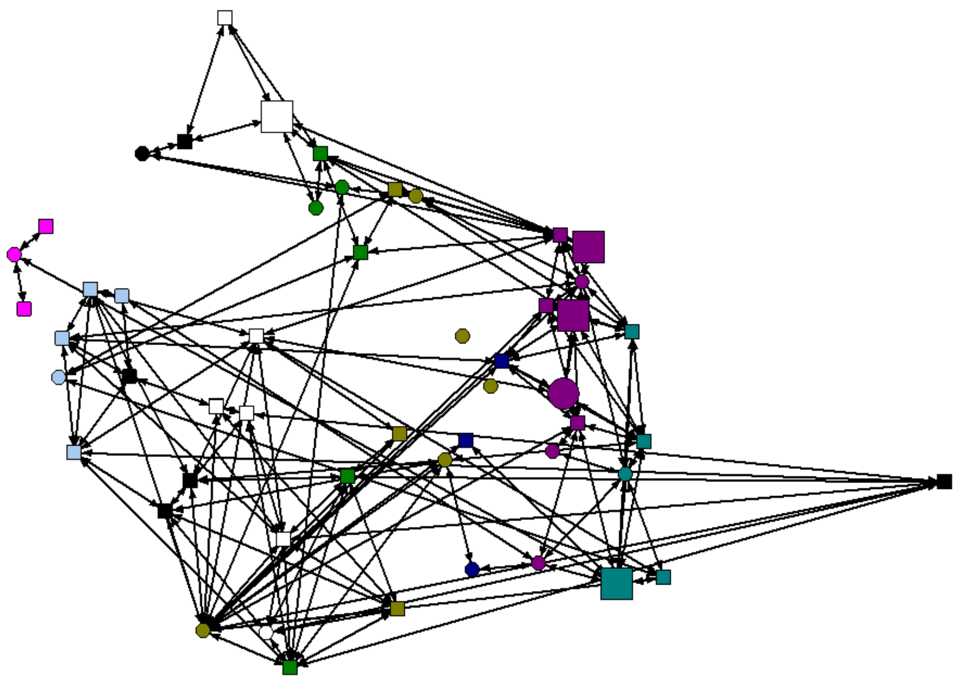

Figure 4.10 (c): Malaha village

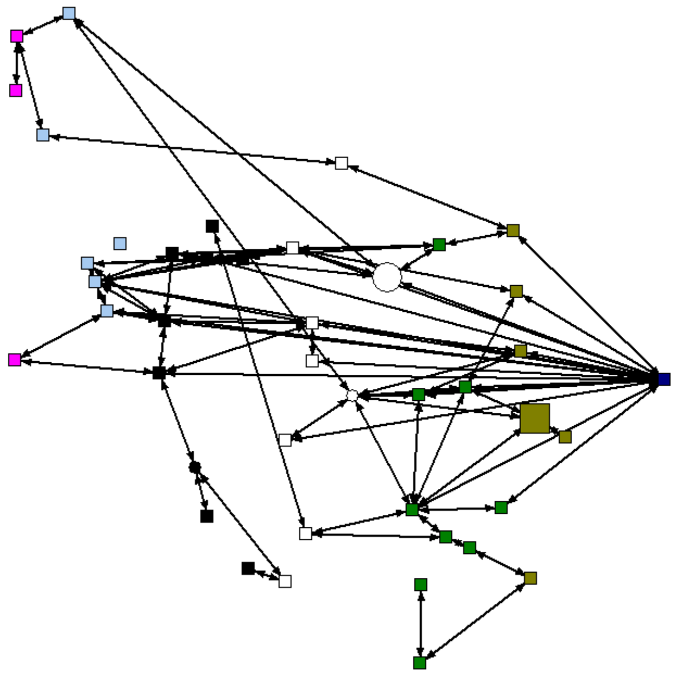

Figure 4.10 (d): Namunyiri village

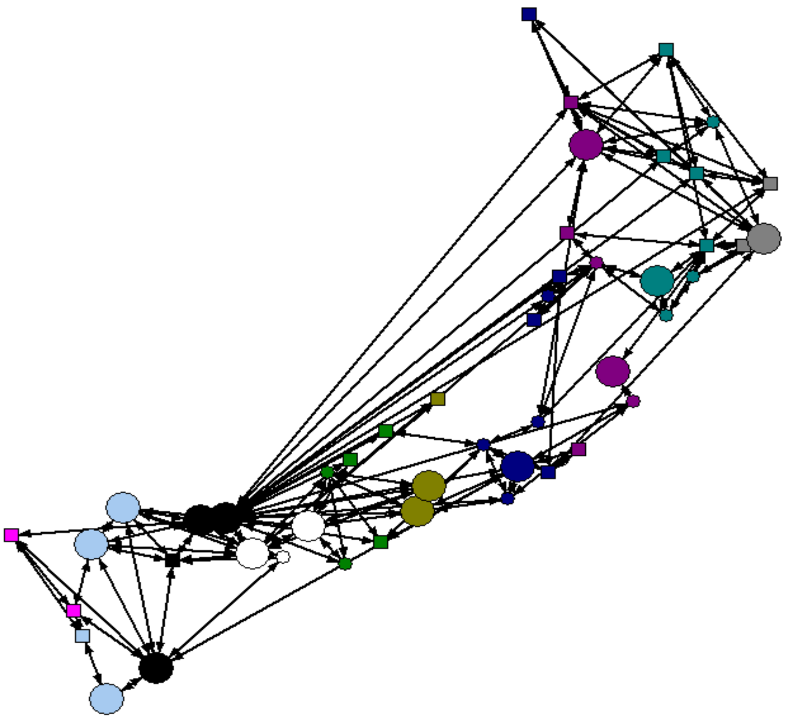

Figure 4.10 (e): Sango village