A retrospective study on transmissible diseases among wildlife, domestic livestock and humans in the wildlife/livestock/human interface of the Mahikeng Game Reserve and its surrounding areas

by

MABEL TENDAI MOZHENDI

Student number: 53264835

Submitted in fulfilment of the requirements for the degree of

MSc Environmental Management

in the

Department of Environmental Sciences

at the

University of South Africa

Supervisor: Dr C.J Louw
CO supervisor: DR J Oosthuizen
Cell: 078 799 0220 / 078 956 9026

DEDICATION

This dissertation is dedicated to my children Zandile and Thabani, my source of strength and encouragement.

ABSTRACT

The key objective of this study was to formulate Susceptible-Infected-Recovered (SIR) epidemiological models to analyse the scientific literature and to identify the trends and dynamics of rabies, brucellosis and tuberculosis through a modelling approach at the Mahikeng Game Reserve and its surrounding areas from 2007-2016. The Susceptible-Infected-Recovered (SIR) epidemiological model was used in this study, together with the questionnaire. The questionnaire assessed the knowledge, practices and attitudes of farmers in order for the policy makers to take sound mitigation measures. The State Veterinary Department of Mahikeng provided annual data to construct the SIR (infected) models. The sum of squared deviation approach was used to fit the models to the data, with the lowest attained sum of squares indicating the best model fit to the data. Infection models and line graphs were constructed. The results from the questionnaire indicated that farmers lack knowledge about these zoonotic diseases. 63% of farmers need information on brucellosis, 43% on tuberculosis and 23 % on rabies. From the data used to model the zoonotic under study it can be concluded that spread of zoonosis at the Mahikeng interface depends more on the probability of the direct and indirect contact rate with the infected class within the population. In addition, data provided by the State Veterinary Department of Mahikeng indicated a high level of human interference, environmental variability, the impact of unpredictable ever-changing climatic conditions and distortion of assumptions of the SIR model. The government of South Africa must make it a legal requirement for all farmers to report cases of abortion, stillbirth, coughing and barking to the Veterinary department who must investigate and determine the disease take precautionary measures. Both commercial and communal farmers must attend Farmer’s Day events to gain knowledge from presentations.

Key terms:

Susceptible, Infected, Recovered, Removed, Zoonotic, Epidemiological, Interface, Ecosystem, Branding, Questionnaire

DECLARATION

I am the sole writer of this thesis, ‘A retrospective study on transmissible diseases among wildlife, domestic livestock and humans in the wildlife/livestock/human interface of the Mahikeng Game Reserve and its surrounding areas.’ All sources I have used or cited have been acknowledged in the references. It has not been submitted for any degree purposes at the University of South Africa or any other university.

SIGNATURE **DATE**

ACKNOWLEDGEMENTS

Special thanks to my supervisor, Dr Louw, and co-supervisor, Dr Oosthuizen, for their guidance throughout the write-up of this thesis. You motivated and encouraged me to always do my best. Your explanations were always very clear when I needed them the most. You had faith in me, even when I doubted myself. It would have been an impossible task without you. You walked with me all the way and gave me advice using your deep knowledge to show me the way. Thank you!!!!!

My sincere gratitude goes to the farmers around the Mahikeng Game Reserve for their cooperation and understanding in answering my questionnaire.

Last, but not least, a special thanks to the staff at the State Veterinary Department of Mahikeng for their support and guidance. You always answered my questions and you had time to enlighten me on each and every disease under my study.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION AND BACKGROUND

1. 1 INTRODUCTION AND BACKGROUND

Transmissible diseases among wildlife, domestic livestock and humans at the interface have always been of great concern in developing nations (Wiethoelter, Alcrudo, Kock & Mor 2006). In this study, the researcher focused on three important zoonotic diseases: tuberculosis, rabies and brucellosis. These are the most common infectious diseases affecting the North West province of South Africa. Sometimes, transmissible diseases may cause the death of livestock, as is the case with rabies, which killed more than 20 cattle on 9 February 2017 in Schweizer-Reineke and Bloemhof in the North West province of South Africa (Heyns & Magdaleen, 2017). This leads to food insecurity for both humans and animals, a decrease in market values and a loss of trade, while also affecting livestock owners' income and livelihood. Disease transmission mostly takes place when an animal infected with a pathogen comes into close contact with humans (Wiethoelter et al., 2006). Examples of zoonotic diseases include but are not limited to tick-borne illnesses like Lyme disease, rabies, bovine tuberculosis, anthrax, West Nile Virus, malaria and yellow fever. Infected wildlife also presents a risk to biodiversity and could lead to the extinction of some animal species in an ecosystem (Fischer & Gerhold, 2002).

Wild animals play a bigger role in the spread of transmissible diseases than humans and domestic livestock. A larger population led to the increase in the production of domestic livestock, and wildlife and this resulted in the sharing of resources like grazing land and water sources at the interface. Wiethoelter et al. (2006) argue that wildlife populations act as a reservoir of pathogens which they transmit to domestic livestock and humans. Transmission of zoonotic diseases from wildlife to domestic livestock and humans has a negative impact on the country's economy and the health of other species (Jones et al., 2012).

1.1.1 Zoonosis

Wiethoelter et al. (2006) state that any form of zoonosis is part of an ecosystem and the control of zoonoses in wildlife is expensive, difficult and/or impossible (Fischer & Gerhold, 2002). Disease outbreaks in wildlife ecosystems may not be detected early enough due to difficulty to locate carcasses in vast wildlife parks and sanctuaries. Tracing, testing and diagnosis of zoonotic diseases in an entire wildlife population could be impossible, with the possibility of re-testing being very slim (Fischer & Gerhold, 2002). Outbreaks of zoonosis to humans, domestic livestock and wildlife population must be investigated by the animal and public health departments in order to implement measures to prevent, monitor and control the transmission of diseases.

1.1.2 Wildlife, domestic livestock and humans interface

Wildlife, domestic livestock and humans interact where they share resources like water and food, and this is where zoonotic diseases are transmitted among them (Paulsen, Bauer & Smulders, 2014). Phukon (2012) states that co-existence at interfaces creates huge problems for wildlife, livestock and public health, and that interface information on the spread of zoonosis must be considered as essential because social interaction among livestock, wildlife and humans is unavoidable. Transmissible diseases have become a great concern for the scientific community as it affects wildlife, domestic livestock and humans.

Bengis, Kock and Fischer (2002) state that some interfaces, such as fences, are linear. In transfrontier conservation areas such as water points and grazing land, interface resources are shared among humans, livestock and wildlife. These areas pose a risk for disease transmission in many ways. Transmissible diseases can be transmitted directly or indirectly among wildlife, domestic livestock and humans by means of livestock trade, consumption of bush meat and an increase in demand of farming land. New settlements require new agricultural land for food production (Jones et al., 2011). As the human population increases, the intake of protein also increases, thus and livestock production becomes a major activity. Newell et al. (2010) suggests that the establishment of new settlements and the conversion of natural veld into agricultural land lead to outbreaks of diseases. The expansion in livestock production brings domestic livestock, wildlife and human population into close proximity, with Kock, Kebkiba, Heinoen and Bedane (2002) stating that infectious disease syndromes originate from changing agro-ecology.

Interface resources shared in this study include grazing land and water sources from the Molopo River, which flows through the Mahikeng Game Reserve and ends in the Disaneng Dam. This river also supplies water to the Mahikeng community. Because domestic livestock, wildlife and humans use this same source of water, effective contact is created between them, which provides conditions that increase the likelihood for the transmission of diseases, as bodily discharges such as faeces, urine, saliva or nasal secretions are deposited into the water

(Woodford, 2009). Kock et al. (2002) state that faecal discharges sometimes stay on shared insect vectors or intermediate hosts.

In the Mahikeng Game Reserve, grazing land is shared between wildlife and livestock. Livestock farming, in combination with wildlife, increases land pressure, and the possibility of conflict between pastoralists and wildlife may occur (Kock et al., 2002). Smith (2008) states that livestock are at risk of contracting zoonotic diseases when they eat infected faeces during grazing. With ongoing expansions in livestock grazing land where wildlife and livestock share the same habitat, the possibility of transmission of pathogens to new hosts exists.

1.1.3 Factors that facilitate transmission of diseases

Bryony et al. (2011) note several factors that increase the transmission of diseases, such as high numbers of livestock production, poor animal husbandry and misuse of antibiotics. Killian et al. (2007) state that physical contact during the mating of animals gives rise to transmission of diseases, especially by traditional, pulmonary and nasal routes. Bengis et al. (2002) classify diseases into three groups, namely indigenous diseases; alien or exotic diseases; and emerging, re-emerging or truly novel diseases. The transmission of diseases among wildlife, domestic livestock and humans is usually ignored due to a lack of knowledge by the community (Wiethoelter et al., 2006). Infectious agents must be determined first to find ways to stop the spread of infectious diseases by these agents. Jones et al. (2011) argue that the approach to reduce the spread of disease should be based on the outbreak incidences, distribution between animals and possible measures to control the spread of diseases between animals and humans.

Strategies implemented must limit the direct or indirect contact between animals and humans where they share resources, because the control of zoonotic diseases is expensive or even impossible (Fischer & Gerhold, 2002). Scientific literature has abundant data on disease agents and potential control methods. Information about the animal and human populations, which include wild animal distribution, husbandry and the condition of the disease agent, is of paramount importance in this study to determine the prevention and control methods of diseases.

1.2 STATEMENT OF THE PROBLEM

Transmission of tuberculosis, rabies and brucellosis among wildlife, domestic livestock and humans at the interface is becoming a problem in the North West province in South Africa. The spread of transmissible diseases from wildlife to domestic livestock and humans is always a challenge (Paulsen, Bauer & Smulders, 2011). Wiethoelter et al. (2006) state that most of the zoonotic diseases affecting domestic livestock and humans originated in wildlife. The study sought to identify and assess how wildlife, domestic livestock and humans transmit infectious diseases. There is also a need to investigate ways to control and mitigate these zoonotic infectious diseases.

1.3 SIGNIFICANCE OF THE STUDY

Wiethoelter et al. (2015) note that the health and well-being of wildlife, domestic livestock and human populations are easily affected by zoonotic diseases. Mathematical disease transmission models have been constructed in this study, which can provide well-justifiable predictions for future use by responsible organisations. The advantage of mathematical modelling is that it is very accurate and can achieve more in the prevention of zoonotic diseases. It tests our understanding of the disease epidemiology by comparing the model results and observing the patterns over a given period. This will assist animal and public health departments in decision making on important matters such as intervention and induced changes in the transmission of disease. Policy makers can also make use of mathematical models for infectious disease interventions. Resources must be made available in all languages to educate, control, mitigate and study the transmissible diseases that threaten livestock, wildlife and humans in order to promote human and animal health livelihoods, and wildlife conservation efforts at the transfrontier conservation area interfaces.

1.4 RESEARCH QUESTIONS

The study sought to answer the following research questions:

1. Which factors facilitate the transmission of rabies, bovine tuberculosis and bovine brucellosis where animals and humans interact?
2. How severe is the problem of rabies, bovine tuberculosis and bovine brucellosis, and do they have a seasonal pattern for transmission at the interface of wildlife/domestic livestock/humans in North West province of South Africa?

3. What risk management strategies are in place for managing the interface and what are the socio-economic implications of these intercessions between wildlife, livestock and humans in and around the Mahikeng Game Reserve?
4. Are farmers aware of these three zoonotic diseases, rabies, tuberculosis and brucellosis?

1.5 THE AIMS OF THE STUDY

1. To carry out a structured analysis of the scientific review of the prevalence of tuberculosis, rabies and brucellosis and to examine and assess the status of this zoonosis at the wildlife/livestock/human interface of Mahikeng Game Reserve and its surrounding areas.
2. To establish trends and dynamics of tuberculosis, rabies and brucellosis among wildlife, domestic livestock and humans in the wildlife, livestock and human interface of the Mahikeng Game Reserve and its surrounding areas.
3. To assess critical issues in managing these diseases and to identify risk reduction approaches and policy strategies for addressing these transmissible diseases at the livestock, wildlife and human interface.
4. To conduct a questionnaire survey on practices, knowledge and attitude among farmers so as assess the risk of zoonotic transmission at the domestic livestock/wildlife/human interface.

1.6 OBJECTIVES OF THE STUDY

1. To decsribe the scientific literature after detailed analysis using desktop study of the data from clinical and laboratory annual reports on tuberculosis, rabies and brucellosis at the interface of humans, livestock and wildlife at the Mahikeng Game Reserve and surrounding areas provided by the State Veterinary of Mahikeng.

2. To formulate Susceptible-Infected-Recovered (SIR) epidemiological models for brucellosis, tuberculosis and rabies of the Mahikeng Game Reserve and its surrounding areas in the North West province of South Africa using the compartmental model approach by collecting and making use of the numbers of susceptible, infected and recovered from annual reports compiled by the State Veterinary of Mahikeng.

3. To determine the critical issues in prevention measures considered in managing these diseases at the interface and to identify the risk reduction methods and policy strategies fo addressing these transmissible diseases at the livestock,wildlife and human interface through analysing how SIR models progressed from 2007 to 2016.

4. To identify the level of education, practices and attitudes among farmers at the interface of the Mahikeng Game Reserve and its surrounding areas with the help a questionnaire.

1.7 METHODOLOGY

The methods used in this study included a questionnaire and SIR models. A questionnaire was used for the Mahikeng Veterinary Department and for communal and commercial farmers, which consisted of a series of questions and other prompts for the purpose of gathering information on the transmissible diseases rabies, tuberculosis and brucellosis transmissible diseases. Questionnaires were handed directly to the respondents. Cluster sampling was implemented, which allows individuals to be selected in geographical batches. Areas selected were within a radius of five kilometres from the boundary of the Mahikeng Game Reserve. These areas include Lomanyaneng, Bokone, Stad, Dihatshwane and Top Village. The multistage sampling allows the selected cluster to be selected at random. The questionnaire yielded practical, fast results on the knowledge of commercial and communal farmers about these transmissible diseases and what the Mahikeng Veterinary Department is doing to reduce the risk of these transmissible diseases.

In the SIR model, the population was divided into three categories consisting of susceptible, infected and recovered. The researcher identified the system models by using ordinary differential equations. The equilibrium points and the basic reproductive number were established. The quantitative and the qualitative research paradigms (mixed approach) were used. Descriptive design was also incorporated to obtain information regarding the risk factors that augment the spread of zoonotic diseases at the human/domestic livestock/wildlife interface. The study reviewed scientific literature and records on tuberculosis, rabies and brucellosis outbreaks from 2007 to 2016 in Mahikeng and surrounding areas in the North West province. Databases were compiled of tuberculosis, rabies and brucellosis susceptible, infected and recovered animals during each year. The records were obtained from the Mahikeng State Veterinary Offices.

1.8 CHAPTER BREAKDOWN

The dissertation is presented in the following six chapters:

Chapter 1: Introduction

This chapter deals with the background and the significance of the study. It contains the statement of the problem, the contribution of the study to academia/science, research questions and aims, objectives, an indication of the research design and methodology, and site selection.

Chapter 2: Literature review

The risk factors that facilitate the transmission of diseases on the interface of domestic livestock, wildlife and humans are discussed in detail.

Chapter 3: Research design and methodology

This chapter comprises a more detailed discussion of the study area, research design and research methodology. Modelling in wildlife and resource conservation techniques are discussed in depth and a questionnaire is used as method to collect data.

Chapter 4: Results of the study

The results from the questionnaires of the State Veterinary Department of Mahikeng, communal and commercial farmers are discussed. Illustration is done of models on disease dynamics and outbreaks of rabies, brucellosis and tuberculosis from 2007 to 2016.

Chapter 5: Discussion of the results

This chapter provides the discussion of the results from questionnaires, models and line graphs as well as the analysis of trends and the dynamics of rabies, brucellosis and tuberculosis from 2007 to 2016.

Chapter 6: Conclusion, limitations, guidelines and recommendations

This chapter contains an overview of the research and gives the conclusions. Recommendations are provided for further research.

Annexure

The annexure comprises the questionnaires for the State Veterinary Department and communal and commercial farmers, as well as letters requesting and granting permission to conduct the study.

CHAPTER 2

LITERATURE REVIEW: RISK FACTORS THAT FACILITATE TRANSMISSION OF DISEASES ON THE INTERFACE

2.1 INTRODUCTION

An increase in the human population and the emergence of new settlements have led to an increase in human ecosystem interactions (Dibaba, Kriek & Thoen), which had a big impact on the Mahikeng area. These new settlements require new agricultural land for food production (Jones et al., 2011). Akhtar (2012) states that as the human population increases, the demand for protein also increases and livestock production becomes a major activity. The expansion of livestock production worldwide increases the frequency of contact between domestic livestock, wildlife and the human population. The transfer of diseases from wildlife to humans or livestock is due to human encroachment on the wildlife habitat, land use change and environmental effects such as climate change (Paulsen et al., 2014; Hassel, Begon, Ward & Fevre, 2017). Kock (2014)states that infectious disease syndromes originate from changing agro-ecology. Newell et al. (2010) suggest that the establishment of new settlements and the expansion of agricultural land lead to outbreaks of diseases. Morand, Beaudeau and Cabaret (2012) note that most zoonoses comprise human infectious diseases of which the highest percentage is transmitted from wildlife.

The interface of wildlife, domestic livestock and humans is a possible threatening area for cross-transmission of zoonosis within species and for the development of new hosts. Habitat encroachment leads to interaction between wildlife, domestic livestock and humans, and promotes the emergence of zoonotic diseases (Hassel et al., 2017). There are human, economic and natural factors that facilitate the transmission of infectious diseases from wildlife to humans or domestics animals. These factors cause the epidemiology of certain pathogens to vary from one area to another (Rhyan & Spraker, 2010). Natural factors, such as landscape, geography, rainfall, vegetation and soil type are critical factors affecting the speed of transmission (Woodford et al., 2009). Human and economic factors determine the pathogen, host and vector; these contribute to new trends and are discussed more formally below.

Ecological factors give rise to the distribution of wildlife reservoirs and vectors within the interface. The existence of different infectious agents varies depending on the soil composition of the area (Jones et al., 2011). Air movements are associated with the movement of infectious pathogens and this result in the transmission of zoonotic diseases. The transmission of infectious diseases occurs either directly or indirectly where direct transmission includes air-borne and vector-borne pathogens. If infected wildlife is present in the ecosystem, this does not automatically result in the transmission of zoonotic diseases. There are predominant factors like the severity of infection in the infected animals, the size of the herd and their distribution, direct or indirect contact among humans and domestic livestock, and the ability of the population to acquire the infection.

Different animals are responsible for carrying a variety of zoonotic pathogens (Jones et al., 2011); for instance, wild boar can transmit many dominant zoonotic bacteria such as *Mycobacterium Bovis* or *Coxiella Burnetti Yersinia* pests (Meng, Lindsay & Sriranganathan, 2009). For the purpose of this study, the researcher reviewed literature on the risk factors that facilitate bi-directional transmission of infectious diseases on wildlife, domestic livestock and humans, focusing on human, economic and natural factors.

2.2 HUMAN AND ECONOMIC FACTORS

2.2.1 Human settlement invasion into the wildlife habitat

Invasion of humans into new settlements and the expansion of agriculture are good examples of where people occupy the natural foci of certain pathogens (Jones et al., 2011). The expansion of human settlements into forest areas normally brings wildlife and humans into close contact and this facilitates spillover of wildlife diseases to humans and domestic livestock. Gilbert et al. (2012) carried out a study in Amazonian communities to investigate the risk factors to bat exposure due to human settlement invasion. These communities in Peru were believed to be at a high risk to vampire bats because they were close to the areas where rabies outbreaks had taken place. From 1996 to 2010, bites from vampire bats were reported as the main cause of human rabies transmissions. The rural living conditions in Peru led to the transmission of rabies to human populations by vampire bites.

Jones et al. (2011) note that pathogens of the Chikungunya virus were found in other parts of the world where infected animals and transmission agents were present. If humans inhabit these areas, they expose themselves to infected vectors. If infected humans carry pathogens of the Chikungunya virus to their settlements, they can transmit it to domestic vectors. This leads to the peri-domestic cycle whereby the disease will remain in and around human habitations (Gould & Higgs, 2009).

2.2.2 Deforestation

Jones et al. (2011) states that fragmentation of land may reduce the number of animals and change the animal's demographics and behaviour, which influences their vulnerability to infection and the extent of infectious disease transmission. Alterations to patterns of gastrointestinal helminths and protozoa occur through deforestation. Goldberg, Gillespie, Rwego, Estoff and Chapman (2008) state that the human interference with the fragmentation of habitats hinders pathogen transmission rates among animals due to increased geographical and ecological overlaps. Deforestation for new settlements and agricultural land increases the risk of zoonotic infection in forest workers who come into close contact with wildlife reservoirs or vectors of zoonoses. Chomel, Belotto and Meslin (2007) note that Kyasanur forest disease was found among forest workers who cleared forest areas to establish cashew tree plantations. Goldberg (2008) state that people who settle close to disturbed forest fragments are at risk of disease transmission from primates.

In contrast, reforestation provided suitable areas for the reservoir and led to an outbreak of Lyme disease in the United States. Transmission levels of zoonotic diseases in new settlements depend on the profusion of the vector and the density of hosts (Jones et al., 2011). Gould and Higgs (2009) state that the transmission of the West Nile virus between humans and birds requires high mosquito densities. Therefore, both deforestation and reforestation promoted the transmission of this infectious disease and zoonosis.

2.2.3 Agriculture

Agricultural practices require deforestation and this leads to increased contact between wildlife and human beings. The invasion of the natural ecosystem for farming is considered the highest risk factor for disease transmission. Agricultural activities lead to multi-land use patterns of buffer zones in which wildlife and livestock share land. This increases transmission of zoonosis due to the close proximity of these animals. Bi-directional transmission of disease can also take place. Phukon (2012) notes that the outbreaks of the Nipah virus in Malaysia in 1998 to 1999 was due to ecological and environmental changes when pig farming and the planting of fruit trees expanded. On the other hand, agricultural expansion can lead to the evolution of other parts of agricultural land that support and maintain pathogen reservoirs (Jones et al., 2011).

Some farming practices provide conditions conducive to pathogen growth, which could lead to the spread of zoonotic diseases within the humans/livestock/wildlife interface.

The Argentine haemorrhagic fever outbreak was due to corn plantations' farming practices. Corn plantations support the living conditions of the corn mouse which acted as the reservoir of Argentine haemorrhagic fever (Chomel et al., 2007). The use of manure in developing nations leads to the transmission of food-borne diseases, such as Verotoxigenic Escherichia coli (VTEC) and salmonella (Newell et al., 2010).

Edge effects such as ecological ecotone promote interaction among pathogens, vectors and hosts (Jones et al., 2011). Edge effects are associated with Lyme disease. Pfeffer and Dobler (2010) support that the widespread prevalence of the Japanese encephalitis virus (JEV) in South East Asia over the past few decades was due to an increase in the human population, which led to an increase in rice production through irrigation and pig farming. Irrigated farming areas provide favourable living conditions for the mosquito vector of the JEV *Culex Tritaniorhynchus,* which multiplies in wet conditions. Gould (2003) notes that the mosquito vectors feed on water birds like herons and egrets, domestic livestock and wild animals such as pigs, horses and humans. Irrigated fields increased the water birds' population. Humans and horses are dead-end hosts. Pfeffer and Dobler (2010) argue that pig farming acts as a favourable host for the mosquito vector; therefore, pig farming later led to the spillover of the JEV to the human population.

2.2.4 Livestock production

Pastoralists who look after livestock and non-human primates may be at risk of contracting diseases from livestock because livestock can be a risk factor in the transmission of pathogens between humans and primates (Goldberg et al., 2008). An increase in the human population resulted in high dependency on livestock production. Grazing land and water resources become a conflict between pastoralists and wildlife. If domestic livestock and wildlife are in close contact, the risk of transmission of zoonoses is increased as habitats are shared, especially around Mahikeng Game Reserve. Phukon (2012) notes that livestock are at risk most of the time of inter- and intra- certain disease transmission.

As livestock production increases, it invades wildlife habitats. This will facilitate the spillover of diseases from wildlife to livestock or from livestock to wildlife. Nyirenda, Letloyane and Syakalima (2016) carried out a study about Brucella abortus in buffaloes of the Mahikeng

Game Reserve. Because of land conflict, cattle farms and buffaloes in the Mahikeng Game Reserve share the grazing land. Eight three out of 365 buffaloes tested positive for Brucella abortus from 2008 to 2010. Nyirenda et al. (2016) argue that this constituted 23% prevalence of Brucella abortus. The percentage might seem low but in reality, Brucella abortus must not be present at all. The presence of Brucella abortus affects recreation negatively and hinders trading of these buffaloes. According to Nyirenda at el. (2016), the buffaloes tested negative for brucellosis when they were translocated in terms of regulation of 20 of the Animal Disease Act 35 of 1984. According to this regulation, a movement permit must be granted after buffaloes test negative for Brucella abortus.

A controlled case study of the threats of seropositivity of bovine brucellosis was conducted in Peninsular Malaysia (Robi & Gelelcha, 2020). This study focused on four states in Malaysia: Kelantan, Pahan, Selangor and Nigeri Sembila. A desktop study was conducted and the data was provided by the public health department and was obtained from the farm management bio-security records. The medical history of the individuals under study was also considered. Anka et al. (2014) state that they selected 35 cases and 36 controls of herds. Multivariable logistic regression was used in their study and the results indicated that the domestic livestock that tested positive had contact with wildlife before the study was conducted (Anka et al., 2014). The animals that were selected in the study were from extensive animal production. Animals like buffalo and goats or sheep were reared together. From these results, it was found that the seropositive herds had a higher history of abortion than the seronegative herds. During the study in Peninsular Malaysia, it was found that they had limited educative resources on the epidemiology of bovine brucellosis. In addition, measures to curb the transmission of bovine brucellosis were not available. This study contributed to ongoing areas on eradication programmes.

Field (2009) found that the outbreak of the Nipah virus infection in pigs and humans resulted from the encroachment of commercial production farming on the habitat of fruit bats that were infected with the Nipah virus. Graham et al. (2008) established the environmental pathways in which intensive livestock production increases the transmission of diseases from livestock to wildlife and humans. Some of the ways include ventilation systems, which allow pathogens like campylobacter and the avian influenza virus in surrounding areas.

On livestock farms, animals produce large quantities of waste containing pathogens, which is spread on open land. These pathogens can remain for a long time if untreated. When the waste is spread over open land, it will contaminate ground water and surface water, and the wildlife can come into contact with this livestock waste. Graham et al. (2008) argue that the wild birds can acquire infectious transmissible diseases from aquaculture, especially when animal waste is used. These transmissions can happen through the faecal-oral route while grazing.

As livestock and wildlife share habitats, the transmission of pathogens from the host to other animals can take place, thereby increasing the number of hosts. In tropical countries with high temperatures during the day, animals are likely to graze under trees (Jones et al., 2011), especially early in the morning. The areas mentioned above act as interface for transmission of diseases to both livestock and wildlife.

2.2.5 Habitat alterations

A change in habitat leads to the alteration of the population composition, the movement of animals, the size of the herd, susceptibility to infectious diseases, higher contact rates and the transmission of infectious diseases between domestic livestock and humans (Mathews, 2009). Johnston, Gettinby and Cox (2005) conducted a study with a population of 268 farms from South West England. From this study, they noted that the higher number of outbreaks of tuberculosis was associated with the movement of cattle herds from markets or farm sales to the farm, operating farms on various other sites or properties; and the use of building-covered cattle-kraals or other types of housing.

Vaz, D’Andrea and Jansen (2007) carried out a study on the re-emergence of Chagas disease (also known as American trypanosomiasis) in Brazil. *Trypanosoma Cruzi* was infecting human beings and, according to Vaz et al. (2007), this was most likely caused by anthropogenic, environmentally induced low mammal diversity and affluence of the common Opossum *Didelphisaurita*. Mathew (2009) states that the fragmentation of the natural ecosystem in South America led to lower bio-diversity and the increase in the number of white-footed mice (*Peromyscus leucopus).* White-footed mice acted as host for the pathogen of Lyme disease (*Borrelia burgdorferi)* and its *Lxodesspp* tick vector. Vaz et al. (2007) argue that this gave rise to the increase in the risk of Lyme disease in humans.

Jones et al. (2011) state that, in Australia, the outbreak of bat viruses was due to a loss of bat habitat because of deforestation and the increase in agricultural land, and these environmental changes affected the bat colonies. The bat colonies moved to other areas, and their population composition and size were altered. Migratory patterns also changed and they fed on suburban and urban fruit trees (Jones et al., 2011). The environmental changes led to contact with livestock and the human population. Spillover of pathogens in such a scenario can increase to the human population and livestock (Field, 2009). Pig farming, together with fruit plantations in forests, facilitated infection with the Nipah virus. The causative agent (fruit bats) had a conducive habitat in these plantations and pig farming areas (Field, 2009).

2.2.6 Wet markets and animal migration

Live animal markets and livestock movements give rise to the spread of infectious organisms. Intensive livestock production results in an increase in livestock animals and by-products on the markets globally (Jones et al., 2011). Livestock markets globally lead to the transmission of zoonotic diseases among animal species in a process that is known as cross-species transmission (CST) by which foreign infections are spread to new individuals, which then become the new host. According to Jones et al. (2011), transmission of infection among species is even worse if wildlife markets are in the same area where domestic livestock trade is carried out. Livestock markets increase contact between animals from different farms and areas, which leads to the transmission of pathogens in one region or country. Africa is one of the continents on which livestock sales is common, involving migratory animals and the transmission of zoonosis (Dibaba, Kriek & Thoen, 2009). Animal movements have led to the outbreak of bovine tuberculosis, *Mycobacterium Bovis,* in cattle herds in the United Kingdom (UK) and infected foxes and domestic dogs transmitted *E Multilocularis* to Northern Japan (Jones et al., 2011).

Katale et al. (2012) carried out a study on the transmission of tuberculosis in Tanzania. In the study, it was noted that the movement of cattle and the sale of cattle to the community contributed to the transmission of bovine tuberculosis in the area. This uncontrolled movement of cattle, combined with the decrease in veterinary services, hindered disease control programmes in Tanzania.

It was argued that in the Middle East and Africa, the movement of herds for trade and uncontrolled grazing without bio-security measures facilitated the transmission of foot and mouth disease and rift valley fever. Fevre, Bronsvoort, Hamilton and Cleaveland (2006) state that the outbreak of human trypanosomiasis in Uganda was due to the movement of infected cattle in the area. Seasonal movements of animals affect the epidemiology of certain infectious diseases. Jones et al. (2011) note that wildebeests in calving season develop malignant catarrhal fever. The infection of brucellosis in aborted tissues may have related motif in wildlife reservoirs (Jones et al., 2011).

Tian and Xu (2011) state that the live bird markets resulted in the spread of avian influenza (H5N1) infection. The trade of live bats in China brought infected bats with the SARS coronavirus in close proximity to wild animals. Some animals became magnifying individuals for human infection such as the masked palm civet *Pargumlarvata* (Jones et al., 2011, p60 cited by Fevre et al., 2006).

2.2.7 Illegal trade of wildlife

The trade of wildlife nationally and internationally transmits zoonosis from infected animals to other animals (Jones et al., 2011) and illegal trade forms the basis of trans-boundary disease. Pathogens are introduced to new areas via infected animals and the translocation of animals to other areas is a common factor that transmits diseases. Transportation conditions are very poor as animals are packed in small lots, which makes them susceptible to infectious diseases (Phukon, 2012). Illegal trade of wildlife also poses a risk to people working with these animals.

Seetahal, Vokaty, Vigilato and Carrington (2018a) carried out an investigation of rabies in the Caribbean. The investigation was based on situational analysis and historic review (Seetahal et al., 2018a). From their analysis and review, they discovered that the illegal introduction of dogs from areas with a history of infection outbreaks amplified the rabies infections in the Caribbean, the non-endemic area. Ninety-five percent infections were recorded in for Trinida, Guyan and French Guiana. Seetahal et al. (2018a) further state that illicit importation of dogs and cats could re-introduce canine-transmitted rabies. In Belize, Trinidad, Grenada and Suriname, the migration of wildlife was noted as a great risk to the transmission of sylvatic rabies.

According to Chomel et al. (2007), psittacosis affected customs officials in Belgium who came into contact with infected parakeets. In this study, time was a deterring factor. The risk of officials who were exposed for more than two hours was three times higher than for those exposed for less than two hours (Chomel et al., 2007). Jones et al. (2011) argue that illegal wildlife trade is very common in third-world nations and they struggle to curb the transmission of zoonosis at the human/domestic livestock/ wildlife interface.

2.2.8 Hunting and butchering: consumption of bush meat

Consumption of wild meat plays a major role in the transmission of many zoonotic pathogens. Chomel et al. (2007) state that in Southern Cameroon, the human T-lymph tropic virus types 3 and 4 infected people through hunting and butchery practices. Meng et al. (2009) note that the cases of brucellosis infection in humans revealed that humans are infected due to their handling of infected wild boars.

Griffin et al. (1993) note that an investigation was carried out on the roles of farm management activities, habitat factors and farmer attributes in the epidemiology of bovine tuberculosis. The investigation took three months, from August to October in 1990, in the counties Cork and Kilkenny in the Republic of Ireland as study areas. A standardised questionnaire was used. The results indicated the ongoing outbreak of tuberculosis was due to sustenance elements, such as the trade of cattle bulls, the existence of budger and the spreading of sludge.

A study was carried out on the prevalence of zoonotic tuberculosis (Bapat et al., 2017). In the study, Bapat et al (2017) investigated the threat of zoonotic tuberculosis among the Central Indian population. The study was carried out from March 2014 to June 2015 and was aimed at establishing the factors that facilitated the transmission in the highly populated Central India. Blood samples of 301 people were sent to the laboratory. A polymerase chain reaction and differentiation were used to differentiate Mycobacterium bovis and Mycobacterium tuberculosis. Bapat et al. (2017) argue that the results indicated that most participants who tested positive for M bovis were living in the high tuberculosis endemic region. Consumption of raw milk was found as the major cause of transmission of bovine tuberculosis in the population (Bapat et al., 2017).

Jones et al. (2011) state that Ebola virus infection outbreaks in humans were due to the consumption of meat of Chimpanzees that were found dead. Other researchers discovered that besides eating Chimpanzee meat, handling infected dead Chimpanzees also caused Ebola. Seventy-five percent of trichinellossis infections in Spain were due to the butchering of wild boar, which the human population fed on (Jones et al., 2011). Meng et al. (2009) found conclusive evidence of the transmission of the hepatitis E virus in two incidences which involved humans after consuming boar meat in Japan.

Adesokan, Alabi, Stack, Simeon and Cadmus (2013) investigated the knowledge and practices that led to the transmission of brucellosis among livestock holders and marketers in Yewa, an international livestock-trading centre in South Western Nigeria. The cluster sampling method was adopted and interviews were implemented to cluster samples. A total of 157 participants were interviewed, 57 of which were livestock holders (LH) and 103 were livestock marketers (LM). The LH and LM groups were poorly knowledgeable about brucellosis. Adesokan et al. (2013) found factors that transmit brucellosis from animals to humans, which included the consumption of raw milk and uncooked meat, the sharing of habitation and poor hygienic living conditions. They found that it is important to educate the public sector and to introduce control measures in cattle.

2.2.9 Wildlife-management

Certain aspects of wildlife management, such as hunting or recreation, may increase contact rates between livestock and wildlife, which increases the threat of zoonotic disease transmission. The designated areas are fenced. Rhyan and Spraker (2010) state that wildlife management with high densities within a fence and feeding them has a high risk on the transmission of zoonotic diseases at the livestock/wildlife interface. Sometimes they introduce new species and supplement feeding or water provision. This increases the animal population density and results in disease transmission to livestock and humans.

Rhyan and Spraker (2010) state that stress among wildlife due to higher densities may result in the change of habitation and the increase in animal prey, which results in behavioural changes among wildlife. This leads to these animals intensifying the unnoticed infection and sometimes it spills back to livestock. Meng et al. (2010) and Mathews (2009) argue that bovine tuberculosis was transmitted to domestic livestock by the wild boar in Spain and by tailed deer in the USA. Brucellosis infected bison and cattle in Elkin in the greater Yellowstone area in the USA (Rhyan & Spraker, 2010).

2.3 NATURAL FACTORS

2.3.1 Climate change

Mills, Gage and Khan (2010) investigated how climate change affects vector-borne and zoonotic diseases. Change in climate can influence the geographic distribution of wildlife species and their population densities, potentially influencing the interrelationship between wild life and livestock. Mills et al. (2010) note that climatic change and habitat change interactively affect pathogen transmission between the hosts' population and the vector's population, as well as the human population. On the other hand, Mills et al. (2010) state that the influence of climate change and habitat change on the transmission of zoonosis is difficult to speculate.

Animals move to higher latitudes or altitudes, which results in the expansion or contraction of a range. The hispid cotton rat (*Sigmodon hispidus),* for example, moved northward and this resulted in altitudinal expansion in North America. In addition to the transmission agent of Lyme disease, the white-footed deer mouse, human granulocytic *anaplasmosis babesiosis* and hantavirus moved northwards too (Mills et al., 2010). It is possible that a change in climate affects migration patterns and population distribution of wild birds. Domestic poultry can be infected by the avian influenza virus, which is transmitted by wild birds (Gilbert et al., 2008).

El Nino Southern Oscillation (ENSO) has an impact on the transmission of diseases. A study was carried out in the Gaudeloupe French West Indies, which focused on human patients hospitalised with leptospirosis. The results of the study indicated that a rise in rainfall received due to El Nino from 2002 to 2004 led to an increase in leptospirosis patients, as compared to other seasons. In addition, contact with rodents also increased the risk of infection in the period 2002 to 2004 during the ENSO (Storck, Postic, Lamaury & Perez, 2008). This study suggested high rainfall or a rise in rainfall in that area, which gave rise to rodent populations and an increase in the risk of patients with leptospirosis. Mills et al. (2010) state that in 1997 in Southern Western USA, ENSO resulted in increased rainfall. This increased the primary productivity of the area and gave rise to the North American deer mouse (*Peromyscus maniculatus)* populations. Mills et al. (2010) argue that *Peromyscus maniculatus* populations later became the transmission agents of Hantavirus pulmonary syndrome to humans. Anyamba, Linthicum, Small, Kathrine and Collins (2012) note that the rift valley fever outbreaks in East Africa in 1997 and 2006 took place after heavy rainfall associated with ENSO.

The impact of temperature is still debatable when it comes to the SARS-Cov-2 pandemic. Sil and Kumar (2020) are of the opinion that temperature changes have an impact on the coronavirus infection rate. Liu et al. (2020) carried out an analysis on meteorological data for 30 cities in China. The results from the study indicated that conditions like low to moderate temperatures and low humidity allow the fast spread of coronavirus infections. According to Shi et al. (2020), temperature has a positive impact on the transmission of the coronavirus as a rise in temperature lowers the coronavirus cases. Sil and Kumar (2020) state that countries like the USA, Italy, Spain and China experienced a decrease in temperature to lower than 15 °C and these countries suffered a high infection rate, while India, Africa and Australia with higher temperatures (higher than 15 °C) reported low infection rates and death tolls due to covid-19.

Zhu, Xie, Huang and Cao (2020) used the same meteorological data that Liu used. Data from 172 cities in China were scrutinised. The results indicated that no tangible, conclusive evidence is available to prove that a rise in temperature reduces the number of coronavirus infections. The contradictory conclusion can be due to the distribution of human population characteristics in different cities. These include population size and densities, because population size and adherence to covid-19 regulations will control the spread of covid-19.

2.3.2 Water resources

Zoonosis can be transmitted, especially when wild animals, domestic animals and humans share the same water source (Woodford, 2009) as bodily discharges are left in the water resource. Discharges include faeces, urine, saliva, or ocular or nasal discharges. Bodily discharges are also left on shared insect vectors or intermediate hosts (Kock, 2014). This led to domestic animals and wildlife coming into close proximity and it foments the transmission of diseases. Intrinsic and extrinsic factors determine the life period of infective agents within a habitat. Intrinsic factors include the cell structure of the organism and the adaptation of the transmission agent. Extrinsic factors we considered were weather conditions like temperature and humidity. A study was carried out in Uganda on the genetic similarity of Escherichia coli strains from primates and humans (Goldberg et al., 2008b). The findings of this study indicated that using open source water increases the genetic similarity between strains of primates and humans. Kankya et al. (2010) note that the results proved that human sources of water that are not used by wildlife lessen the people’s exposure to mycobacterial infections.

2.3.3 Vectors

Infected arthropod vectors such as rats, sand flies and biting midges were spreading vector-borne infectious diseases. Bean, Baker, Stewart, Cowled and Deffrasnes (2013) state that natural reservoir hosts for vector-borne diseases include bats, pigs, primates, birds and several other vertebrate species. It is of importance to understand the natural life cycles of vectors, which include daily probability, biting rate, incubation time of the virus and vector competence (Beebe, Cooper, Mottram, Anthony & Sweeney, 2009). The above parameters depend on the temperature of the environmental habitat where the vectors are found. These vectors are poikilothermic and experience temperature at the local level from a scale of meters, or even centimetres (Haider, 2018). Infected vectors like mosquitoes, tsetse flies and ixodid ticks transmit brucellosis and tuberculosis directly or indirectly to susceptible hosts (Kock, 2005). Ticks and flies act as bi-directional transmitters of infectious agents in domestic livestock and wildlife interface (Phukon, 2012). Ticks can transmit pathogenic microorganisms, protozoa, rickettsiae, spirochaetes and viruses that can affect livestock and wildlife.

Michael and Bengis (2012) note that if the environment is contaminated with infected ticks (*theileriosis* or fomites (anthrax)), these can transmit infectious diseases to livestock even though the interface is not shared. Vector-borne diseases contribute to emerging infectious diseases (EIDs) globally (Gubler, 1998) and this hinders the control efforts by the animal and public health departments. The control efforts can be impossible due to land use changes like urbanisation, agriculture and deforestation. These can impact on the vector prevalence and cause the emergence of vector-borne diseases in new environments (Rochlin, Ninivaggi, Hutchinson & Farajollahi, 2013; Weaver & Reisen, 2010; Gubler, 1998). The World Health Organization (WHO) (2018) states that almost 17% of all infectious diseases in the world, which cause more than 700 000 human deaths annually, are due to vector-borne diseases and that more than 400 000 human deaths are due to malaria. Gubler (2009) notes that in the fourteenth century, the black death in Europe was due to vectors; it was caused by a bacterium, *yersinia pestis,* which is carried by rodent fleas. This killed 30 to 60% of the total population of Europe (Gubler, 2009).

Bluetongue outbreaks in 2007 and 2008 in Denmark were also due to vector-borne diseases (Haider, 2008). Bluetongue causes weight loss, abortion, reduced milk yield and, ultimately, death in ruminants (cattle and sheep). The outbreak of bluetongue caused restrictions in the trade of animals and animal products internationally. The first outbreak of bluetongue was recorded in Cyprus in 1943 (Haider, 2008). Another outbreak of bluetongue was recorded in Portugal in 1956 (Maclachlan, 2011). Chikungunya, Zika, Rift valley fever, Lyme disease and tick-borne encephalitis are common vector-borne diseases in humans around the world (WHO, 2018). Laaksonen (2010) notes that three outbreaks in Finnish reindeer in 1973 were due to setaria tundra, a mosquito borne filarial parasite. This reduced the population to 98 000 from 140 000. This disease causes a poor body condition and is associated with peritonitis and perihepatitis.

Ramatla et al. (2019) carried out a study for the identification of the species of rodents infesting poultry runs/houses in Mafikeng, South Africa. These rodents affect farm production, destroy food, contaminate feed and circulate infectious diseases. Rodents are a small group of mammals, which include rats, mice and squirrels (Ramatla et al., 2019). These rodents transmit pathogens that cause diseases in domestic livestock, wildlife and humans (Wakawa, Mahommed & Momman, 2015). Types of rodents that are commonly found worldwide include the brown rat (*R. norvegicus*), house mouse (*Mus musculus*) and roof rats (*Rattus rattus*) (Backhans & Fellstrom, 2012). Normally, the genus Rattus would be the ones infesting the poultry houses. Genus rattus includes the Norway rat *(R. norvegicus*), the Asian rat (*R. tanezumi*) and the black rat (*R. rattus*) (Ramatla et al., 2019). In their study, they identified that *Rattus* and *Rattus tanezumi* invaded poultry houses in Mafikeng. *R. tanezumi* was the second prominent species on the farms. They did not expect to find *R. tanezumi* because it was introduced to South Africa not long ago. This species is not indigenous to Africa; it originates from Asia (Ramatla et al., 2019). The rats spread infectious diseases to human beings and it was found that rats carry species of trematode, cestode and nematode (Ramatla et al., 2019).

Vector-borne diseases cause a global burden of infectious diseases and the public health sector faces challenges to contain vector-borne diseases worldwide. Miller (2016) was of the opinion that detection and surveillance of the pathogen and vector are critical and it becomes difficult to control a vector-borne disease. Vector borne diseases can even infect nonhuman animal reservoirs due to its sylvatic cycle.

A variety of factors have been discussed, such as humans, and economic and natural factors that influence the transmission of zoonoses. Human and economic factors or indirect mechanisms that were discussed include human settlement invasion in wildlife habitat, deforestation, agriculture, livestock production, habitat alterations, wet markets and animal migration, illegal trade of wildlife, hunting and butchering, and consumption of bush meat and wildlife management. Natural factors include climate, water resources and vectors. The exact mechanism of transmissions is poorly understood and is part of the focus of this study. The role played by vectors direct or indirect transmission can be very difficult to understand. The issue of climatic change on vectors can have a positive or negative impact on transmission of zoonotic diseases. The next chapter deals with research design and methodology.

CHAPTER 3

THE RESEARCH DESIGN AND METHODOLODY

3.1 INTRODUCTION

The theories in this study are introduced and explained in this chapter. First, the study area (location, climate, flora and fauna) is discussed and then the research methods used; both the quantitative and qualitative approaches. This is followed by a brief introduction of mathematical modelling of infectious diseases derived from literature, and then a discussion of the data collection methods used (questionnaire, the classical Susceptible-Infected-Recovered (SIR) model and ordinary differential equations). Data analysis strategies are also discussed and solutions and control measures suggested.

3.2 STUDY AREA

3.2.1 Location

The City of Mahikeng is situated on an open land 1 500 m above sea level (Ramatla et al., 2019). There is an international border that separates South Africa from Botswana to the north of the city, which is located 260 km to the west of Johannesburg. Its coordinates are 25052’18 12$^{''}$S 25^{0}43$^{'}$28.92^{0} E. The study area was the Mahikeng Game Reserve and its surrounding areas in the North West province of South Africa. The study focused on areas within a 5 km radius from the boundaries of Mahikeng Game Reserve (Lomanyaneng, Bokone, Stad, Dihatshwane and Top Village). The Mahikeng Game Reserve was established in 1982 and is located adjacent to the municipal boundary of the town of Mahikeng. The game reserve extends eastwards and covers an area of 4 600 ha. The maps below show the study area in detail.

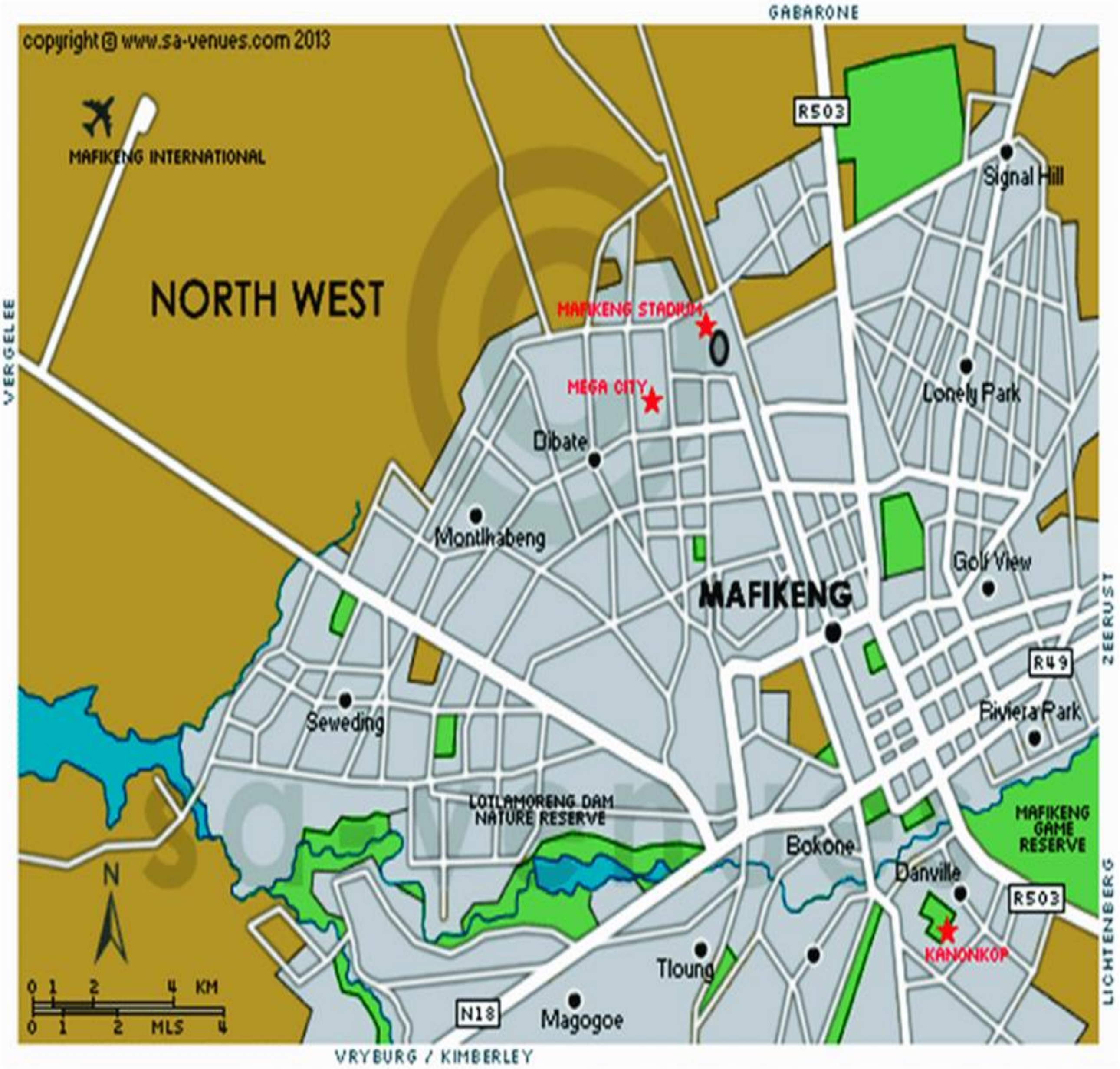


Figure: 3.1: Map of Mahikeng in North West province of South Africa (www.researchgate.net. Retrieved 10 April 2021)

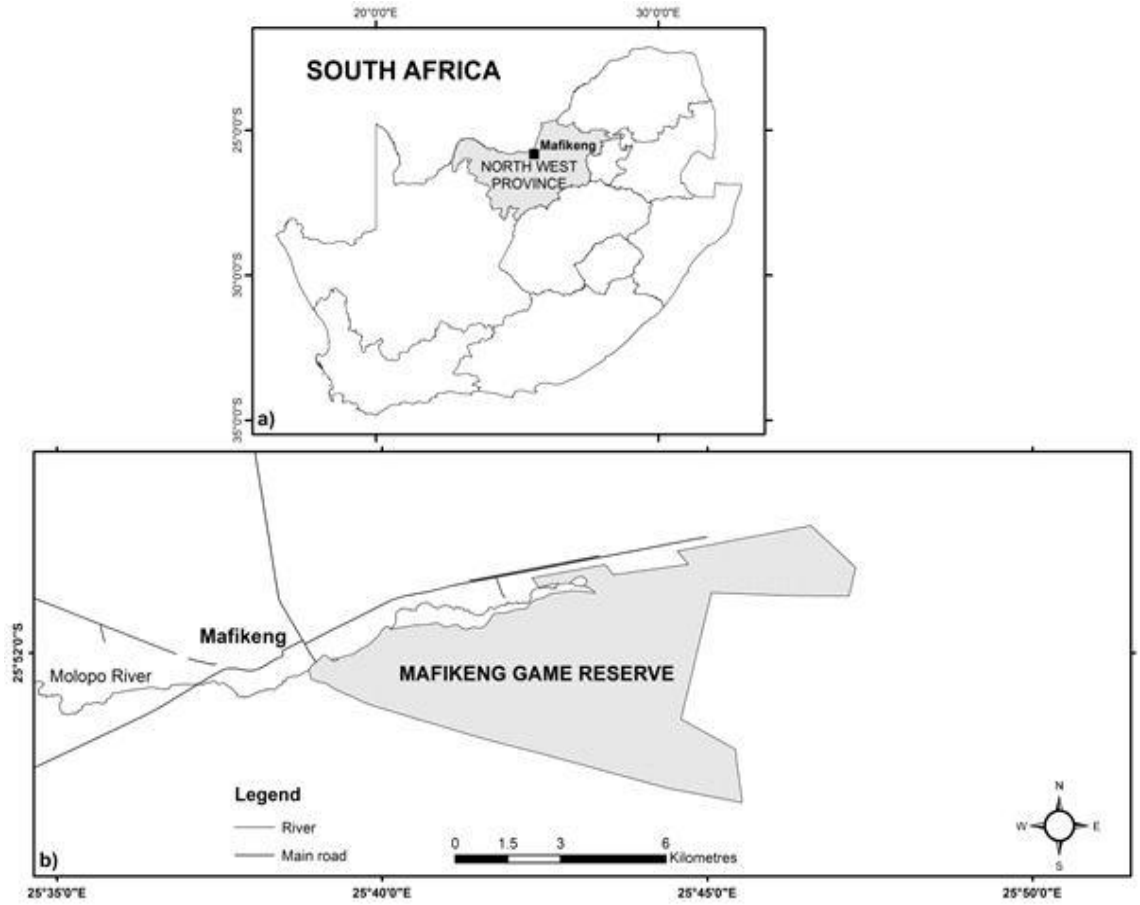


Figure 3.2: Map of South Africa highlighting the North West Province (Top) and the Mahikeng Game Reserve (Bottom) (Indian Journal of Animal Research)

3.2.2 Climate of Mahikeng

3.2.2.1 Rainfall

The North West province forms the southern part of the Kalahari Desert. It is a predominantly savannah type of climate, with sunshine occurring almost throughout the year. Seasonal rainfall is characterised by low and highly variable rainfall in space and time (Freeland, 2001). The amount of rainfall received varies with the region to the west receiving less than 300 mm per year, the middle region receiving 500 mm per year and the region to the south receiving more than 600 mm per year (Ramatla et al., 2019). Average rainfall in Mahikeng ranges from 300 mm to 1 000 mm per annum, which occurs during the summer month of January which is the wettest month (Van Veelen et al., 2009). Most of the rainfall occurs as brief afternoon convection thunderstorms during summer.

3.2.2.2 Temperature

Maximum temperatures occur in January, while minimum temperatures occur in June and are sometimes accompanied by frost. The city of Mahikeng is located between 25° and 28 ° south of the Equator and 22 ° and 28 ° longitude east of the Greenwich meridian (Ramatla et al., 2019). Mean summer temperatures range between 22,5 ºC and 25 ºC. Summers are long, warm and partly cloudy and winters consist of short, dry sunny days and chilly nights. During the winter months, mean temperatures of about 10 ºC are recorded (DWAF, 2003).

3.3 FLORA

The Mahikeng Game Reserve is dominated by the Kalahari and Vachellia bushveld. It consists of the flat open grass plains of open Kalahari grassland and Vachellia thorn scrub (Mafikeng Spatial Development Framework, 2005). It is a typical African landscape of sour mixed bushveld through which the Molopo River winds. Most of the vegetation in the game reserve consists of xerophytes that are adapted to low rainfall environments (Van Veelen et al., 2009; Mafikeng Spatial Development Framework, 2005). Some of the grass species found in the game reserve are *Aristida congesta*, *Cynalon dactylon*, *Eragrostis lehmanniana* and *Anthephora pubescenens* (De Villers et al., 2002). Dominant trees in the game reserve are *Senegalia Caffra*, *Vachellia Karoo Celtis African*, *Rhus laneea* and *Ziziphus muicronata*, shrubs include *Vachellia mellifera, Vachellia hebaclada, Dichrostachys cinerea, Grewia flava, Grewia rehnervis* and *Rhus tenuinervis* and woody climbers include *Asparagus Africanus.* The area has a problem of invasive alien species such as *Atriplex Lindleyi* (sponge fruit saltbush), *Nummularia* (old man saltbush) and Opuntia *Ficus Indica* (sweet prickly pear) (Van Veelen et al., 2009).

3.4 FAUNA

The Mahikeng Game Reserve consists of white rhino, buffalo, gemsbok, the giraffe, zebra, springbok and red hartebeest, which can be viewed and photographed on the open plains. Birds found along the Molopo River include finches and waxbill. The vegetation in the Mahikeng Game Reserve supports indigenous mammals, reptiles, amphibians and insects that are endemic to the area.

3.5 RESEARCH MODEL

3.5.1 Quantitative approach

A research model is an accepted plan for conducting research with a substantial number of people in a research community. The quantitative and qualitative methods were followed in this study. Questionnaires were used for farmers and the State Veterinary Department of Mahikeng to collect information. A descriptive desktop study was also used by using data that had been provided by the State Veterinary Department of Mahikeng. In the quantitative approach, the researcher quantified the problem using numbers or numerical data that have values and anything that is measurable in a systematic way when investigating the trend and dynamics of transmissible infectious diseases.

Most of the data was kept in a file by the State Veterinary services and data was obtained through the questionnaires. Information on animals infected each year was recorded, as well as the name of the disease and the number of animals infected, recovered or dead. Clinical and laboratory tests were conducted to determine the infected animals. Vaccination dates and the vaccine administered were also recorded in the file. The questionnaire yielded quantitative data from closed-ended questions. In the quantitative approach, a computation and system analysis approach was followed. All the information was compiled and recorded on a spreadsheet. The main purpose of the spreadsheet was for storing and retrieval of numerical data as the trends and dynamics of infectious diseases can easily be analysed using this numerical data. The main focus of adapting the quantitative approach was to develop SIR models for brucellosis, rabies and tuberculosis from 2007 to 2016. This allowed the evaluation of the trends and dynamics of transmissible diseases at the interface of the Mahikeng Game Reserve and its surrounding areas. Quantitative data is also known as numeric data and the quantitative approach was divided into discrete data and continuous data. For discrete data, infected animals and secondary infections were counted (Wonham, 2008) as well as the number of animals recovered and removed. This generated counts of data to which the SIR models were fitted. The data used to model the dynamics of the different diseases spanned over the period 2007 to 2016.

3.5.2 Qualitative approach

In a qualitative approach, categorical data is used to understand and interpret social interactions of wildlife, domestic livestock and humans. Examples include nominal (named), ordinal (ordered) and dichotomous (presence or absence or yes or no) data. Data such as species of animals involved in the transmission of infectious diseases, whether cows, dogs or humans responsible for a specific infectious disease is recorded. In this study, open-ended and contingency questions also provided such valid and reliable qualitative information. The Veterinary Department of Mahikeng recorded laboratory specimens that tested positive or negative for the diseases under study.

Leedy and Ormrod (2010) state that these two approaches work hand in hand, with the qualitative approach providing an understanding of the problem and facilitating the formulation of the hypothesis for quantitative research.

3.6 QUESTIONNAIRE

In this study a questionnaire was compiled as a research instrument that gathers information by obtaining people's responses to questions set by the researcher (Leedy & Ormrod, 2010). The questionnaire consisted of closed ended, open ended and contingency questions. The questionnaires were handed directly to the respondents who were willing to take part in the survey.This method allows the researcher to collect complete and accurate data in an orderly manner. The questionnaire provides practical, fast and inexpensive data, which is easy for analysis, although sometimes a paper-based questionnaire would be inappropriate to an illiterate target audience (Leedy & Ormrod, 2010).

3.6.1 Basic structure of a survey method

- The purpose and goal of the survey were explained in the questionnaire.
- The sample size was selected from targeted populations from five villages around the Mahikeng Game Reserve that share the interface.
- Data was collected, processed and stored in Microsoft Excel with the SOLVER added.

3.6.2 Paper-based survey

A paper-based survey was used because internet access of most of our communal farmers is poor. A questionnaire approach is a traditional survey method that makes use of a large amount of resources through survey reproduction and manual respondent assistance. Questionnaires were administered to farmers individually.

3.6.3 Questions used

3.6.3.1 Closed-ended questions

In these questions, a variety of optional answers were provided by the researcher. According to Krosnick and Presser (2010), these can be multiple-choice questions, dichotomous questions or scaled questions. Farmers had to select the signs and symptoms they observed in their herds for each disease under study and they had to select their level of education from a given range. From closed-ended questions, a researcher collects quantitative data. Closed-ended questions are easy for participants to answer, but they limit information that the researcher can obtain due to the options given.

3.6.3.2 Open-ended questions

Respondents wrote down their own answers. Open-ended questions may require a respondent's viewpoint or opinion (Krosnick & Presser, 2010). In open-ended questions, respondents can complete a sentence or story as part of the questionnaire. Information from an open-ended questionnaire is more complicated to analyse and is used more often in qualitative research.

3.6.3.3 Contingency questions

These questions require a response based on the answer that was given to a prior question. Contingency questions prevent respondents from answering questions that are not meant for them (Krosnick & Presser, 2010; Sincero, 2012).

3.6.4 Participation selection

In this study, the researcher approached communal and commercial farmers who agreed to be part of the study and the personnel from the Veterinary Department of Mahikeng. A paper-based survey was conducted with the farmers who agreed to participate. Selection was done randomly and it was determined based on the farmers' willingness. Cluster sampling was used. Areas within a radius of 5 km from the Mahikeng Game Reserve were selected. (Lomanyaneng, Stad, Bokone, Dihatswana and Top Village). This enabled individuals to be selected in geographical batches, smaller units or clusters (Gangrade, 1982). Geographical access to the farmers and their participation were taken into consideration by the researcher for the completion of questionnaires.

3.6.5 Ethical consideration

Ethical considerations are an important element of ethical approval in every research study. A consent letter was attached to the questionnaires. In addition, farmers were informed verbally that participation in the study was not compulsory. This was also stipulated in writing in the letter of informed consent. Participants who were willing to complete the questionnaire were required to sign the letter of consent for anonymity purposes. Participants were not allowed to write their names on the questionnaire; they only had to give their signature on the consent letter. In case of illiteracy, the researcher explained the consent letter verbally and an X was entered on the form to indicate consent although the farmer did not sign. A participation anonymity was maintained as no details of respondents were collected.

3.6.6 Advantages of questionnaire survey

1. A questionnaire is a cheap and flexible method to collect qualitative, descriptive and quantitative data.
2. A questionnaire enables the researcher to collect data from a large group of participants.
3. A questionnaire yields comparability (easy to compare and contrast to other research findings after quantifying the data).
4. The results from a questionnaire are easy to analyse and visualise, and allow the researcher to give conclusions and predictions. The researcher can give topics for further research.
5. In a questionnaire, the participant's anonymity is granted and this enables the respondents to answer truthfully (Leedy & Ormrod, 2010).

3.6.7 Disadvantages of a questionnaire survey

1. Misinterpretation of questions is common, especially when presented in a language the participant is not fluent in (Sincero, 2012).
2. Dishonest answers due to hidden agenda or fear of personalisation.
3. Some questions can be skipped, but it remains a reliable instrument to collect information on surveys.

3.7 MODELS

Models are defined as simplified representations of reality (Owen-Smith, 2007, p.1; Tawhir, 2012). Computer models assist in projecting the future, although they are a time-consuming and expensive activity (Owen-Smith, 2007; Thomas, 2012). These computer models assist the policy makers and epidemiologist to analyse the trends and dynamics of disease spread (Anderson & May 1991).

3.7.1 Mathematical models

A mathematical model is defined as formulas or equations related to the quantitative description of real phenomena in an attempt to mimic the behaviour of a natural system (Tawhir, 2012, p.24). Mathematical models represent the skeletal structures of real systems (Owen-Smith, 2007; Tawhir, 2012). Infectious diseases are a great field for mathematical modelling and mathematical techniques are used in the analysis of the trends and dynamics on the disease models that contain ordinary differential equations (ODRs) (Grenfell et al. 2002; Owen-Smith, 2007). The main purpose of using models is to identify and offer possible explanations for the temporal spread of disease. Model analysis and numeric simulations are used to interpret the trend, the dynamics of transmissible diseases, and how to manage and control these infectious diseases (Heesterbreek & Roberts, 1982; Adebiyi, 2016). Mathematical models can be fitted to available time series data obtained from surveys.

Quantities used in mathematical models are categorised as constants, variables, parameters and input functions (Tawhir, 2012). Variables such as time or positions in mathematical models are the independent variables. A dependent variable is the quantity that undergoes a change to the given problem under study. A dependent variable varies based on changes in independent variable(s). A fixed value is a constant (Tawhir, 2012) with a fixed quantity throughout the model being the parameter. A parameter incorporates a number of different types of numerical or other measurable elements forming a set of related problems. With these mathematical models for a selected period of time, it becomes easy to analyse the trends and dynamics of infectious diseases.

3.7.2 Compartmental models

A compartmental epidemiological disease model places a population into groups based on whether it is susceptible, infected, or recovered or removed (SIR). Compartments within a population show the stages that each individual must pass through during the infection. In a compartmental model, an individual becomes susceptible to an infection after contracting the disease. The individual then passes latency before being considered infected (Nika, 2015, p. 35). After the individual is considered infected, it moves to the removed or recovered state. For the purposes of this study, removed animals are dead.

3.8 SUSCEPTIBLE-INFECTED-RECOVERED/REMOVED (SIR) MODEL

The susceptible-infected-recovered (SIR) model that was developed by Kermack and McKendrick (1927) in 1927, and later used by Owen-Smith (2007), was adopted in this study. The SIR model consists of the susceptible population, the infected population and the recovered or removed population (Bloomfield, 2009; Smith, 2009; Kermack & McKendrick, 1927), and is considered the best modelling formulation for an epidemic (Nika, 2015). Susceptible individuals refer to the healthy animals that can be infected by infectious diseases (Kermack & McKendrick, 1927). This class is represented by the letter S (Owen-Smith, 2007; Bloomfield, 2009; Kermack & McKendrick, 1927). The animals that were infected by the diseases and became sick are called infected individuals and they can infect other animals. The infected class is denoted by the letter I. The individuals who recovered are assumed to have developed immunity and these individuals are denoted by the letter R (Bloomfield, 2009; Owen-Smith, 2007; Nika, 2005). The letter R could represent animals that are dead, and they were removed from the herd. For this study, the susceptible, infected, and recovered/removed were counted when the disease outbreak occurred. This assisted in answering questions like: “How many animals were infected at a particular point in time?”, “How many animals were vaccinated to prevent an epidemic?” This will generate counts for data analysis.

Figure: 3.3 SIR linear model. Adapted from (Owen-Smith, 2007)

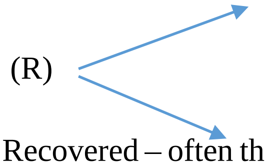
Where:

Susceptible (S) – healthy animals and humans that are exposed to infection.

Infected (I) – animals and humans who have the disease or are carriers of the disease. This group can infect the susceptible group.

Recovered or Removed (R)

Removed – animals and humans who are dead



Recovered – often the animals or humans that already had the disease and developed immunity.

3.8.1 General assumptions for the study

- The population size (N) is constant and large.
- There is homogeneous mixing of animals and people, and contacts are, therefore, random.
- Infected animals are introduced to the total population.
- The infected, recovered and removed populations are counted (Thomas, 2012).
- The spread of rabies, tuberculosis and brucellosis to the rest of the population will occur with time.
- The number of animals or people in susceptible, infected and removed/recovered classes will change with time (Bloomfield, 2009; Nika, 2015; Owen-Smith, 2007).

$$N = S(t) + I(t) + R(t)$$

As the study covers a decade, the system of ordinary differential equations (ODE) manages the population dynamics under this study over a period of ten years. The number of infected and recovered animals or humans can change over a period of time; therefore, requiring Owen-Smith's formulation (2007).

3.9 DIFFERENTIAL EQUATIONS

The researcher adopted differential equations one to five from Owen-Smith (2007). The following are differential equations that were used in the formulation of the SIR model.

$$\frac{dI}{dt} = \beta SI - v \qquad \text{(Eq.1)}$$

Where:

I = the density or number of susceptible hosts who are capable of transmitting diseases (Bolzoni & De Leo, 2000).

S = the density or number of susceptible hosts who are at risk of being infected (Bolzoni & De Leo, 2000).

β = the transmission rate.

ν = the rate of recovery of infected hosts.

βSI = the product of the transmission rate and susceptible hosts.

dI = the density of the infected host.

dt = the density of animals per unit of time (Owen-Smith, 2007).

The transmission rate is determined by the frequency of contact between wildlife/domestic livestock/humans at the interface of the Mafikeng Game Reserve and its surrounding areas. According to Bolzoni and De Leo (2007), the functional population size determines the contact rate between the infected host and susceptible hosts. The product βI means the force of infection (Owen-Smith, 2007). The spread of pathogens must take place for infectious diseases to spread. The infected animals or people must transmit the pathogen to the susceptible population to produce secondary infections. Secondary infections are produced by primary infections during its infectious period (Owen-Smith, 2007). This is known as the basic reproduction ratio R_0 (Owen-Smith, 2007) and is one of the most important threshold parameters (Adebiyi, 2016; Owen-Smith, 2007). The R_0 will assist in describing the features of mathematical problems of the infectious diseases (Diekmann & Heesterbeek, 1991; Owen-Smith 2007). In the basic reproduction number, the focus is on the transmission of the disease, and the rapidity of transmission is not of relevance.

The rapidity of transmission of the disease between infected and susceptible hosts is important. If $R_0 < 1$, it means the infected hosts produce less than one new infected individual during the whole period of being in the infected class (Owen-Smith, 2007). The above statement illustrates that the disease will stop spreading within the entire population and then fade out (Diekmann & Heesterbreek, 1991). If $R_0 > 1$, it means that infected individuals produce more than one new infection and the disease will spread through the entire population. Bolzoni and De Leo (2007) note that, in short, R_0 is the product of transmission rate, the duration of infection and the number of susceptible hosts. Owen-Smith (2007) states that the period of infection is the inverse rate of recovery.

$$R_o = \frac{\beta N}{v} \qquad \text{(Eq.2)}$$

Where:

The R_o = number of secondary infections

β = transmission rate

N = population size

ν = rate of recovery of infected hosts

βN = product of transmission rate and population size.

Owen-Smith (2007) states that temporal dimensions β and ν cancel each other out. The researcher assumed that if there is a slow rate of recovery of infected animals, it means there is a high percentage rate of infection. For transmission of the disease to occur, there is a need for a threshold population size or density N_T (Owen-Smith, 2007). The equation can be rearranged to set R_0 equal to:

$$N_T = \frac{v}{\beta} \qquad \text{(Eq.3)}$$

Susceptible individuals decrease in number when the disease spreads. Some infected animals or humans may become immune or they may die. If all infected animals die, it means the spread of the disease stops. According to Owen-Smith (2007), the reduction in susceptible hosts causes the effective R_0, given by the product

$$\frac{\beta SI}{\nu} \qquad \text{(Eq.4)}$$

to fall below 1. This means that the infectors have been wiped out.

When it comes to sexually transmitted diseases, contact takes place through selection, resulting in the transmission of diseases occurring in small population sizes. Contacts are actively sought (Owen-Smith, 2007). Individuals of one biological sex choose mates depending on specific characteristics of the other sex to mate with and, sometimes, the members compete among themselves for access to the members of the opposite sex. Owen-Smith (2007) states that proportional dependency could also arise in a very dense population where the rate of contact saturates. Dobson and Meagher (1996) state that the prevalence of brucellosis among bison in Yellowstone Park was most consistent in this pattern due to the high density of bisons in large herds.

$$Ro = \left(\frac{\beta}{\nu}\right)\left(\frac{S}{N}\right) \qquad \text{(Eq.5)}$$

Owen-Smith (2007) notes that the stage that follows depends on whether the pathogen can survive in a dormant structure, another host or anywhere in the environment. A spatial variation in the proportion of infected hosts, and temporal variation in the rate of transmission can contribute to maintain infections, unless host mortality removes the infective agent fast enough (Owen-Smith, 2007, p.151). The wildlife animals can transmit infectious diseases to domestic livestock, humans, and potentially also to endangered wildlife species (Owen-Smith, 2007; Jones et al., 2008).

The departments responsible for animal health and public health must consider the critical population size when monitoring and controlling infectious diseases. The rate of the spread of the disease from the infected to the susceptible is important when monitoring the transmission of the disease. The basic reproduction number R_o was modified due to a lack of immunity by susceptible hosts to prevent the spread of the pathogen (Owen-Smith, 2007). The infected animals become infectious with time. Bolzoni and De Leo (2007) state that, in reality, the spread of the disease may not be linearly dependent on the contact rate between infected and susceptible individuals as assumed in the mass action model. In some areas, the population size determines direct or indirect contact among wildlife/domestic livestock/humans on the interface for the transmission of diseases to take place. A spatial dispersion of the host population is important as well as the overall population density for the transmission of infectious diseases to take place at the interface (Owen-Smith, 2007; Nika, 2015).

3.10 SUM OF SQUARES

The researcher used the sum of squared deviation (sum of squares) which was put forward by Fowler, Cohen and Jarvis (1998) to fit the model to the data with the lowest attained sum of squares, indicating the best model fit to the data. Sum of squares is a statistical tool that denotes the dispersion of data and explains how the data sequence was created. The parameters like transmission rate were changed iteratively until a reasonable fit was achieved. The researcher then used the Solver package (Microsoft Excel) to further minimise the sum of squares. The least square regression predicts the behaviour of dependent variables. The data collected from the State Veterinary Department of Mahikeng was not detailed enough to enable the researcher to model yearly trends infections. The researcher modelled the infections only for the decade under study and drew line graphs summarising the susceptible, infected and recovered for each year from 2007 from 2016. The data was generated from annual reports for each year under study (2007 to 2016). Each year had its own susceptible, infected and recovered numbers. For the susceptible group, the researcher had to use the mean number for the ten years for each disease under study to model the infections for the decade. Mean is the average set of numbers and is the most commonly used measure of central tendency. Arithmetic mean is calculated by summing up the values in the data set and dividing it by the number of values.

3.11 DATA ANALYSIS

Different software mediums can be used to formulate mathematical models. Solver, which is a Microsoft Excel add-in, was used for quantitative and qualitative analysis of data in this study. The benefits of using Solver are that it processes any mathematical scenario very fast, it offers solutions to difficult formulas, swiftly analyses data and the maximum or minimum value of a formula can be determined within one cell (Highland, 1998). Solver saves time from doing manual algebra calculations and it is quick to process multiple, unknown variables like a recovery rate and transmission rate that are involved in this study.

This chapter presented the study area (location, climate, rainfall, temperature, flora and fauna). In addition, the chapter offered an extensive discussion of the quantitative and qualitative research paradigms, the questionnaire data collection method and the SIR model. In addition, the sum of squared deviation was explained in order to model the infected group. The researcher was more interested in the infected group, as it was indicated that the spread of infectious diseases does take place at the interface. The following chapter presents results from the questionnaires and SIR models of disease outbreak dynamics from 2007 to 2016.

CHAPTER 4

THE RESULTS OF THE STUDY

4.1 INTRODUCTION

Mahikeng is situated on the dry western region of South Africa in the North West province. This is the home of extensive cattle herds found on big farms and vast open lands around the Mahikeng Game Reserve. Major breeds that are found in this area are Brahman, Bonsmara, Simmental and Simbra. Farmers also look after the Kalahari Red and Boerbok goats that are found in large numbers. Poultry is also part of the activities that bring income to the farmers around Mahikeng. Other domestic animals they look after include sheep and donkeys, and cats and dogs are also found in their homesteads.

The role of wildlife in the transmission of these zoonotic diseases remains a challenge. The researcher used a questionnaire and susceptible-infected-recovered (SIR) epidemiological models for brucellosis, tuberculosis and rabies to gather information. The formulas in SIR models are defined (Owen-Smith, 2007). The qualitative and quantitative research methods were both used in this study. The quantitative approach allowed the researcher to quantify the problem using numerical data. In the quantitative approach, computation and system analysis were done. In the qualitative paradigm, categorical data was used to understand and interpret social interactions of wildlife, domestic livestock and humans.

4.2 QUESTIONNAIRE RESULTS

4.2.1 Results from the Mahikeng Veterinary Department

The study revealed that there were approximately 50 communal farmers and 20 commercial farmers around the boundaries of the Mahikeng Game Reserve (5 km radius). Outside the boundary, there were approximately 10 communal dip tanks. Communal extensive farmers were those who attended most of the Farmers’ Days, of which the attendance ranged from 40 to 60% and their ages were in the range of 51-70 years.

4.2.2 Analysis of presentations on rabies, tuberculosis and brucellosis by the Veterinary Department of Mahikeng

The Veterinary Department of Mahikeng noted that they impart knowledge about these transmissible diseases to farmers. They move around from one district to another during the year. The results are displayed in table 4.1 below.

Table 4.1: Presentation analysis of rabies, tuberculosis and brucellosis

Disease	**Regularly**	**Once a year**	**Never**
Tuberculosis			X
Brucellosis	X		
Rabies	X		

4.2.3 Signs and symptoms of brucellosis, rabies and tuberculosis reported to the Veterinary Department of Mahikeng

The State Veterinary Department noted some of the signs and symptoms of rabies, tuberculosis and brucellosis that communal and commercial farmers reported to them. These signs and symptoms are tabulated below.

Table 4.2: Clinical signs and symptoms reported to the Veterinary Department of Mahikeng

Brucellosis	**Rabies**	**Tuberculosis**
Abortions	Foaming at the mouth	Weakness
Hygromas	Disorientation, incoordination and staggering	Lethargy
Weak calves'	Loss of appetite	
	Weakness	
	Sudden death	

4.3 OVERVIEW OF THE VETERINARY DEPARTMENT OF MAHIKENG ON RABIES, BRUCELLOSIS AND TUBERCULOSIS

The Veterinary Department of Mahikeng noted that the community was aware of rabies, tuberculosis and brucellosis. Emergency stock of drugs and supplies were available for rabies only. The department had a district plan for outbreak preparedness for and responses to these three zoonotic diseases, and the Veterinary Department of Mahikeng had a budget set aside for outbreaks of these diseases. They conducted mandatory regular surveillance for tuberculosis for dairy farms only every two years, and for brucellosis for commercial farmers only every two months. The department was aware of the risk factors surrounding these transmissible diseases and they had an action plan targeted at eradicating or eliminating these diseases. The personnel at the State Veterinary Department of Mahikeng have been trained in disease surveillance.

4.4 RESULTS FROM QUESTIONNAIRE SURVEYS

Farmers outside the radius of 5 km from the Mahikeng Game Reserve boundary were selected randomly and interviewed. Pretested questionnaires were given to the respondents to answer both closed- and open-ended questions on different aspects of zoonotic diseases (rabies, tuberculosis and brucellosis). Aspects included awareness, knowledge, signs and symptoms, as well as the community's practice and attitude towards tuberculosis, brucellosis and rabies. The data about independent variables like education, age, gender and livestock ownership was collected using structured schedules and scales. Out of 35 questionnaires handed out, only 30 questionnaires were returned. All the percentages were calculated by finding the total number of farmers with the same response, regardless of gender, divided by 30 and multiplied by 100.

4.4.1 Age distribution of respondents

The questionnaire requested farmers to place their age in different categories given. Categories given were 18-49, 50-75 and 76 and above. The results indicated that middle-aged farmers (50-75years) constituted the highest proportion of respondents, and elderly farmers (76+ years) the least.

The results are shown in figure 4.1 below.

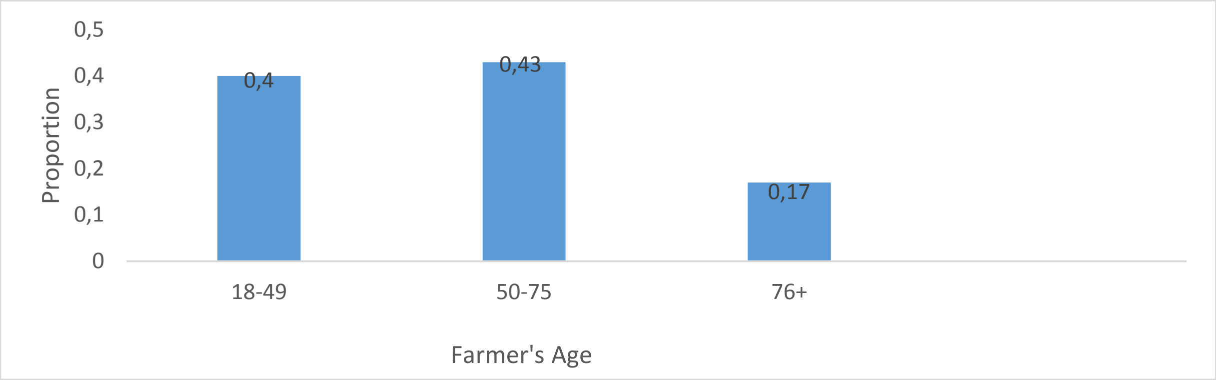


Figure 4.1: Proportional distribution of respondent age classes

Out of 30 respondents, almost 57% were female farmers and 43% were male farmers. Sixty percent of the respondents had qualifications from primary to higher secondary level, and 27% had a highest qualification at primary level.

4.4.2 Livestock ownership

The researcher wanted to find out what types of animals the farmers had. Farmers had to select the animals that they owned.

The number of farmers and the animals that they owned are listed in table 4.3 below.

Table 4.3: Livestock ownership

Livestock ownership	Number of farmers
Sheep	11
Cattle	26
Goats	11
Pigs/Swine	5
Dogs	20
Donkeys	10

According to the results above, some farmers owned more than two types of animals. Sixty percent of the respondents sold animals over the previous 12 months. The buyers included fellow villagers, abattoirs and Indian business people.

4.4.3 Livestock replacement

The farmers stated that they bought animals from other farms for replacement or breeding purposes and some depended more on their animals. The results are shown in the table 4.4 below. Livestock were replaced for breeding purposes and provision of food and non-food items to the people. Food items included meat and milk for human consumption and non-food items include animal skin for purposes of exporting.

Table 4.4: Livestock replacement for breeding purposes and provision of food and non-food items to the people

Own farm	50%
Outside and own farm	50%

A total of 53% of the respondents stated that the pens or premises of their livestock were clean and disinfected at all times and 46% of the respondents noted that their pens or were not clean and disinfected.

4.4.4 Awareness of zoonotic diseases

Twenty-three percent of the farmers interviewed had never heard of rabies before (figure 4.2) and 77% knew about rabies. The respondents obtained their knowledge of rabies for the first time from the radio, television, school, the government's community meeting, newspapers, local community, parents, neighbours or friends. The results suggested that 37% of the farmers were aware of brucellosis and 63% had never heard of it. Fifty-seven percent of the respondents noted that they were aware of tuberculosis and 43% had never heard of it. This information is displayed in figure 4.2 below.

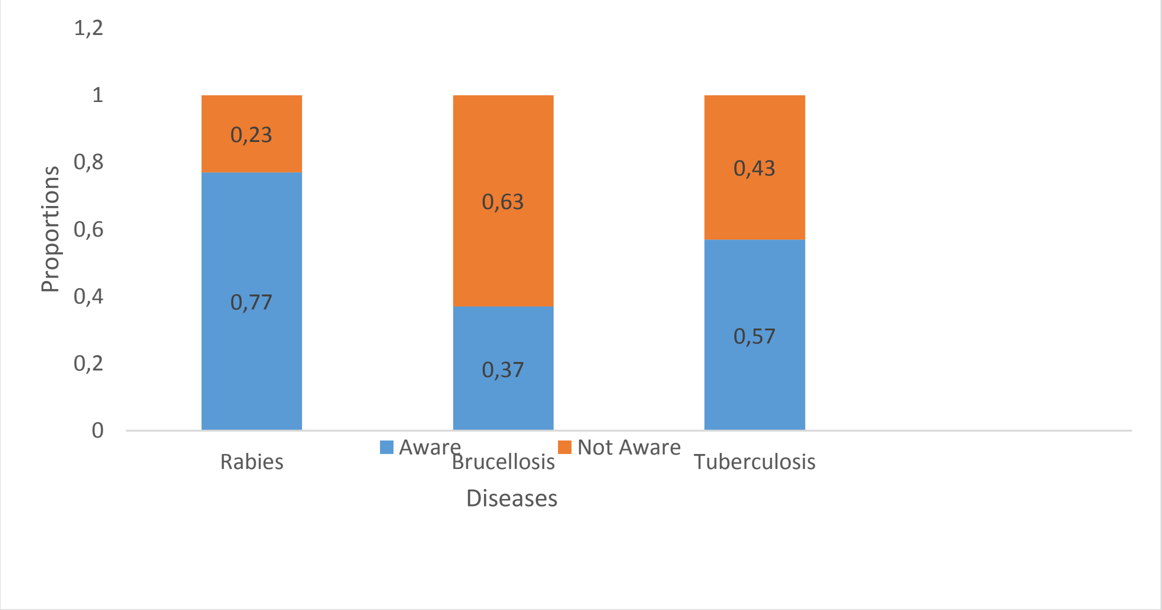


Figure 4.2: Proportional distribution of respondent awareness of zoonotic diseases (rabies being the highest followed by tuberculosis and brucellosis being the least)

4.5 RABIES

Sixty percent of the respondents did take their dogs for vaccination. According to the study, none of the respondents faced difficulties in handling their own dogs. Almost 79% never heard of any outbreak of rabies and, according to the study, the respondents had no family member who had been exposed to a suspected rabid animal. These percentages in the table below were calculated from the data collected from the questionnaire. Table 4.5 has the detail below.

Table 4.5: Clinical signs and symptoms of rabies

Signs and symptoms	**Percentage %**
Animals	
Madness	46,6
Barking	70
Red eyes	63,3
Abnormal biting	30
Emaciation	3
Loss of appetite	36,6
Death	63,3
Human beings	
Madness	13
Death	33

4.6 BRUCELLOSIS

According to the study, farmers were asked if they had any animal from their livestock that suffered from brucellosis, as well as the gender of the animal. Four farmers (13%) acknowledged that their livestock suffered from brucellosis. Two farmers (7%) indicated that the infected animals were male and five farmers (almost 17%) indicated that they were female. Table 4.6 below shows the percentages calculated from the data on clinical signs and symptoms of brucellosis that farmers knew.

Table 4.6: Clinical signs and symptoms of brucellosis

Signs and symptoms	Percentage %
Animals	
Abortion	70
Emaciation	16,6
Milk drop	53,3
Fever	56,6
Human beings	
Joint paints	16,6
Recurrent fever	20
Vomiting	40
Malaria like	36,6
Emaciation	3,3

4.6.1 Risk factor (use of raw milk)

The use of raw milk was identified as a risk factor for brucellosis (Adesokan et al., 2013). Farmers responded in different ways on how they used raw milk. Out of 30 farmers, 14 indicated that they used raw milk regularly, five indicated more often and nine said that they never used raw milk. The percentages were calculated from the original data or number of farmers, divided by 30 and multiplied by 100. Table 4.7 below gives the detail.

Table 4.7: Raw milk usage

Risk factor	Percentage %
Regularly	46,6
More often	16,6
Never	30

4.7 TUBERCULOSIS

Thirteen percent (four farmers out of 30) of the respondents confirmed that their herd suffered from tuberculosis. Most farmers noted that they had seen some of the signs and symptoms of tuberculosis. Approximately 22 farmers had animals coughing, four found emaciation, 18 saw milk drop, 19 found fever and 20 had animals dying. Signs and symptoms of tuberculosis in human beings: coughing 19 farmers, emaciation one farmer and one farmer indicated adenitis. The table below illustrates the percentages of the farmers calculated from the real data and their responses.

Table 4.8: Clinical signs and symptoms of tuberculosis

Signs and symptoms	Percentage %
Animals	
Coughing	73,3
Emaciation	13,3
Milk drop	60
Fever	63,3
Death	66,7
Human beings	
Coughing	63,3
Emaciation	3,3
Adenitis	3

4.8 RESOURCE SHARING WILDLIFE/DOMESTIC LIVESTOCK/HUMANS

According to the study, almost 70% of the respondents let their livestock graze within the boundaries of the Mahikeng Game Reserve. Twenty-three percent (seven farmers out of 30) of the respondents indicated that their animals drank water from the Molopo River, which runs through the Mahikeng Game Reserve. The respondents said that they used the communal dip tanks around the area. During dry seasons, they moved their animals to surrounding areas in search of food.

4.9 SIR MODELS

SIR models consist of three equations representing the three categories of individuals during an outbreak, where each group feeds into the next (S>I>R) until the entire population attains immunity. The SIR model is used as a building block for other complex models (Owen-Smith, 2007) and serves to project or follow the disease outbreaks. SIR epidemiological models in this study were based on a descriptive desktop study. The State Veterinary Department of Mahikeng provided most of the data, and the figures of animals susceptible, infected and recovered/removed were compiled from the annual reports of the Mahikeng State Veterinary Department from 2007 to 2016. These mathematical models for the spread of zoonotic diseases assume uniform mixing at the wildlife/domestic livestock/human interface (Owen-Smith, 2007), an assumption that might not necessarily hold up because of human interference once infected animals are detected. The data used in each individual zoonotic disease under study come from various surveillance systems. These various surveillance systems may sometimes provide data that are either underreported or delayed, thus introducing the observation error that makes it difficult to reconcile models with data.

The entire population was included in the study and grouped into three distinctive classes according to their epidemiology status. In the study, the researcher assumed a limited population. The researcher adopted the assumption put forward by Pellis, Ball and Trapman (2012) which states that no births or migrations occurred during an outbreak. Individuals may be susceptible (S), infectious (I), and removed or recovered (R) (Pellis et al., 2012). In this study, infected models of multiple levels of mixing were constructed. The animals mix within and between groups at different rates. The independent variable in this study is time, measured in years from 2007 to 2016. The dependent variable identified in the study is the counts of individuals (livestock, wildlife and humans) in each of the groups as a function of time. This can be made a fraction of the total population under study (N) in each of the three classes. Thus:

S (t) = $\frac{S(t)}{N}$ the susceptible fraction of the population.

$I(t) = \frac{I(t)}{N}$ the infected fraction of the population.

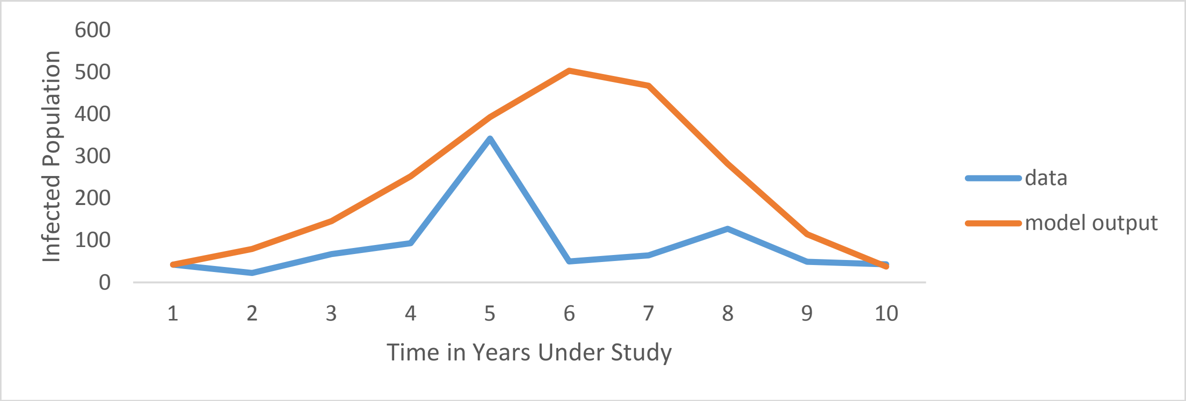
$R(t) = \frac{R(t)}{N}$ the recovered fraction of the population.

S (t) + I (t) + R (t) = N

Data was collected on counts of susceptible, infected and recovered, which are recorded in the annual reports, and the researcher drew infected models with the assistance of the sum of the squared deviation to fit the models with the lowest attained sum of squares, indicating the best model fit to the data and line graphs summarising the susceptible, infected and recovered individuals for brucellosis, tuberculosis and rabies. Transmission rate and recovery rate were also estimated from the real data collected. It seems most counts were done from wildlife and domestic livestock. Information on human beings is underreported from various surveillance systems.

4.9.1 Brucellosis

The infection model for brucellosis and the line graph displaying the susceptible, infected and recovered population for brucellosis are given below. The infection model and the line graph were drawn from the real data counts collected from the annual reports provided by the State Veterinary Department of Mahikeng. Parameter values used to help to improve the fit of the model included Transmission rate (β) and Recovery rate (γ).



Model 1: Infection model for brucellosis in the Mahikeng district derived from the State Veterinary Department (2007-2016)

Parameter values: Transmission rate (β) 0,0007 and Recovery rate (γ) 0,999

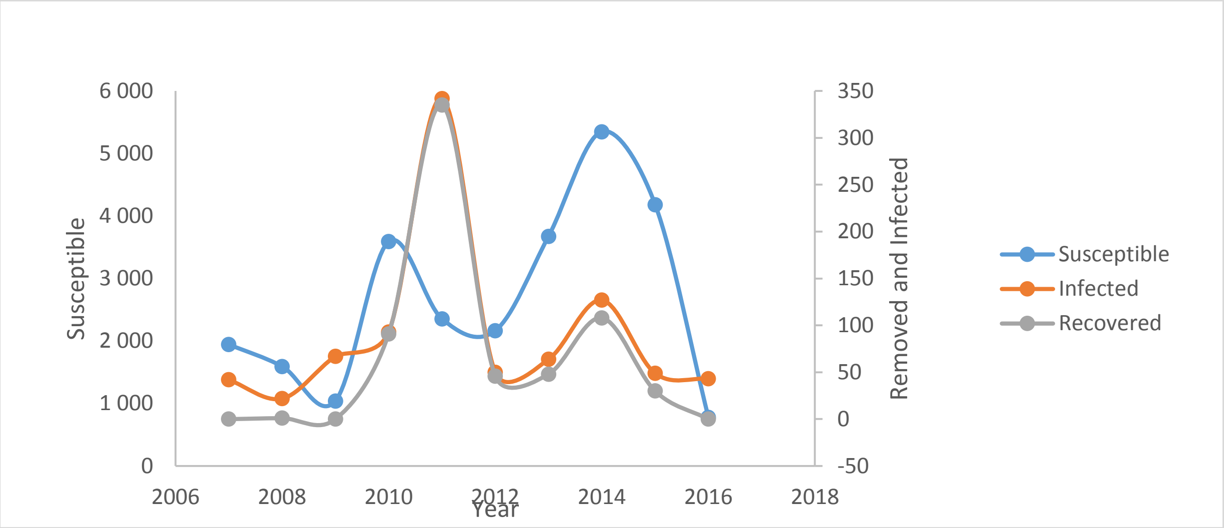
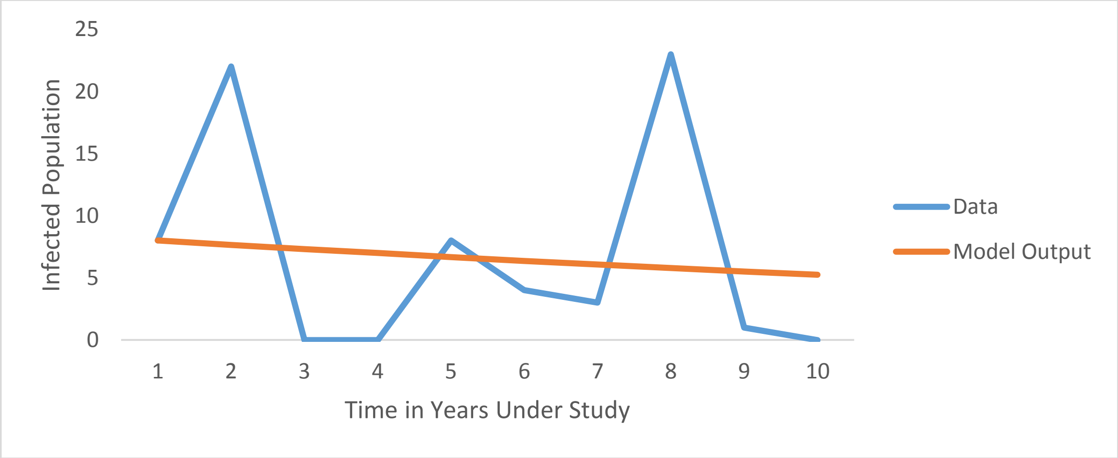


Figure 4.3: Line graph summarising the temporal trends and dynamics of susceptible, infected and recovered individuals for brucellosis in Mahikeng District derived from the State Veterinary Department (2007-2016)

4.9.2 Tuberculosis

The infection model and the line graph below include susceptible, infected and recovered data counts for tuberculosis from 2007 to 2016. Transmission rate (β) and recovery rate (γ) were used to help to improve the fit of the model.



Model 2: Infection model for tuberculosis in the Mahikeng district derived from the State Veterinary Department (2007-2016)

Parameter values: Transmission rate (β) 0,0004 and recovery rate (γ) 0,28

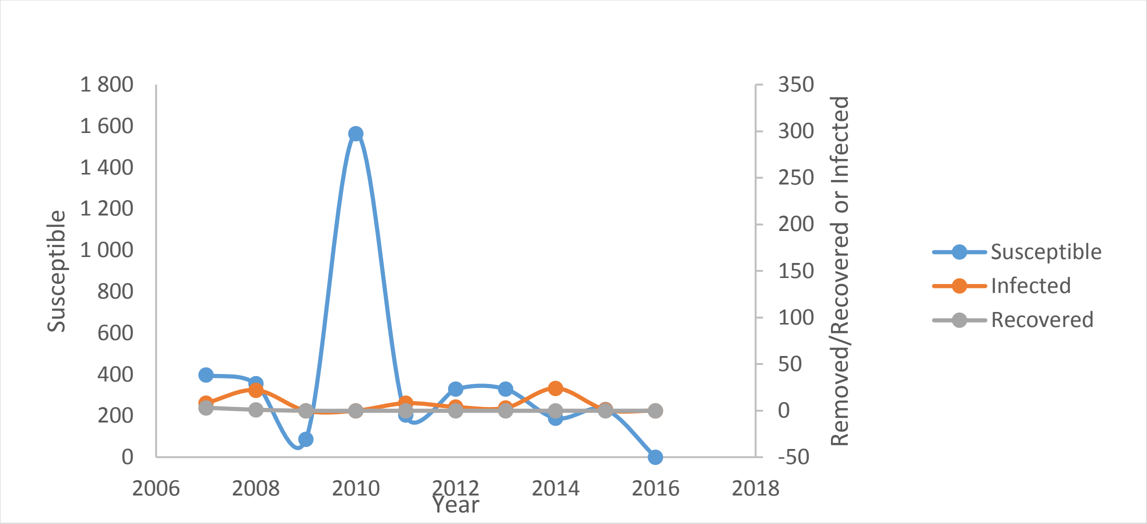


Figure 4.4: Line graph summarising the temporal trends and dynamics of susceptible, infected and recovered individuals for tuberculosis in the Mahikeng district derived from State Veterinary Department (2007-2016)

4.9.3 Rabies

Due to limited data, no infection model was drawn since it is a vaccine-preventable disease. The number of infections recorded was very low and only a line graph was drawn below to summarise the number of susceptible, infected and recovered from 2007 to 2016.

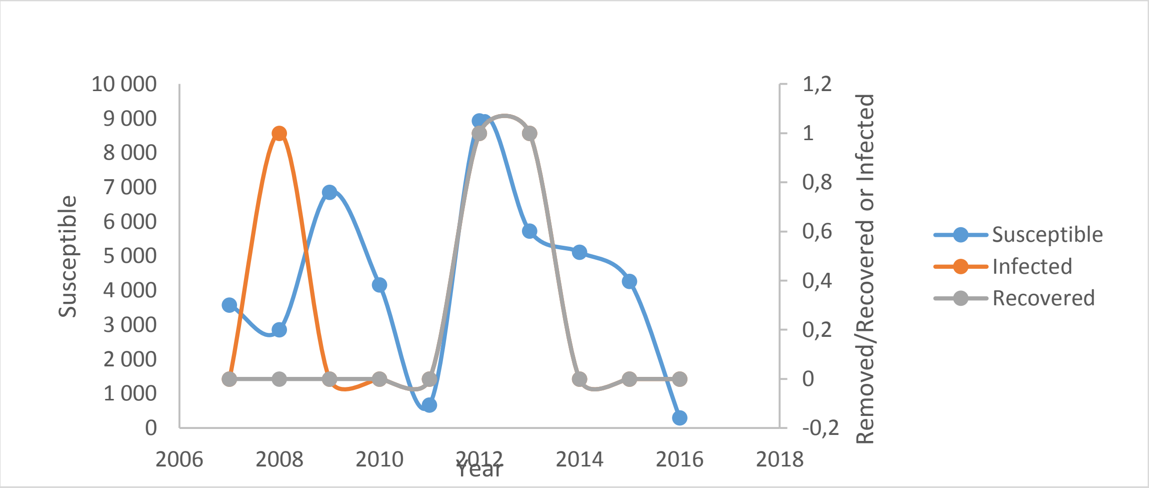


Figure 4.5: Line graph summarising the temporal trends and dynamics of susceptible, infected and recovered individuals for rabies in the Mahikeng district derived from State Veterinary Department (2007-2016)

The above models are just an imitation of reality due to limited data derived from annual reports summarising the changes in frequency of the categories of infected from 2007-2016. This analysis is dealt with in detail in chapter 5. The line graphs summarised the limited data provided by the State Veterinary Department of Mahikeng. Limited data was available, which proves that transmission of these zoonotic diseases under study take place in the domestic livestock/wildlife/human interface.

4.10 TRANSMISSION RATE (Β) AND RECOVERY RATE (Γ)

The transmission rate (β) and recovery rate (γ) were estimated through iteratively tweaking the values to improve the fit. The Solver add-in (Excel 2013) was then used to improve the fit further. Violation of the assumptions of the SIR model includes the following: seasonal births due to breeding behaviour and compensatory reproduction are not included on the SIR assumptions. Some animals are treated and livestock trade is very common. Ever-changing climatic conditions, human interference and environmental variability also affect transmission rates. Homogenous mixing is unrealistic when dealing with the compound nature of animals and human interface. Wild animals have territorial dominance and different social systems. Human behaviour and culture also affect the exposure to wild animals' related zoonotic diseases. Given the above violations, the results are likely to be biased. There are many gaps in our data as seasonal data is not available. Population densities are not constant, as it seems that there are different densities each year due to the violation of assumptions. Transmission rate and recovery rate can only be an estimation.

Transmission rate (β)

Transmission rate is the average number of individuals to which each infectious animal spreads the infectious disease each day. When contact takes place, an infected individual will produce new infected individuals, although not all contact results in infection. The transmission rate was estimated with the help of Solver and sum of squared deviation when trying to improve the fit of the model.

Recovery rate (γ)

Recovery rate (γ) is the rate of transition from the state of being infected to being recovered from disease. It represents a portion of those that are infectious that recover per given time. SIR models assume that recovery from the disease indicates lasting resistance, meaning that the recovered individual cannot be infected again. An estimation of the recovery rate was performed with the assistance of Solver and sum of squared deviation when trying to improve the fit of the model.

The estimated transmission rate and the recovery rate of transmissible diseases under study are tabulated in table 4.9 below.

Table 4.9: Estimated transmission rate (β) and recovery rate (γ)

Disease	**Transmission rate (β)**	**Recovery rate (γ)**
Brucellosis	0,0007	0,999`
Tuberculosis	0,0004	0,28
Rabies	0,0001	0,00001

This chapter presented the results collected from the questionnaire from the Veterinary Department of Mahikeng, commercial and communal farmers. Infected models for each disease were constructed as well as line graphs using Solver add-ins in Microsoft Excel. The following chapter deals with the analysis of these results.

CHAPTER 5
DISCUSSION OF RESULTS

5.1 INTRODUCTION

The study yielded important information that can be used by the animal technicians and the veterinary staff of the Mahikeng Veterinary Department and the Public Health Department in implementing disease control programmes. Homogeneous mixing of livestock, wildlife and humans is unavoidable at the interface, although it is not definite; it is merely a probability that it might take place. If direct or indirect contact takes place, the spread of infectious diseases is facilitated. According to the study, the respondents that were interviewed were the owners of the animals; therefore, the answers to the questions in the questionnaire are reliable and can be considered as a true reflection of how these zoonotic diseases spread at the interface. The information presented below is on how these three zoonotic diseases spread among animals and human beings, and how the responsible authorities are trying to do to reduce the spread of these zoonotic diseases.

According to the Veterinary Department of Mahikeng, rabies is a vaccine-preventable zoonotic disease caused by a rabies virus. It can spread through the saliva of infected animals and get into open wounds or mucous membranes such as the mouth or eyes (WHO, 2020). Bites and scratches play an important role in the transmission of rabies. The WHO is working with “United Against Rabies” so that the nation can eradicate rabies spread by dogs by the year 2030. Rabies is 100% fatal (WHO, 2020). The WHO (2020) notes that each year, more than 29 million people across the world are vaccinated against rabies. Pre- exposure immunisation is also administered to people who work with animals and live rabies. Rabies vaccination programmes are in place and this decreases the incidence of human rabies. Central point vaccination is also carried out. Dogs and cats are brought to the veterinary department for vaccination and their owners pay a set fee for these vaccinations. The amount was not disclosed. People are increasingly educated and informed about rabies prevention and control, as well as being responsible pet owners.

The WHO (2006) also considers immunising people before they visit areas with high numbers of rabies infection. In most cases, children are the most targeted population for pre-exposure immunisation because they do not report bites or scratches when playing with animals. The

WHO is supporting countries as they implement their national rabies elimination programmes. The WHO is regularly updating and giving guidance on rabies, especially on epidemiology, surveillance, diagnostic vaccines, safe and cost-effective immunisation control, and prevention strategies for human and animal rabies. Due to the above measures, the individuals infected with rabies were limited. Infected individuals were recorded in 2008, 2012 and 2013. In 2012 and 2013, no recoveries were recorded, as rabies is a fatal infectious zoonotic disease.

Bovine tuberculosis can be transmitted directly by infected wildlife or domestic animals to uninfected animals or indirectly by ingestion of contaminated material (WHO, 2020). Calves can contract tuberculosis through ingesting colostrum or milk from infected animals. Human beings can be infected by ingesting raw milk or any dairy products unprocessed from infected cows. The WHO (2020) states that human beings can also contract tuberculosis through contact with infected cow tissues at abattoirs or butcheries. The course of bovine tuberculosis is slow and it takes months or years to reach the fatal stage. Infected animals can transmit bovine tuberculosis to the herd before any clinical signs appear. The Veterinary Department of Mahikeng argued that undetected infected domestic animals are the main spreader of bovine tuberculosis.

Brucellosis is caused by the Brucella bacteria. Brucellosis infects people in several ways, including infection from a contaminated environment, occupational exposure and food-borne transmission.

Infected animals that are close to places that people inhabit can spread brucellosis. People or other animals may inhale contaminated dust or dried dung, contact with contaminated skin can take place, and aborted animals and rainwater flowing from contaminated environments can pollute water sources. The WHO (2020) states that Brucella spp. survives for longer in water, dust, dung, aborted foetuses, soil, slurry, dairy products and meat.

Farm workers who work with pigs, sheep, cattle and goats are at risk of contracting brucellosis from animals or contaminated environments. Untreated milk and its products are the main sources of infection in most communities (WHO, 2020).

5.2 EFFECTS OF THE CLIMATE ON THE TRANSMISSION OF ZOONOTIC DISEASES

The compound nature of the interface between humans and animals is mostly influenced by climate change, anthropogenic factors and natural factors (Naicker, 2011). Hiko et al. (2016) state that climatic changes produce new ecological niches for vectors, which can change temporal and spatial distribution of zoonotic diseases. SIR (infected) models produced in this study aims to map the risk of zoonotic diseases (brucellosis and tuberculosis) and predict future outbreaks so that people at risk are warned and for the animal health department to prepare for the outbreak. Forecasting the vector-borne disease can be a tricky endeavour due to ever-changing climatic conditions. Changes in climatic conditions have an impact on how vectors survive and reproduce. It also affects their biting rate, the rate of incubation for pathogens and the distribution of pathogens.

The survival and reproduction of vectors, pathogens and hosts each require a specific range of climatic conditions. Rainfall received influences transportation and the spread of zoonotic diseases and temperature impacts on their growth and survival. Climatic changes are the main cause of changes in trends and dynamics of zoonotic diseases. This is shown by the fluctuating numbers of susceptible and infected groups in the line graphs and infected models that were constructed during this study. We have other climatic conditions such as sea level elevation and daylight duration that are also important. Zake (2020) notes a number of years during which the North West province of South Africa experienced drought. According to Zake (2020), the following seasons 2002/2003, 2004/2005, 2006/2007, 2012 /2013 experienced dry to extremely dry conditions, with the 2015/2016 season having been the driest. Precipitation received in an area and temperature play a pivotal role in determining vector-borne disease transmissions.

Extreme temperatures increase the mortality rates of some pathogens; hence, it can decrease the number of infected groups as shown by brucellosis and tuberculosis in 2012/2013 and 2015/2016. Wu, Yongmei, Sen, Lifan and Bing (2016) state that the amount of sunshine received affects the disease host through the synergistic function. A rise in temperature forces insects in low areas to move to high areas and this creates disease geographical expansion or the shift of diseases. Disease hosts will move to favourable temperature ranges due to the continuous rise in global warming. Xu and Rutledge (2016) note that the lower ambient temperature can lengthen the extrinsic incubation period, resulting in reduced transmission of diseases. Drought reduces the number and usability of breeding sites for certain hosts like mosquitos. This in turn reduces the population of vectors and the spread of diseases. On the other hand, rainfall increases the transmission of vector-borne diseases. Hoshen and Morse (2004) state that some mosquito larvae develop at a faster rate with increased rainfall and temperatures. Abrupt rainfall after a prolonged drought usually causes an increase in pathogens, which leads to an outbreak of a disease.

Droughts are associated with wind and dust storms, which transport pathogens of airborne diseases; for example, bovine tuberculosis from endemic regions to other regions. This is illustrated on the infected model for tuberculosis in 2015/2016, as only one animal was recorded in the infected group in 2015 and none was recorded in 2016. Reid (2000) states that wind reduces the biting opportunities for other vectors like mosquitos but extend their flight distance.

5.3 ANALYSIS OF RISK FACTORS AT THE INTERFACE

5.3.1 Animal movement

Cattle owned by different communal farmers graze together as a single herd, creating a single epidemiological unit and this increases the risk of spreading diseases (Diez & Coelho, 2013). Farmers argued that they move their herds to other grazing lands during the dry season in search of food. There is no bio-security and, in most cases, the extensive communal farmers cannot afford to buy supplementary feed. Mixing of cattle at the grazing lands and a lack of control when it comes to movement lead to the epidemiology of contagious diseases such as brucellosis, rabies and tuberculosis because free movement and extensive mixing of herds facilitates the spread of bovine brucellosis (Matope, Bhebhe, Muma, Lun & Skjerve, 2010). Extensive communal farmers have limited land for their animals due to pressure on land as a resource. Land reform should target extensive communal farmers by giving them more land as they provide food to their families.

Farmers actively trade in livestock. At the trading centres, there is direct and indirect contact within humans, domestic livestock and wildlife. Livestock markets increase the movement of livestock and contact between the animals and herdsmen. Fevre et al. (2006) state that the management and control of diseases can be challenging due to trading markets. Sometimes, trading occurs among farmers and there is a high possibility of trading infected animals since some signs and symptoms take long to appear, especially bovine tuberculosis. According to the study, the farmers trade in cattle for meat or for replacement purposes. Diez and Coelho (2013) note that cattle replacement from other farms is a risk factor for the introduction and spread of brucellosis.

According to the State Veterinary Department of Mahikeng, there is +/- 10 dip tanks around the area under study. Research findings suggest that communal dip tanks are used for most domestic animals. There is free interaction at the dip tanks and no fence for bio-security and herdsmen separate the livestock when they are herded to different kraals at night. Some researchers believe that some commercial farmers are very strict when it comes to bio-security. In this study, it was somewhat different. One of the farmers uses grazing land within the Mahikeng Game Reserve, which means that cattle and buffalo graze together in the reserve. Nyirenda et al. (2015) conducted a study on the prevalence of Brucella abortus in buffaloes in the Mafikeng Game Reserve. According to the study, out of 365 buffaloes, 83 tested positive for Brucella abortus, thus a prevalence of 0, 23%. The percentage might seem to be low but actually Brucella abortus should not be present at all in game reserves. This can have an economic impact on the market trade of these buffaloes. Wildlife can be infected by domestic livestock and thus become a reservoir of these transmissible diseases. According to Crawford, Huber and Adam (1990), bigger herds without proper bio-security and separation facilitate the spread of zoonoses at the interface. This increases direct and indirect contact between animals and humans at the interface. The State Veterinary of Mahikeng, therefore, must implement better bio-security measures and management of movement of livestock or wildlife.

The study did not demonstrate the importance of movement permits. Farmers must move animals with movement permits or with free declaration certificates on brucellosis, rabies and tuberculosis. The issue of free declaration certificates should be encouraged even when herds of cattle are moved to communal dip tanks. This movement is not for financial reasons, but for control of zoonosis at the interface. Proximity of infected animals to each other, a lack of bio-security and a lack of knowledge about these three transmissible diseases lead to the transmission of diseases to non-infected herds (Hesterberg et al., 2008).

5.3.2 Farmers' knowledge on rabies, tuberculosis and brucellosis

According to the study, 63% of the farmers had never heard of brucellosis, 23% had never heard of rabies and 43% had never heard of tuberculosis. This is attributed to the low attendance by farmers of Farmers' Days. According to the State Veterinary of Mahikeng, attendance ranged from 40 to 60%, consisting mostly of communal farmers. A lack of knowledge, sound practices, prevention strategies and management can cause the transmission of contagious diseases within the population. Musallam et al. (2015) argue that communities without knowledge of zoonoses are more likely to be exposed than those with knowledge.

Farmers who are educated or received training in zoonoses are more prone to take preventative measures to safeguard their livestock than those who are not trained or not aware of the diseases. Therefore, knowledge is low and, combined with poor herd bio-security practices, this contributes to the prevalence of these diseases. Furthermore, farmers might be motivated by low livestock prices, while these low prices actually indicate that these animals are contaminated. Participation of communal and commercial farmers on Farmers' Days can be used to reduce the spread of diseases. On Farmers' Days, the animal technicians should focus more on all zoonotic diseases in their presentations because of the negative impact of these diseases on the economy. Disease control activities must educate the farmers about different zoonoses at the interface. According to the results from the questionnaire, information on brucellosis and rabies is presented regularly to farmers, but tuberculosis was never presented.

All infectious transmissible diseases have the same economic impact and every disease must be presented to farmers in order to educate them. Knowledge, practice and attitude by farmers pertaining to rabies, tuberculosis and brucellosis are important for controlling and eradicating zoonosis at the wildlife/ domestic livestock /human interface (Adesokan et al., 2013). Farmers need to cooperate with the State Veterinary activities on control and management of rabies, tuberculosis and brucellosis.

Control strategies should be implemented at the livestock/ wildlife/ human interface (Dallaz-Pozza, Martini, Marangon, Manca & Ricci, 1997: Smits, 2013). The contents of the State Veterinary Department's presentations must include early warning signs and symptoms of diseases and precautionary measures that farmers must exercise. When signs and symptoms are reported to the department of veterinary services, it is the duty of the veterinarian to investigate and diagnose the type of disease. This will reduce the spread of diseases at the interface, as farmers will practice control measures such as bio-security, isolation of suspected infected animals, vaccination, branding and good record keeping. Early detection reduces the spread of disease and helps in the reduction of losses. If no bio-security measures are in place, farmers struggle to identify animals that are healthy and the ones that are worst sick. Animal identification and vaccination are of importance in animal management. Branding must also be considered a good management practice for animals that tested positive as branding of positive animals will discourage both farmers from keeping infected animals and potential buyers from buying infected animals. Educating farmers will assist them in decision-making on what to do with positive animals and vaccination.

Equipping the farmers with knowledge also protects their workers. The Human Health Department must make use of the State Veterinary Services in order to identify early warning on zoonotic diseases. Reading materials in all languages (English, Tshivenda, isiZulu, isiXhosa, Xitsonga, isiNdebele, Sepedi, Sesotho, siSwati, Afrikaans and Setswana) on rabies, tuberculosis and brucellosis must be made available in community libraries to educate the community. Educating the farmers will make them aware of crucial times in the outbreak of epidemiology of the diseases and ensure that they can implement control measures. A lack of knowledge among farmers provides a false sense of security. In most cases, the farmers who are ignorant about disease transmissions do not bother to know the status of herds of animals that belong to other farmers. Community participation works very well in disease control.

Surveillance and expert opinion are important for the determination of the source of infection. Animals that test positive can be separated and removed from the herd. According to the results, extensive communal farmers are excluded from mandatory regular surveillance for tuberculosis and brucellosis. Tuberculosis is only for dairy farms every two years and brucellosis only for commercial farmers every two months. Mandatory regular surveillance should target all commercial and communal farmers.

5.4 USE OF RAW MILK

About 63% of the farmers were using raw milk that is milked by hand. Raw milk consumption is a high-risk factor for human infection (McDermott & Arimi, 2002). Consumption of raw milk may be due to consumer groups that emphasise the use of natural products that are not processed. According to a study conducted by Makita et al. (2011) on the prevalence of bovine brucellosis and risk factors in cattle from Kampala and surrounding areas in Uganda, smallholder farmers were selling raw milk to urban dwellers, which poses a high risk for infection of bovine brucellosis.

Claeys et al. (2013) state that some traditionalists believe that raw milk is more nutritious than pasteurised milk. The importance of pasteurisation needs to be discussed with the community in order to curb the spread of diseases.

5.5 STOCK DRUGS AND SUPPLIES

The results indicated that emergency stock of drugs and supplies is only available for rabies; hence, few infections were recorded in the period under study. Emergency stock of drug and supplies must be made available for all zoonotic diseases at all times in order to minimise the spread of diseases.

5.6 MODELING OF SUSCEPTIBLE-INFECTED-RECOVERED

The key objective of this study was to understand the dynamics of the diseases through the modelling approach, in order to reduce zoonosis transmission. Variables used in this study are presented in the table below.

Table 5.1: Variables used in the models

Variable	Description
S	The Susceptible fraction of a population
I	The Infected fraction of a population
R	The Recovered fraction of a population
N	Total number of animals (N=S+I+R)

5.6.1 Critical analysis of the assumptions of SIR model

Infectious diseases are the main cause of morbidity and mortality across the globe. Zoonosis affects agriculture production and wildlife management. The public and the animal health sector depend on surveillance and expert opinion to control the spread of zoonotic disease outbreaks. Daughton, Generous, Priedhorsky and Deshpande (2017) note that, in many situations globally, surveillance and expert opinion are unavailable. Modelling comes in to fill the gaps in the decision-making with the animal and public health departments using available data so that quantitative estimates of outbreaks can be made. Although collaboration between the modelling community and the public health policy community is important in reducing the spread of infectious diseases, such collaboration is rare (Daughton et al., 2017). This hinders the development of models that meet the need of the public health community. The spread of infectious diseases, which includes wild animals, is very complex and non-linear (Alexander *et al*., 2012), and brought about a number of problems in the modelling of zoonotic diseases. Some of the problems are the lack of pathogen systems, empirical characterisation of wildlife host species, the ever-dynamic size of the population and the density of wildlife hosts.

5.6.1.1 Population size N is constant and large

An SIR model excludes natural births and mortalities, differences in susceptibility and co-infections. In a standard incidence, disease-induced deaths reduce the size of the population N. Alexander et al. (2012) state that population thresholds are difficult to apply, especially in wildlife populations. Population demographic heterogeneity differs from one specie to another. We have seasonal births due to different breeding behaviour and compensatory reproduction that is not included in SIR assumptions. Zoonotic diseases can affect the population dynamics in wildlife systems. Eradication of infectious diseases can be impossible given such a situation. Even control may not work from such a population threshold. Allen et al. (2012) note that due to a lack of sufficient data, threshold populations in wildlife are more difficult to assess than humans and domestic animals. This leads to failed outbreaks that are not observed (Allen at al., 2012).

5.6.1.2 Homogenous mixing and contacts are therefore random

The above assumption is problematic, especially when including wildlife hosts. Wild animals have territoriality dominance and different social systems. Wildlife hosts have a complex spatial and social structuring. Behaviour according to gender or sickness can hinder the transmission of zoonoses at an interface. Contact between animals depend more on spatial proximity and habitat heterogeneity. Daughton et al. (2017) state that different environments and direct human interference are the main factors that hinder the successful spread of zoonotic pathogens. Direct and indirect contacts at the human/wildlife/domestic livestock interface sometimes amplify or dilute the transmission of pathogens (Schmidt & Ostfet, 2001; Keesing et al., 2006; Keesing et al., 2010). This situation leads to the expansion or contraction of the spread of zoonoses. Control activities like culling and vaccination may have unexpected negative effects on the host population and pathogen transmission dynamics. Culling can disrupt social groups, which increases dispersal rates and infected animals can be dispersed.

Human behaviour and culture may affect the exposure to zoonotic infectious diseases related to wild animals (Alexander & McNutt, 2010). The way in which humans come into contact with pathogens from wild animals' meat will differ from one community to another or from one family to another because different communities prefer different species and the way they process and distribute animal meat and products differ (Alexander et al., 2012). Due to these traditional beliefs, human exposure to zoonotic pathogens from the wildlife reservoirs is relatively rare and it becomes difficult to model a structure. It was found that the spread of zoonotic pathogens among wildlife and humans can be very complex and varies much across systems. However, this hinders the modelling efforts on the transmission dynamics in human hosts' reservoir. The complexity of the interaction between humans and wildlife at the interface creates a barrier to the understanding of the concept of spillover dynamics. This brings about difficulties in controlling the spread of potential zoonotic disease outbreaks. Alexander et al. (2012) note that homogeneous mixing at the interface is problematic due to complex behaviour and dependence among wildlife species. This can affect results negatively. Levin et al. (1997) further state that any model, whether good or not, is just an imitation of reality due to limitations on the assumptions.

Furthermore, it was found that in the emerging of zoonoses, the role played by domestic animals is generally more understood than the role played by wild animals. The research on the emerging zoonoses in domestic livestock is controllable, yet collecting important data for wildlife can be very difficult.

5.6.2 Differential equations

The basic epizootic SIR model's main objective is to partition the population according to the state of disease (susceptible, infected and recovered). These partitions are joined by differential equations. Alexander et al. (2012) state that SIR models become difficult to work with and to use in solving differential equations for complex infectious disease systems which involve multiple wildlife species. Allen et al. (2012) note that, according to the model, the susceptible population becomes infected with the pathogen, which depends on the rate of contact (c) per unit of time, while the infectious animal is within the population. In normal situations, contact may not be definite due to the limitations discussed on critical analysis of assumptions. Contact is just a probability (q) that it might occur between infectious individual and susceptible population (Allen et al., 2012). The SIR model assumes that the spread of zoonotic diseases takes place due to homogeneous mixing within the total population N. N =S+I+R. One infected individual infects the susceptible population $\frac{S}{N}$ per unit of time. Allen et al. (2012) came up with an equation of the rate of infections within the whole population, which is

$cq\ (\frac{S}{N})\ 1= \frac{\beta SI}{N}$

Where:

cq = the product of the rate of contact and the probability of contact.

I = the density or number of susceptible hosts who are capable of transmitting diseases (Bolzoni & De Leo, 2000).

S = the density or number of susceptible hosts who are at risk of being infected (Bolzoni & De Leo, 2000).

N = the total population size.

β = the transmission rate.

βSI = the product of the transmission rate and susceptible hosts.

The above is true if it is a standard incidence or frequency-dependent incidence, while the SIR model assumed that contact is definite. The SIR model does not consider the issue of probability, which is governed by many aspects of the animals’ behaviour and environmental variability.

If modelling depends on the density of the population and not the size of the population, the contacts per unit of time depend on population density c (N) (Lacey & Kaya, 2000). The rate becomes cq SI –βSI. Allen et al. (2012) named it density dependent incidence or mass action incidence. Estimating the incidence rate becomes very difficult. When following the standard assumptions of the SIR model and ignoring births and deaths not caused by the diseases, the recovery rate (γ) does occur if there is an exponential distribution of infectious periods. Daughton et al. (2017) state that larger values of the recovery rate indicate shorter infectious times and result in small outbreaks. If a disease has a short infectious period, it infects fewer individuals because the zoonotic disease is infectious for a shorter period of time. Data about such cases for modelling can be very limited. Allen et al. (2012) state that an SIR model resembles a system of differential equations for a single outbreak over time. Allen et al. (2012) suggest the following equations.

$\frac{ds}{dt}$ = - β $\frac{S}{N}$ 1

$\frac{dI}{dt}$ =β $\frac{S}{N}$ 1 – γ1 –α1 =1 (β $\frac{S}{N}$ – γ – α)

$\frac{dR}{dt}$ =γ1 Adopted from Allen et al. (2012).

Where:

I = the density or number of susceptible hosts who are capable of transmitting diseases (Bolzoni & De Leo, 2000).

S = the density or number of susceptible hosts who are at risk of being infected (Bolzoni & De Leo, 2000).

β = the transmission rate.

ν = the rate of recovery of infected hosts.

α = the number of individuals that die from a disease.

ds = the density of susceptible host.

dI = the density of the infected host.

dt = the density of animals per unit of time (Owen-Smith, 2007).

dR= the density of recovered hosts.

The basic reproduction number (R_o) is the threshold for a disease outbreak (Allen et al., 2012). It represents the individuals that contracted the disease through direct or indirect contact with an infected individual during its infectious period (Alexander, et al. 2012). If $R_o > 1$, it means there is an outbreak of an infectious disease and the number of infectious animals increases. When the rate of transmission (β) is high or there is a prolonged infectious time, R_o increases, which will end up in an outbreak. If mass action incidence happens, R_o is

$$\mathrm{Ro} = \frac{\beta So}{\gamma+\alpha} \approx \frac{\beta N}{\gamma+\alpha}$$

Adapted from Allen et al., 2012

In the above equation, animals that die from diseases are also considered and the probability of mass action incidence is incorporated, which differs from the SIR model.

The contact rate depends on the size or density of the total population ($\beta=\beta$ (N)) (Allen et al., 2012). Allen et al. (2012) further argue that in a standard model with a standard incidence, the number of deaths caused by the disease and $R_o > 1$. All animals become extinct and the whole population will die N (t) 0; but in a mass action incidence, the total population is reduced. If there are no disease mortalities, the population size remains constant.

According to Allen et al. (2012), contacts remain the same in the standard incidence in any size or density of the population. Contacts decrease and the population density decreases in a mass action incidence. It was observed that in limited systems, with the availability of data, standard or mass action incidence provides meaningful fits to the model (Allen et al., 2012). Herd immunity is also of importance as it determines the proportion (p) of the susceptible population that must be removed or vaccinated to curb the outbreak. Allen et al. (2012) state that the proportion of herd immunity can be calculated by R_o (1-p) <1, which leads to

$p > 1 - \frac{1}{Ro}$ Allen et al. (2012).

If a minimum proportion is vaccinated for herd immunity, the equation becomes

$p = 1 - \frac{1}{\mathrm{Ro}}$.

When we follow the assumption of homogenous mixing of the population, R_o is present in the above formula and the limitations in p also apply to R_o. This only takes place on a vast population size with the assumption that all individuals are first found in the susceptible group. Allen et al. (2012) came up with the above equations in an attempt to cover the gaps that existed in the SIR model. According to Allen et al. (2012), the continuous time in the SIR model gave rise to new forms of modelling like the discrete-time and continuous-time, deterministic and stochastic SIR models. The stochastic SIR or SIS model includes the changes in the environment due to recovery, transmission and deaths caused by diseases. It can also be a way of predicting an outbreak possibility, distribution levels of the zoonosis and the duration of the outbreak relating to the limiting stationary or quasi-stationary probability distribution.

5.7 ANALYSIS OF THE INFECTED MODELS AND THE LINE GRAPHS

The models are characterised by a fluctuation in the number of infected animals, while line graphs display the fluctuating numbers in susceptible, infected and recovered animals, which are discussed below.

5.7.1 Susceptible population (t) (brucellosis, tuberculosis and rabies)

The susceptible population in the line graphs for rabies, brucellosis and tuberculosis fluctuated throughout the decade. The highest susceptible population for brucellosis was recorded in 2014, tuberculosis in 2010 and rabies in 2012. Temporal increases are due to new births in the susceptible population, animal replacement from other farms, trade of livestock and wildlife, vaccination programmes that were being implemented within that period of ten years; and decreases may be due to deaths by natural cause or diseases. The lowest numbers in the susceptible population for brucellosis and rabies were recorded in 2016 and, for tuberculosis, nothing was recorded in 2016. Owen-Smith (2007) assumes a constant population size for modelling purposes, while under natural conditions, births and deaths do occur and can never be avoided in a population.

Imparting knowledge to farmers about rabies, tuberculosis and brucellosis plays a pivotal role in driving fluctuations in the susceptible population. During the decade under study, the susceptible population sometimes decreased, which may be due to early detection of the disease by the animal health department. Early detection also reduces infections. The SIR model assumption supports homogeneous mixing, which is unavoidable at the interface and this promotes the spread of diseases throughout the population. Indirect or direct contact must take place for the spread of infectious diseases to take place.

A high contact rate promotes the spread of the diseases. If the contact rate decreases, the infected population also decreases and the spread of the diseases fades out. Individuals from the susceptible population enter the infected class after contracting the disease in the susceptible class.

5.7.2 Infected (t) (brucellosis and tuberculosis)

The infected population for brucellosis and tuberculosis fluctuated until 2016. The rise in the infected population can be attributed to low vaccination rates, high levels of illiteracy, uncontrolled interface and unreported herd immunity level. When the contact rate increases, the number of infected individuals also rises sharply. The training in disease surveillance and early detection of the disease by the veterinary doctors is important in reducing the number of infected individuals. This facilitates the decrease in the infected population. If regulation 20 of the Animal Disease Act 35 of 1984 is followed, the infective individuals would be reduced. If a movement permit is only granted to the animals that test negative, the movement of infected individuals is prevented. If the contact rate is high, the rate of infection of the disease will also be high. Individuals from the infected class leave this group when they are cured and join the recovered class, or are removed after death, which then adds up to the removed population.

5.7.3 Infected (t) rabies

There are very few infections with rabies because of the low contact rate and the use of vaccines, since it is a vaccine-preventable zoonotic disease. The veterinary department stated that they kept emergency stock of drugs for rabies. Early detection of the disease and early provision of these drugs reduce the infected class. Vaccination and imparting knowledge to the farmers play a pivotal role in the reduction of infections. Kermack and McKendrick (1972) argue that culling can also be considered to reduce infective individuals. However, Owen-Smith (2007) is of the opinion that culling can be ineffective when it comes to some diseases. In the current researcher’s opinion, culling can be effective when it comes to rabies, because it reduces the spread of rabies by separating the infected population from the susceptible population. The animal health department sets aside certain dates to vaccinate animals against rabies as vaccination plays a pivotal role in the reduction of infected individuals. From the findings of this study it was revealed that the infected individuals with rabies leave the infective class and join the removed class.

5.7.4 Recovered (t)

Brucellosis

The number of recovered individuals rose sharply from 2010 to 2014 and then decreased in 2016. The veterinary department noted that they have a mandatory regular surveillance for brucellosis for commercial farmers every two months. It is therefore clear that the commercial farmers are well taken care of when it comes to brucellosis, and communal farmers are excluded. It can be concluded that 63% of farmers who are not aware of brucellosis constitute mostly communal farmers who are not included in regular mandatory surveillance. Early detection, vaccination and imparting knowledge to farmers increase the recovery class.

Tuberculosis

Recovered individuals were recorded in 2007 and 2008. In other years, no recoveries were recorded. Bovine tuberculosis can be transmitted to other animals before the signs and symptoms are detected in an infected individual. The course of bovine tuberculosis is slow and it takes years or months to reach the fatal stage. The infected animal could die before the infectious disease is detected. The veterinary department states that for tuberculosis, there is mandatory regular surveillance for dairy farms every two years and, again, the communal farmers are excluded.

5.8 ESTIMATED TRANSMISSION RATE (Β) AND RECOVERY RATE (Γ)

The estimated transmission rate and recovery rate vary from one year to the next, as each year has its own susceptible, infected and recovery rates. Fluctuations are experienced within the S, I and R classes. From the results, it can be concluded that brucellosis has the highest transmission rate and recovery rate, as compared to the other two diseases. Rabies has the lowest transmission rate, which can be attributed to the fact that it is a vaccine-preventable disease. In addition, rabies has the lowest recovery rate as most of the individuals joined the removed class in this study. In an active population, new births and deaths do occur. Training of farmers, trade, regular mandatory surveillance and vaccination programmes are also in place. Births increase the susceptible population, which supports the spread of an epidemic throughout the population.

According to this study, the SIR (infected) epidemiological models that were produced in this thesis were different from other epidemic models that were put forward by other researchers. Alexander et al. (2012) state that all models are merely imitations of reality, regardless of the fact that they are good. In this study, the reason was the violation of the assumption that the population size (N) was constant and large; no births and deaths occurred. First, new births were unavoidable in this study and natural deaths of wildlife and domestic livestock were also experienced in the population under study. Animal trade is part of the communal and commercial farmers under study. Homogenous mixing was also violated in this thesis as mixing is not definite; it is a probability that it will take place. Environmental variability, climatic change and human interference also played a part in distorting the assumptions of the SIR model adopted in this study. The above suggests that caution must be applied to model findings, which was further exacerbated by the data limitations.

This chapter presented the discussion or analysis of results from questionnaires, SIR infected models, and line graphs for rabies, tuberculosis and brucellosis. The next chapter deals with the conclusion, limitations, guidelines and recommendations.

CHAPTER 6

CONCLUSION, LIMITATIONS, GUIDELINES AND RECOMMENDATIONS

6.1 CONCLUSION

Models aimed at projecting the number of infections forward in time and line graphs of tuberculosis, brucellosis and rabies were presented and analysed and were based on real data obtained from annual reports provided by the State Veterinary Department of Mahikeng.They were many gaps in our data as seasonal data was not available. Animal data used in this study to model the infected models were clinicaly and laboratory tested. SIR models assume that susceptible animals become infected with infectors in direct and indirect ways. The infected animal with brucellosis and tuberculosis in this study moves into the recovered class while infected animals with rabies moves into removed class. Most of the animals that were laboratory tested with rabies died in this study. Mathematical modelling for transmission of infectious diseases is becoming popular across the globe. This is of importance to South African policy makers, the veterinary surgeon and the public health sector to control zoonoses at the interface. From the data obtained from Mahikeng State Veterinary Department to model the zoonotic diseases under study, it can be concluded that the spread of zoonosis at the interface depends more on the probability of the direct and indirect contact rate with the infected class within a population. Models produced in this study show that the rate of transmission, to a large extent, dictates the spread of the disease. A high transmission rate produces high infection numbers and this results in a high reproduction number as the case with brucellosis which has high transmission rate in the study.

The trends and dynamics of susceptible, infected and recovered or removed population showed high fluctuating numbers. Highest susceptible population with brucellosis was recorded in 2014,tuberculosis in 2010 and rabies in 2012. This was attributed by high birth rates, animal replacement from other farms and trade of life stock. Decrease in numbers were due to vaccination programmes that were implemented by the State Veterinary Department of Mahikeng. Infected population for brucellosis and tuberculosis fluctuated until 2016.The rise can be attributed by low vaccination rates, high level of illiteracy among the farmers under study, uncontrolled interface and unreported herd immunity. Few rabies infections were recorded due to low contact, use of vaccines and emergency stock drug which is always available for rabies. Early detection of the disease and early provision of these drugs reduce the infected class as the case with rabies in this study. Mandatory regular surveillance is only available for brucellosis and tuberculosis for commercial farmers and communal farmers are left out. This mandatory regular surveillance should target all the farmers around Mahikeng Game Reserve.

Farmers in this study need to be educated about zoonotic diseases in order for them be aware of the dangers of infectious zoonotic disease. This will help to reduce the diseases in the wildlife/domestic life stock/human interface. The analysis from the questionnaire showed that 63% of the farmers needed information on brucellosis, 43% on tuberculosis and 23% on rabies. A minimum sample size in this study was recommended for qualitative studies so as to reach data saturation. A small sample size decreases the statistical power of the study and leads to the margin of error. Internal and external validity of the study is also undermined by a small sample size. In this study the sample was adjusted for economic reasons. To obtain significant results, researchers habitually adjust sample size based on the required confidence level and margin of error. Knowledge about these zoonotic diseases will shape the attitude and practices of farmers in this study which will reduce the risk of infection at the wildlife/life stock/human interface of Mahikeng Game Reserave and it's surrounding areas.

The subject of basic food safety must be addressed in the public health domain, which includes clinics, schools and workplaces around Mahikeng Game Reserve surroundings. Public health education must focus more on the facts and myths, for example raw milk. The importance of pasteurisation must be emphasised by public health as this may educate the community and change their attitude towards pasteurisation of milk.

The government of South Africa must make it a legal requirement for all farmers to report cases such as abortion, stillbirths, coughing and barking to the veterinary department, who must then investigate and determine the disease and take precautionary measures. Branding of all positive animals is necessary. Buyers and auctioneers need to know the status of the animals they are buying. Branding will discourage the buyers and the farmers will not be willing to look after animals that tested positive. Veterinarians and animal health technicians should be tested medically for these zoonotic diseases (brucellosis, rabies and tuberculosis) on a regular basis so that the employer would be able to determine when the employee contracted a disease.

Analytical review on the objectives of the study

- To decsribe the scientific literature after detailed analysis using desktop study of the data from clinical and laboratory annual reports on tuberculosis, rabies and brucellosis at the interface of humans, livestock and wildlife at the Mahikeng Game Reserve and surrounding areas provided by the State Veterinary of Mahikeng.
- To formulate Susceptible-Infected-Recovered (SIR) epidemiological models for brucellosis, tuberculosis and rabies of the Mahikeng Game Reserve and its surrounding areas in the North West province of South Africa using the compartmental model approach by collecting and making use of the numbers of susceptible, infected and recovered from annual reports compiled by the State Veterinary of Mahikeng.
- To determine the critical issues in prevention measures considered in managing these diseases at the interface and to identify the risk reduction methods and policy strategies fo addressing these transmissible diseases at the livestock,wildlife and human interface through analysing how SIR models progressed from 2007 to 2016.
- To identify the level of education, practices and attitudes among farmers at the interface of the Mahikeng Game Reserve and its surrounding areas with the help a questionnaire.

6.2 LIMITATIONS

- Seasonal data sets on susceptible, infected and recovered/removed animals were unavailable; only annual reports were provided. Therefore, the limitations of the models are fully acknowledged and they serve merely as a platform for future expansion as data becomes available. The annual scale at which data was condensed is therefore too crude to allow for meaningful modelling. Environmental variables are certainly important in the spread of any disease, and so are animal densities. These are to be considered in order to add sophistication to the models.
- The questionnaire was unsuitable for farmers who are illiterate and visually impaired and some commercial and communal farmers were inaccessible.
- Some answers were missing as the questionnaires were handed to the farmers; no face-to-face interviews were conducted.
- Clarity on absenteeism of farmers on Farmers' Days could not be obtained by the researcher.

- Unreported signs and symptoms of these three zoonotic diseases to the State Veterinary Department of Mahikeng led to false representation on SIR models.

6.3 GUIDELINES AND RECOMMENDATIONS

- A number of cross-sectional surveys should be conducted in the Mahikeng area during seasonal outbreaks of rabies, tuberculosis and brucellosis in order to compile seasonal data on susceptible, infected and recovered animals, which will enable researchers to analyse seasonal outbreaks, if any.
- The Mahikeng State Veterinary Department should be informed about the results of this study and should be encouraged to educate the farmers more often about zoonotic diseases and conduct control measures to eradicate contagious diseases and both commercial and communal farmers must be encouraged to attend Farmers' Days to gain knowledge from presentations.
- Positive animals should be marked and movement of infected animals or suspected animals should be controlled and dead animals should be examined and the cause of death should be established so that further deaths can be prevented.
- Regular mandatory surveillance of rabies, brucellosis and tuberculosis for both commercial and communal farmers is important to enable the veterinary department to determine the source of infection and remove the infected animals and government should enforce regulations pertaining to rabies, brucellosis and tuberculosis to minimise the spread of these zoonotic diseases.
- The findings of this thesis will assist policy makers and health authorities to plan better to control the spread of zoonotic diseases at the interface and milk producers should meet the standards required by the public and consumer awareness drives should be started. Milk producers should provide nutritional milk values expected in the market.

This dissertation covered modelling of zoonosis at the interface and investigated the knowledge, practices and attitudes of the commercial and communal farmers in and around the Mahikeng Game Reserve (5 km in radius) about these three zoonotic diseases. Further research could be done to focus on seasonal outbreaks of rabies, tuberculosis and brucellosis and to forecast other, different types of zoonoses in the human/wildlife/domestic livestock at the interface. In addition, the results provided insight for future epidemiological studies, which would assist the state veterinary animal doctors to improve diseases control programmes.

REFERENCES

Adebiyi, A.O. 2016. Mathematics modeling of the population dynamic of tuberculosis. Master's dissertation, University of the Western Cape: Department of Mathematics and Applied Mathematics.

Adesokan, H.K., Alabi, P.I., Stack, J.A., Simeon, I.B. & Cadmus, S.I.B. 2013. Knowledge and practices related to bovine brucellosis transmission amongst livestock workers in Yewa, South-Western Nigeria. [Electronic Version] *Journal of the South African Veterinary Association,* 84.

Akhtar, A. 2012. *Animals and public health. Why treating animals better is critical to human welfare*. Palgrave Macmillan.

Alexander, K.A. & McNutt, J.W. 2010. Human behavior influences infectious disease emergence at the human-animal interface. *Frontiers in Ecology and the Environment*, 8(10).

Alexander, K.A., Lewis, B.L., Marathe, M., Eubank, S. & Blackburn, J.K. 2012. Modeling of wildlife associated zoonoses applications and coveats. *Vector Borne and Zoonotic Diseases*, 12(12); 1005-10018. Allen, L.J.S., Brown, V.L., Klein, S.L., Laverty, S.M., Magwedere, K., Owen, J.C. & Van Den Driessche, P. 2012. Mathematical modeling of viral zoonoses in wildlife. *Natural Resource Modeling*, 25(1): 5-51.

Allen, L.J.S., Lou, Y. & Nevai, L. 2009. Spatial patterns in a discrete-time SIS patch model. *Journal of Mathematical Biology*, 58(2): 339-375.

Amaral, M.A. & Arenzon, J.J. 2018. Rumor propagation meets skepticism: aparallel with zombies. *Europhysics Letters.*

Anderson, A., Soman, C., Bekal, S., Domier, L., Lambert, K. & Bhalerao, K. 2018. An agent-based metapopulation model simulating virus-based biocontrol of heterodera glycines. *Journal of Nematology*, 2: 79-90.

Anderson, R.M. & May, R. M. 1991. Infectious diseases of humans. Dynamics and control. Oxford University Press.

Anka, M.S., Hassan, L., Khairani-Bejo, S., Zainal, M.A., Mohamad, R., Salleh, A. & Adzhar, A. 2014. A case-control study of risk factors for bovine brucellosis seropositivity in Peninsular Malaysia. *PLoS ONE*, 9(9): e108673.

Anyamba, A., Linthicum, K.J., Small, J.L., Kathrine M. & Collins, K.C. 2012. Climate teleconnections and recent patterns of human and animal disease outbreaks, *PLoS Neglected Tropical Diseases*, 6(1): e1465.

Backhans, A. & Fellsttrom, C. 2012. Rodents on pig and chicken farms – a potential threat to human and animal health. *Infection Ecology & Epidemiology*, 2(1): 17093.

Bapat, P.R., Dodky, R.S., Shekhawat, S.D., Husain, A.A., Nayak, A.R., Kawle, A.P., Daginowala, H.F., Signh, L.K. & Koshyap, R.S. 2017. Prevalence of zoonotic tuberculosis and associated risk factors in Central Indian populations. [Electronic Version]. *Journal of Epidemiology and Global Health*, 7(4): 277-283.

Barlow, N.D. 1996. The ecology of wildlife disease control: simple models revisited, [Electronic Version]. *Journal of Applied Ecology,* 33: 303–14.

Bartlow, A.W., Manore, C., Xu, C., Kaufed, K.A., Del Valle, S., Ziemann, A., Fairchild, G. & Fair, J.M. 2009. Forecasting zoonotic infectious disease response to climate change: mosquito vectors and a changing environment. *Veterinary Sciences,* 6(2): 40.Bean, A.G., Baker, M.L., Stewart, C.R., Cowled, C. & Deffrasnes, C. 2013. Studying immunity to zoonotic diseases in the natural host – keeping it real. *Nature Reviews Immunology*, 13: 851-61.

Beebe, N.W., Cooper, R.D., Mottram, P., Anthony, W. & Sweeney, A.W. 2009. Australia's Dengue risk driven by human adaptation to climate change. *PLoS Neglected Tropical Diseases*, 3(5): e429.

Bengis, R.G., Kock, R.A. & Fischer, J. 2002. Infectious animal diseases: the wildlife/livestock interface. *Revue Scientifique et Technique*, 21: 53-65.

Bengis, R.G., Swanepoel, R., De Klerk, L.M., Pienaar, N.J. & Prinsloo, G. 2010. 'Rift Valley fever: Current concepts and recent findings'. Paper presented at the 9th Annual Conference of the 'Southern African Society for Veterinary Epidemiology and Preventive Medicine', The Farm Inn, Pretoria, South Africa, 18–20 August.

Bloomfield, V. 2009. Computer simulation and data analysis in molecular biology and biophysics. An introduction using R. New York: Springer-Verlag.

Bolzoni, L. & De Leo, G.A. 2007. A cost analysis of alternative culling strategies for the eradication of classical swine fever in wildlife. *Environment and Development Economics*, 12(2007): 653-671.

Centre for emerging and zoonotic disease and division of the public health surveillance and response (NICD-NHLS). 2016. Available at: www.nicd.ac.za/assets/files/Rabies (Accessed on 10 November 2017).

Childs, J. E., Mackenzie, J.S. & Richt, J.A. (Eds.). 2007. Wildlife and emerging zoonotic diseases: the biology circumstances and consequences of cross species transmission. *Current Topics in Microbiology and Immunology*, 315. Available at: https:// www.springer.com/gp/book/9783540709619

Chomel, B.B., Belotto, A. & Meslin E.F.X. 2007. Wildlife, exotic pets, and emerging zoonoses. *Emerging Infectious Diseases*, 13: 6- 11.

Chomel, B.B. & Sun, B. 2010. Bioterrorism and invasive species. *Revue Scientifique et Technique*, 29: 193- 9.

Cipresso, P. 2015. Modeling behavior dynamics using computational psychometrics within virtual worlds. *Frontiers in Psychology*, 2015.

Claeys, W.L, Cardoen, S., Daube, G., De Block, J., Dewettirick, K., Dierick, K., De Zutter, L., Huyghebaert, A., Imberechts, H., Thiange, P., Vandenplas, Y. & Herman, L. 2013. Raw or heated cow milk consumption: review or risks and benefits. *Food Control*, 31: 251-262.

Crawford, R.P., Huber, J.D. & Adam, B.S. 1990. Epidemiology and surveillance in animal brucellosis. *Animal Brucellosis, Boca Raton* (FL). CRC Press, 131-151.

Dallaz-Pozza, M., Martini, M., Marangon, S., Manca, G. & Ricci, A. 1997. A case-control study on the risk factors for bovine brucellosis in the Veneto Region (Italy). *Epidemiology Sante Animal*, 1997: 31-32.

Dadar, M., Shahali, Y., Fakhri, Y. & Godfroid, J. 2020. The global epidemiology of infections in terrestrial wildlife: a meta- analysis. *Transboundary and Emerging Diseases*.

Daughton, A.R., Generous, N., Priedhorsky, A & Deshpande, A. 2017. An approach to and web-based tool for infectious disease outbreak intervention analysis. *Scientific Reports*, 7.Department of Agriculture, Forestry and Fisheries. 2012. *Cattle (bovine) tuberculosis*. South Africa, Pretoria.

Department of Water Affairs and Forestry (DWAF). 2003. *Eco-regions of South Africa level*. Pretoria: Department of Water Affairs and Forestry.

De Villers,J.F., Dugmore, T.J., Botha, W.A. & Wandrag, J.J. 2002.The value of Kikuyu foggage for over wintering dry ewes. *South Afr. J. Anim.Sci*. 32(1):7-13

Dibaba, A.B., Kriek, N.P.J. & Thoen, C.O. 2019. *Tuberculosis in animals: an African perspective* Switzerland: Springer.

Diekmann, O., Heesterbreek, J. & Roberts, M. 2010. The construction of next generation matrices for compartmental epidemic models, *Journal of the Royal Society Interface,* 7(47): 873-885.

Diez, J.G. & Coelho, A.C. 2013. An evaluation of cattle farmers. Knowledge of bovine brucellosis in northeast Portugal. *Journal of Infection and Public Health,* 6(5): 363-369.

Dobson,A.P. & Meagher, M. 1996.The population dynamics of brucellosis in the Yellowstone National Park. *In Ecology*. 77(4):1026-1036

Ducrotoy, M., Bertu, W.J., Matope, G., Cadmus, S., Conde-lvarez, R., Gusi, A.M., Welburn, S., Ocholi, R., Blasco, J.M. & Moriyn, I. 2015. Brucellosis in sub-Saharan Africa: current challenges for management, diagnosis and control. *Acta Tropica*.

Elkinton, J.S. 2000. *Chapter 13: Assessing impact of naturally-occurring pathogens of forest insects*. Springer science and business media LLC.

Fevre, E.M., Bronsvoort, B.M., Hamilton, K.A. & Cleaveland, S. 2006. Animal movements and the spread of infectious diseases. *Trends Microbial,* 14: 125- 31.

Field, H.E. 2009. Bats and emerging zoonoses: henipaviruses and SARS. *Zoonoses Public Health*, 56(6-7): 278-84.

Fischer, J.R. & Gerhold, R. 2002. *Wildlife as a risk factor in animal health and zoonoses.* College of Veterinary Medicine, University of Georgia, Athens, USA.

Freeland, S. 2001. The Kyoto protocol: an agreement without a future, The. *UNSW Law Journal*, 24: 532.

Fowler,J., Cohen, L. & Jarvis, P.1998. Practical statistics for field biology.John Wiley and sons. New York.

Gage, K.L., Burkot, T.R., Gisen, R.J. & Hayes,E.B. 2008. Climate and vector borne diseases. *American Journal of Preventative Medicine,* 35: 436-450.

Gangrade, K.D.1982.Methods of data collection: questionnaire and schedule. *Journal of the Indian law institute*, 24 (4): 713-722.

Gerba, C.P. 1999. Virus survival and transplant in groundwater. *Journal of Industrial Microbiology and Biotechnology,* (22): 535-539.

Gilbert, M., Slingenbergh, J. & Xiao, X. 2008. Climate change and avian influenza. *Revue Scientifique et Technique - Office International des Épizooties,* 27: 459- 466.

Goldberg, T.L., Gillespie, T.R., Rwego, I.B., Estoff, E.L. & Chapman, C.A. 2008. Forest fragmentation as cause of bacterial transmission among nonhuman primates, humans, and livestock, Uganda. *Emerging Infectious Diseases Journal,* 14: 1375- 82.

Gould, E.A. 2003. *Flavivirus infections in humans*. Wiley & Sons.

Gould, E.A. & Higgs, S. 2009. Impact of climate change and other factors on emerging arbovirus diseases. *Transactions of the Royal Society of Tropical Medicine and Hygiene,* 103: 109- 121.

Graham, J.P., Leibler, J.H., Price, L.B., Otte, J.M., Feiffer, D.U., Tiensin, T. & Silbergeld, E. 2008. The animal- human interface and infectious disease in industrial food animal production: rethinking biosecurity and bio containment. *Public Health Reports,* 123: 282- 299.

Grenfell, B.T., Bjornstad, O.N. & Finkenstadt, B.F.2002. Dynamics of measles epidemics: Scaling noise,Determinism, and predictability with the TSIR Model. Ecology monograph.72 (2):185-202.

Griffin, J.M., Hahesy, T., Lynch, K., Salman, M.D., McCarthy, J. & Hurley, T. 1993. The association of cattle husbandry practices, environmental factors and farmer characteristics with the occurrence of chronic bovine tuberculosis in dairy herds in the Republic of Ireland. *Preventive Veterinary Medicine (Netherlands),* 17(3-4): 145-160.

Gubler D.J. 1998. Resurgent vector-borne diseases as a global health problem. *Emerging Infectious Diseases,* 4: 442-50.

Gubler, D.J. 2009. Vector-borne diseases. *Revue Scientifique et Technique,* 28: 583-588.

Haider, N. 2018. *Division of diagnostic and scientific advice*. National Veterinary Institute Technical University of Denmark: Lyngby Denmark.

Hallbauer, U.M., Joubert, G. & Goosen, Y. 2016. Pertussisin children in Bloemfontein, South Africa: a 7-year retrospective review. *South African Medical Journal,* 106(10).

Harbourt, D., Haddow, A., Piper, A., Bloomfield, H., Kearney, B., Gibson, K. & Minogue, T. 2020. *Modeling the stability of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) on skin, currency, and clothing*. Cold Spring Harbor Laboratory.

Hassel, J.M., Begon, M., Ward, M.J. & Fevre, E.M. 2017. Urbanization and disease emergence: dynamics at the wildlife-livestock-human interface. *Trends in Ecology and Evolution*, 32(1).

Heesterbreek, J.A.P. & Roberts, M.G. 1981. How mathematical epidemiology became a field of biology: a commentary on Anderson and May (1981), 'The population dynamics of micro parasites and their invertebrate hosts.' *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, 370: 1666.

Hesterbmerg, U.W., Bagnall, R., Parret, K., Bosch, B., Horner, R. & Gummow, B. 2008. A serological prevalence survey of Brucella abortus in cattle of rural communities in the province of KwaZulu-Natal, South Africa. *Journal of the South African Veterinary Association,* 79(1): 15-18.

Highland, J. 1998. SOLVER. Available at: https://itsillworl.com/advantages-excel-solver-6368690.html (Accessed at 24 May 2020).

Hiko, A. & Malicha, G. 2016. *Climate change and animal health risk*. Emerald Group Publishing.

Hochreiter, R. & Waldhauser, C. 2019. *Zombie politics: evolutionary algorithms to counteract the spread of negative opinions*. Soft Computing.

Hoshen, M.B. & Morse, A.P. 2004. A weather-driven model of malaria transmission. *Malaria Journal*, (3)32.

Hutchings, L., Morris, T., Van der Lingen, C.D., Lamberth, S.J., Connell, A.D., Taljaard, S., Van Niekerk, L. 2010. Ecosystem considerations of the KwaZulu-Natal sardine run. *African Journal of Marine Science.*

Joao, A.R., Aranha, J.M., Serejo, J.P., Amado, A. & Viera-Pinto, M. 2011. The utility of GIS in studying the distribution of bovine tuberculosis in wild boar (*Sus scrofa*) and red deer (*Cervus elaphus*) in Central Portugal. *Game Meat Hygiene in Focus Microbiology Epidemiolo*, 199-205.

Johnston, W.T., Gettinby, G. & Cox, D.R. 2005. Herd level risk factors associated with tuberculosis breakdowns among cattle herds in England before the 2001 foot and mouth disease epidemic. *Biology Letters*, 1(1): 53-56.

Jones, B., Declan, M., Delia, G., Dirk, P., Mutuu, F., Njuki, J., McDermott, J., Rushton, J., Said, M., Ericksen, P., Kock, R. & Alonoo, S. 2011. *Zoonoses (Project 1) Wildlife/domestic/livestock interaction*. The international livestock research institute, Nairobi and Royal veterinary college: London.

Jones, K., Patel, N., Levy, M., Storeygard, A., Balk, D., Gittleman, J. & Daszak, P. 2008. Global trends in emerging infectious disease. [Electronic Version]. *Nature*, 451: 990-993.

Jones, B.A., Delia, G., Kock, R., Alonso, S., Rushton, J., Said, M.Y., Mckeever, D., Mutua, F., Young, J., McDermotte, J. & Pfeiffer, D.U. 2012. *Zoonosis emergence linked to agricultural intensification and environmental change*. Veterinary epidemiology, economics and public health group and department of pathology and infectious diseases, Royal veterinary college, University of London, Hertfordshire AL9 7TA United Kingdom and International livestock research institute, Nairobi 00100 Kenya.

Kankya, C., Muwonge, A., Olet, S., Munyeme, M., Biffa, D., Opuda-Asibo, J., Skjerve, E. & Oloya, J. 2010. Factors associated with pastoral community knowledge and occurrence of mycobacterial infections in human- animal interface areas of Nakasongola and

Mubende districts, Uganda. *BMC Public Health*, 10: 471.

Katale, B.Z., Mbugi, E.V., Kenda, S.,Fyumagwa, R.D., Kibiki, G.S., Faussett, P.G., Keyyu, J.D., van Helden, P. & Matee, M.I.2012.Bovine tuberculosis at the human-livestock-wildlife interface: Is it a public health problem in Tanzania? A review. *Onderstepoort Journal of veterinary research*.79.

Keesing, F., Belden, L.K, Daszak, P., Dobson, A., Harvell, C.D., Holt, R.D., Hudson,P., Jolles, A., Jones, K.E. & Mitchell, C.E. 2010. Impacts of biodiversity on the emergence and transmission of infectious diseases. *Nature,* 468: 647-652.

Keesing, F., Holt, R.D. & Ostfeld, R.S. 2006. Effects of species diversity on disease risk. *Ecology Letters*, 9: 485-499.

Kermack, W. & Mckendrick, A. 1927. A ontribution to mathematical theory of epidemics. Proceedings of the Royal Society of London, Series A, 115(772): 700-721.

Killian, G., Fagerstone, K., Kreeger, T., Miller, L. & Rhyan, J.2007.Management strategies for addressing disease transmission. The case for fertility control USDA National wildlife research center staff publications paper.758.

Kiyeon, K., Ryosuke, O. & Kimihito I. 2017. Inferring epidemiological dynamics of infectious diseases using Tajima's D statistic on nucleo tide sequences of pathogens. *Epidemics*.

Kock, R., Kebkiba, B., Heinoen, R. & Bedane, B. 2002. Wildlife and pastoral society shifting paradigms in disease control. *Epidemiology Unit OAUIBAR-PACE*, Nairobi.

Kock, R.A. 2005. 'What is the infamous wildlife/livestock disease interface? A review of current knowledge'. Southern and East African Experts Panel on Designing Successful Conservation and Development Interventions at the Wildlife/Livestock Interface: Implications for Wildlife, Livestock, and Human Health. AHEAD Animal Health for the Environment and Development Forum. IUCN/SSC Veterinary Specialist Group, Southern Africa Sustainable Use Specialist Group et al., IUCN, Gland, Switzerland and Cambridge, UK, 14–15 September 2003.

Kock, R.2014 .Drivers of disease emergence and spread: Is wildlife to blame? *Onderstepoor*t *Journal of veterinary research*, 81(2) 739

Kock, N. 2014. Advanced mediating effects tests, multi-group analyses and measurement model assessments in PLS based SEM. International Journal of e –collaboration,10(1)1-13

Krosnick, J.A. & Presser, S. 2010. Question and questionnaire design. In Marsden, P.V. & Wright, J.D. (eds). *Handbook of survey research.* 2nd ed. Bingley: Emerald Group publishing, pp. 263-313

Laaksonen, S. 2010. Setaria tundra, an emerging parasite of reindeer, and an outbreak it caused in Finland in 2003-2006. University of Helsinki. doi: ISSN: 1797-2981

Lacey, L.A. & Kaya, H.K. (Eds.). 2000. *Field manual of techniques in invertebrate pathology*. Springer Netherlands.

Lee, H-M. Park, B., Yang, J-S. & Ha, J-H. 2020. Correlation between food borne pathogens and murine contamination of red pepper powder. *Food Control*.

Leedy, P.D. 1993. *Practical research planning and design*. New Jersey: Prentice Hall.

Leedy, P.D. & Ormrod, J.E. 2010. *Practical research planning and design*. 9th ed. New Jersey: Merril-Upper Saddle River.

Levin, S.A., Grenfell, B. & Hastings, A., et al. 1997. Mathematical and computational challenges in population biology and ecosystems science. *Science,* 1997: 275-334.

Liu, J., Zhou, J., Yao, J., Zhang, X., Li, L. & Xu, X. 2020. Impact of meteorological factors on the covid-19 transmission: a multi-city study in China. *Science of the Total Environment,* 726: 138513. doi: 10.1016/j.scitotenv.2020.138513

Maclachlan, N.J. 2011. Bluetongue: history, global epidemiology, and pathogenesis. *Preventative Veterinary Medicine,* 102(2): 107-111.

Mafikeng Spatial Development Framework & Related Products. 2005. *Status quo report.* Mafikeng, North West Province: Mafikeng Local Municipality.

Makita, K., Fevre, E.M., Waiswa, C., Eisler, M.C., Thrusfield, M. & Welburn, S.C. 2011. Herd prevalence of bovine brucellosis and analysis of risk factors in cattle in urban and peri-urban areas of the Kampala economic zone, Uganda. *BMC Veterinary Research,* 7(60).

Marcotty, T., Matthys, F., Godfroid, J., et al. 2009. Zoonotic tuberculosis and brucellosis in Africa: neglected zoonoses or minor public-health issues? The outcomes of a multi-disciplinary workshop. *Annals of Tropical Medicine and Parasitology,* 103(5): 401-411.

Martcheva, M.2015. *Chapter 2: Introduction to Epidemic Modeling*. Springer Science and Business Media LLC.

Mathews, F. 2009. Zoonoses in wildlife: integrating ecology into management. *Advances in Parasitology,* 68: 185- 209.

Matope, G., Bhebhe, E., Muma, J.B., Lund, A. & Skjerve, E. 2010. Herd-level factors for Brucella seropositivity in cattle reared in smallholder dairy farms of Zimbabwe. *Preventive Veterinary Medicine,* 94: 213-221.

Matope, G., Bhebhe, E., Muma, J.B., Lund, A. & Skjerve, E. 2011. Risk factors for Brucella spp. infection in smallholder household herds. *Epidemiology and Infection,* 139(1): 157-164.

McDermott, J.J. & Arimi, S.M. 2002. Brucellosis in sub-Sahara Africa: epidemiology control and impact. *Veterinary Microbiology,* 90(¼): 111-134.

McDonald, J.L., Robertson, A. & Silk, M.J. 2017. Wildlife diseases ecology from the individual to the population: insights from a long-term study of a naturally infected European badger population. *Journal of Animal Ecology.* 87: 101-112.

Meng, X., Lindsay, D. & Sriranganathan, N. 2009. Wild boars as sources for infectious diseases in livestock and humans, [Electronic Version]. *Philosophical transactions of the Royal Society B,* 364: 2697-2707.

Michael, A.L. & Bengis, R.G. 2012. The African buffalo: a villain for interspecies spread of infectious diseases in Southern Africa. *Onderstepoort Journal of Veterinary Research,* 79(2): E1-E5.

Michel, A.L. & Bengis, R.G. 2012. The African buffalo: a villain for inter-species spread of infectious diseases in southern Africa. Onderstepoort *Journal of Veterinary Research.*

Miller, R. H.2016. *Characterization and detection of vector-borne diseases in endemic transmission areas*. Uniformed services University of Health Sciences.

Mills, J.N., Gage, K.L. & Khan, A.S. 2010. Potential influence of climate change on vector-borne and zoonotic diseases: a review and proposed research plan. [Electronic Version]. *Environmental Health Perspectives,* 118: 1507- 1514.

Morand, S., Beaudeau, F.& Cabaret, J. 2012. New frontiers of Molecular Epidemiology of infectious diseases. Springer Netherland.

Morgan, E. R., Lundervold, M., Medley, G. F., Shaikenov, B. S., Torgerson, P. & Milnergulland, E. J. 2006. Assessing risks of disease transmission between wildlife and livestock: The Saiga antelope as a case study. [Electronic Version]. *Biology Conservation,* 131: 244- 254.

Musallam, I.I., Abo-Shehada, M., Omar, M. & Guitian, J. 2015. Cross-sectional study of brucellosis in Jordan: Prevelence, risk factors and spartial distribution in small ruminants of cattle. *Preventive Veterinary Medicine.* 118 (4): 387-396.

Naicker, P.R. 2011. The impact of climate change and other factors on zoonotic diseases. *Archives of Clinical Microbiology,* 2(2): 4.

Newell, D.G., Koopmans, M., Verhoef, L., Duizer, E., Aidara-Kane, A., Sprong, H., Opsteegh, M., Langelaar, M., Threfall, J., Scheutz, F., Giessen, J.V.D. & Kruse, H. 2010. Food- borne diseases – the challenges of 20 years ago still persist while new ones continue to emerge. *International Journal of Food Microbiology*, 139**:** S3- S15.

Nika, M.M. 2015. *Synthedemic modeling and prediction of internet based spreading phenomena*. PhD Thesis, Imperial College London.

Ntampaka, P., Nyaga, P.N., Niragire, F., Gathumbi, J.K. & Tukei, M. 2019. Knowledge, attitudes and practices regarding rabies and its control among dog owners in Kigali city, Rwanda. *PLOS ONE*, 14(8): e0210044.

Nyirenda, M., Letlojane, L. & Syakalima, M. 2016. *Prevalence of brucella abortus in buffaloes of Mafikeng Game Reserve, North West Province, South Africa: a retrospective study*. North West University Mafikeng Campus, Department of Animal Health Studies.

Oludairo, O.O., Aiyedun, J.O., Olorunshola, I.D., Dibal, M.A., Gungbias, A.A., Ayeni, A.M.J. & Adeyi, A.A. 2017. Transboundary diseases and wildlife management: an overview. *Bangladesh Journal of Veterinary medicine,* 14(2): 123.

Owen-Smith, N. 2007. *Introduction to modeling in wildlife and resource conservation.* Oxford: Blackwell Publishing.

Pani, K.S., Lin, N-H. & RavindraBabu, S. 2020. Association of COVID-19 pandemic with meteorological parameters over Singapore. *Science of the Total Environment*, 740: 140112.

Paulsen, P., Bauer, A. & Smulders, F.J.M. (Eds). 2011. *Game meat hygiene in focus. Microbiology, epidemiology, risk analysis and quality assurance***.** Wageningen Academic Publishers. Available at: https://doi.org/10.3920/978-90-8686-723-3**.**

Paulsen, P., Bauer, A. & Smulders, F.J.M. (Eds). 2014. *Trends in game meat hygiene. From forest to fork.* Wageningen Academic Publishers. Available at: https://doi.org/10.3920/978-90-8686-790-5.

Paulsen, P., Bauer, A. & Smulders, F.J.M. (Eds). 2017. *Game meat hygiene. Food safety and security*. Wageningen Academic Publishers. Available at: htps://www wageningenacademic.com/doi/book/ 10.3920/978-90-8686-840-7.

Pellis, L., Ball, F. & Trapman, P. 2012. Reproduction numbers for epidemic models with households and other social structures. I. Definition and calculation of R0. *Mathematical Biosciences*, 235(1): 85-97.

Pfeffer, M. & Dobler, G. 2010. Emergence of zoonotic arboviruses by animal trade and migration. [Electronic Version]. *Parasites and Vectors*, 3(35).

Phukon, D. 2012. *Wildlife livestock interface: role of disease and its conservation implications.* Wildlife Institute of India: Chandrabani.

Ramatla, T., Ngoma, L., Adetunji, M. & Mwanza, M. 2017. Evaluation of antibiotic residues in raw meat using different analytical methods. *Antibiotics*, 6(4): 34.

Ramatla, T., Mputhi, N., Kutswa, G., Taioe, M.O., Thekisoe, O.M.M. & Syakalima, M. 2019. Identification of rodent species that infest poultry houses in Mafikeng, North West Province, South Africa. *International Journal of Zoology*, 2019: 1-8.

Reid. C. 2000. *Implications of climate change on Malaria in Karnataka, India*. Honours thesis, Brown University.

Rhyan, J. & Spraker, T. 2010. Emergence of diseases from wildlife reservoirs. [Electronic Version]. *Veterinary Pathology Online*, 47: 34-39.

Robi, D.T. & Gelalcha, B.D. 2020. Epidemiological investigation of brucellosis in breeding female cattle under the traditional production system of Jimma zone in Ethiopia. *Veterinary and Animal Science*, (9).

Rochlin, I., Ninivaggi, D.V., Hutchinson, M.L., Farajollahi, A. 2013. Climate change and range expansion of the Asian tiger mosquito (Aedes albopictus) in North-eastern USA: implications for public health practitioners. *PLoS One,* 8: e60874.

Sacristán, C., Neves, C.G., Suhel, F., Sacristán, I., Torstein Tengs, T., Hamnes, I.S. & Madslien, K. 2020. spp. detection in ticks, biting midges and wild cervids from Norway. *Transboundary and Emerging Diseases*, 2020.

Schmidt, K.A. & Ostfeld, R.S. 2001. Biodiversity and the dilution effect in disease ecology. *Ecology,* 82: 609-619.

Seetahal, J., Vokaty, A., Vigilato, M. & Carrington, C. 2018a. Rabies in the Caribbean. A situational analysis and historic review. *Tropical Medicine and Infectious Disease,* 3(3): 89.

Seetahal, J.F.R., Vokaty, A., Vigilato, M.A.N., Carrington, C.V.F., Pradel, J., Louson, B., Saseres, A.V., Roopnarire, R., Arrebato, G.J.C., James, C. & Rupprecht, C. 2018b.

Rabies in the Caribbean: a situational analysis and historic review, tropical Medicine and infectious disease.

Shi, P., Dong, Y., Yan, H., Zhao, C., Li, X., Liu, W., 2020. Impact of temperature on the dynamics of the COVID-19 outbreak in China. *Science of the Total Environment,* 728:138890. doi: 10.1016/j.scitotenv.2020.138890

Sil, A. & Kumar, V.N. 2020. Does weather affect the growth rate of covid-19. A study to comprehend transmission dynamics on human health. *medRxi preprint*. doi: https://doi.org/10.1101/2020

Sincero, S.M. 2012. *Surveys and questionnaires guide*. Available at: http://explorable.com/surveys and questionnaires/ (Accessed 12 December 2019).

Smits, H.L. 2013. Brucellosis in pastoral and confined livestock: prevention and vaccination. *Revue Scientifique et Technique (International Office of Epizootics),* 32(1): 291-228.

Smith, L.A. 2008. Inter- and intra-specific exposure to parasites and pathogens via the faecal-oral route: a consequence of behaviour in a patchy environment. *Epidemiology and Infection*, 5: 630-643.

Smith, L.A., Marion, G., Swain, D.L., White, P.C.L. & Hutchings, M.R. 2008. Inter and Intra-specific exposure to parasites and pathogens via the faecal oral route: a consequence of behaviour in a patchy environment. *Epidemiology and Infection,* 137(50): 630-643.

Storck, C. H., Postic, D., Lamaury, I. & Perez, J. M. 2008. Changes in epidemiology of leptospirosis in 2003- 2004, a two El Niño Southern Oscillation period, Guadeloupe archipelago, French West Indies. *Epidemiology and Infection*, 136: 1407- 1415.

Strydom, S. 2015. *Brucella Militensis a forgotten disease?* Epidemiology, directorate animal health. Department of Agriculture, Forestry and Fisheries.

Tawhir, A. 2012. *Modeling and control of measles transmission in Ghana*. Kwame Nkrumah University of Science and Technology. Department of Mathematics.

Thomas, R. 2012. *Knowledge aware and culturally sensitive SIR models for infectious disease spread.* MSc Thesis, University of Windsor.

Tian, H. & Xu, B.2015. Persistence and transmission of avian influenza A (H5N1): virus movement, risk factors and pandemic potential. *Annals of GIS*, 21(1): 55-68.

Traxler, R.M., Guerra, M.A., Morrow, et al. 2013. Review of Brucellosis cases from laboratory exposure in the United States in 2008 to 2011 and improved strategies for disease prevention, [Electronic Version]. *Journal of Clinical Microbiology*, S1(9): 3132-3136.

Traxler, R.M., Lehman, M.W., Rosserman, E.A., Guerra, M.A. & Smith, T.L. 2013. A literature review of laboratory – acquired brucellosis. [Electronic Version]. *Journal of clinical Microbiology*, S1(9): 3055-3062.

Turton, A.R. & Ashton, P.J. 2008. Basin closure and issues of scale: the Southern African hydropolitical complex. *International Journal of Water Resources Development*, 24:2, 305 - 318.

Upadhyay, R.K. & Roy, P. 2016. Deciphering dynamics of recent epidemic spread and outbreak in West Africa. The Case of Ebola Virus. *International Journal of Bifurcation and Chaos*, 26(9).

Van Veelen, M., Baker, M., Mulale, K., Bron, A., Fanta, A., Jonker, V., Mullins, W. & Schoeman, H. 2009. *The feasibility study of the potential for sustainable water resource development in the Molopo-Nossob watercourses*. Main report No: 007/2009

Vaz, V.C. D'Andrea, P.S. & Jansen, A.M. 2007. Effects of habitat fragmentation on wild mammal infection by Trypanosoma cruzi. *Parasitology*, 134: 1785-1793.

Villiers, S. & Thiart, C. 2007. The natural status of South African rivers: concentrations trends and fluxes from the 1970-2006. [Electronic Version]. *South African Journal of Science*, 103: 343-352.

Wakawa, A., Mohammed, F. & Mamman, H. 2015. Isolation and antibiotic susceptibility of Escherichia coli and salmonella gallinarum isolated from rats in commercial poultry farms with recurrent colibacillosis and fowl Typhoid Cases in Zaria, Nigeria. *Journal of Veterinary Advances*, 5(11): 1147-1152.

Wang, W., Yang, L., Wronski, T., Chen, S., Hu, Y. & Huang, S. 2019. Captive breeding of wildlife resources – China's revised supply- side approach to conservation. *Wildlife Society Bulletin.*

Weaver, S.C. & Reisen, W.K. 2010. Present and future arboviral threats. *Antiviral Research*, 85: 328-345.

Wiethoelter, A.K., Alcrudo, D.B., Kock, R. & Mor, S.M. 2006. *Global trends in infectious diseases at the wildlife livestock interface*. University of Florida, Gainesville.

Wiethoelter, A.K., Alcrudo, D.B., Kock, R. & Mor, S.M. 2015. Global trends in infectious diseases at the wildlife-livestock interface. Proceedings of the National Academy of Sciences, 112(31): 9662-9667.

Williams, P.D., Dobson, A.P., Dhondt, K.V., Hawley, D.M. & Dhondt, A.A. 2014. Evidence of trade-offs shaping virulence evolution in an emerging wildlife pathogen. *Journal of Evolutionary Biology*.

Wonham, M.J. 2008. *A comparative analysis of models for West Nile Virus. Lecture notes in mathematics.*

Woodford, M.H. 2009. Veterinary aspects of ecological monitoring: the natural history of emerging infectious diseases of humans, domestic animals and wildlife. *Tropical Animal Health and Production,* 41: 1023- 33.

World Health Organization. 2018. *Vector-borne diseases: Key facts*.

Wu, X., Yongmei, L., Sen, Z., Lifan, C. & Bing X. 2016. Impact of climate change on human infectious diseases: empirical evidence and human adaptation. *Environment International*, 86: 14-23.

Xu, W.& Rutledge, S.A.2016. Time scales of shallow-to- deep convective transition associated with the onset of Madden-Julian Osscillation, Geophys. Res. Lett.43

Zake, E.S. 2020. The impact of rainfall variability on subsistence farmers in North West Province South Africa. Master’s dissertation, North West University.

Zhu, Y., Xie, J., Huang, F. & Cao, L. 2020. Association between short-term exposure to air pollution and COVID-19infection: evidence from China. *Science of the Total Environment.*

Zug, R., Koehncke, A. & Hammerstein, P. 2012. Epidemiology in evolutionary time: the case of Wolbachia horizontal transmission between arthropod host species. *Journal of Evolutionary Biology*.

ANNEXURE 1: QUESTIONNAIRE FOR THE VETERINARY DEPARTMENT OF MAHIKENG

Dear Sir/Madam

You are kindly requested to fill in the questionnaire. Aim of the questionnaire is to:

1. Establish a systematic review of the scientific literature on tuberculosis, rabies and brucellosis infectious disease prevalence and to examine and evaluate the status of these zoonoses at the wildlife, livestock and human interface of Mahikeng Game Reserve and its surrounding areas.
2. To assess critical issues in managing these diseases

Your opinion on scientific literature and critical issues in managing these diseases is of importance to further the research efforts in wildlife/domestic livestock and human interface.

Instructions

- Do not write your name on the questionnaire. It remains anonymous.
- There is no correct or wrong answer. Only your opinion is required.
- Answer all questions.
- Return the questionnaire to the person from whom it was received after having completed it.

Information obtained from this questionnaire will be confidential.

Thank you once again in advance for your assistance.

1. How many commercial/communal farmers are around the boundaries of Mahikeng Game Reserve (5 km radius)

   Commercial farmers: ______

   Communal farmers: _______

2. How often do you present farmers days for farmers to educate and inform them about :

   TUBERCULOSIS (**Tick in the appropriate box**)

Regularly	
Once a year	
Never	

RABIES

Regularly	
Once a year	
Never	

BRUCELLOSIS

Regularly	
Once a year	
Never	

3. Select the attendance range in percentages of farmers on Farmers' Day

0-30%	
40%-60%	
70%-100%	

4. Who attends most?

Commercial	
Communal	

5. Select from the ones provided which age group mostly attends the farmers day.

0-30 years	
31-50 years	
51-70 Ears	
71 and Above	

6. How many dip tanks are in the Mahikeng Game Reserve (5km radius)

____

7. Do farmers report any form of: (**Tick in the appropriate box**)

Abortions	
Hygromas	
Reduction in milk production	
Weak calves	

8. Do farmers report any form of:

Loss of appetite	
Weakness	
Seizures	
Foaming at the mouth	
Disorientation, incoordination and staggering	
Sudden death	

9. Furthermore, do farmers report any form of:

Persistent moist cough	
Weakness	
Lethargy	

10. From the given list, select some of the challenges that you face as a department in managing tuberculosis, rabies and brucellosis.

Tick in the appropriate box on challenges that you think assist the department in managing these diseases.

Challenges	**Yes**	**No**
Is the department providing personal protective equipment when handling affected or suspected animals?		
Is the community aware of the following diseases (rabies, tuberculosis and brucellosis)?		
Is there existence of emergency stocks drugs and supplies at all times?		
Rabies		
Tuberculosis		
Brucellosis		
Does the department have a district plan for outbreak preparedness for and response to these diseases?		

As a department, is there mandatory regular surveillance for rabies, tuberculosis and brucellosis. If yes, what is the interval for each specific disease:

Rabies:____

Tuberculosis:____

Brucellosis:____

Is there any action plan targeted for eradication or elimination of these diseases.

From the past outbreaks, as a department, are you aware of the risk factors of these transmissible diseases?

Is there a budget line for outbreaks?

Have you been trained in disease surveillance?

ANNEXURE 2: QUESTIONNAIRE FOR THE COMMERCIAL AND COMMUNAL FARMERS AROUND MAHIKENG GAME RESERVE (5 KM RADIUS) Areas include (Lomanyaneng, Bokone, Stad, Dihatshwane, Riveira Park & Top Village)

Area: ____________________________

Tick in the appropriate box

Age:

18-49 Years	
50-75 Years	
76 and Above	

Sex:

Male	
Female	

Educational Status of farmers:

< 8th grade	
> 8th grade	

Livestock ownership

Sheep	Cattle	Goats	Swine	Dogs	Pigs	Donkeys

Have you sold animals in the last 12 months?

Yes	No

Who were your buyers? ______________________________

Livestock replacement:

Outside source (From other farmers)	
Own farm	
Outside source and own farm	

Are the pens or premises where you keep your livestock clean and disinfected all the time?

Yes	
No	

SECTION A

RABIES

Do you know about rabies disease?

Yes	
No	

If yes, where did you get knowledge of rabies for the first time?

TV	Radio	Newspaper	School	Government /Community meetings	Posters/ leaflets/ brochure	Local community (Parent neighbor, friend)	Other specify

How many dogs do you have? ___________

Do you take your dogs for vaccination?

Yes	
No	

Were your dogs vaccinated?

Yes	
No	
Uncertain	

Number of dogs not vaccinated

0	
1-3	
> 4	

Do you face any difficulties in handling your own dogs?

Yes	
No	

Is there an outbreak of rabies you are aware of?

Yes	
No	

Is there any member of your family who has been exposed to suspected rabid animals?

Yes	
No	

Clinical signs and symptoms associated with **RABIES** in animals and humans.

Tick in the appropriate box if you have witnessed any of these signs and symptoms in humans or animals.

Animals	**Signs and symptoms**	**Human beings**	**Signs and symptoms**
Madness		Madness	
Barking		Death	
Red eyes			
Abnormal biting			
Emaciation			
Loss of appetite			
Death			

SECTION B

Have you ever heard of brucellosis?

Yes	
No	

Have any animals from your livestock suffered from brucellosis?

Yes	
No	

What was the sex of the animal?

Male	
Female	

How often do you use raw milk?

Regularly	
Never	
More Often	

Clinical signs and symptoms associated with **BRUCELLOSIS** in animals and humans.

Tick in the appropriate box if you have witnessed any of these signs and symptoms in humans or animals.

BRUCELLOSIS			
Animals	**Signs and symptoms**	**Human beings**	**Signs and symptoms**
Abortion		Joint pains	
Emaciation		Recurrent fever	
Milk drop		Vomiting	
Fever		Malaria-like	
		Emaciation	

SECTION C

TUBERCULOSIS

Have you heard about bovine tuberculosis BTB?

Yes	
No	

Have any animals from your herd suffered from tuberculosis?

Yes	
No	

Do your animals drink water from Molopo River or Disaneng Dam? ________________

Have your cattle been in close contact with the wild animals from Mahikeng Game Reserve?

____

Do your animals share grazing land within the Mahikeng game Reserve?

Yes	
No	

Clinical signs and symptoms associated with **TUBERCULOSIS** in animals and humans.

Tick in the appropriate box if you have witnessed any of these signs and symptoms in humans or animals.

TUBERCULOSIS			
Animals	**Signs and symptoms**	**Human beings**	**Signs and symptoms**
Coughing		Coughing	
Emaciation		Emaciation	
Milk drop		Adenitis	
Fever			
Death			

UNISA
university of south africa

UNISA GENERAL RESEARCH ETHICS REVIEW COMMITTEE

Date: 02/02/2018

NHREC Registration # : REC-170616-051
ERC Reference # : 2018/CAES/003
Name : Ms MT Mozhendi
Student #: 53264835

Dear Ms Mozhendi

Decision: Ethics Approval from 01/02/2018 to 31/01/2019

Researcher(s): Ms MT Mozhendi
mabeltendai@gmail.com

Supervisor (s): Dr CJ Louw
louwcj@unisa.ac.za; 011-471-3784

Mr J Oosthuizen
oostej@unisa.ac.za; 011-471-2984

Working title of research:

A retrospective study on transmissible diseases among wildlife, domestic livestock and humans in wildlife/livestock/human interface of Mahikeng Game Reserve and its surrounding areas

Qualification: MSc Environmental Management

Thank you for the application for research ethics clearance by the Unisa CAES General Research Ethics Review Committee for the above mentioned research. Ethics approval is granted for a one-year period. After one year the researcher is required to submit a progress report, upon which the ethics clearance may be renewed for another year.

Due date for progress report: 31 January 2019

*The **low risk application** was **reviewed** by the CAES General Research Ethics Review Committee on 01 February 2018 in compliance with the Unisa Policy on Research Ethics and the Standard Operating Procedure on Research Ethics Risk Assessment.*

The proposed research may now commence with the provisions that:

ع

1. The researcher(s) will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.
2. Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study should be communicated in writing to the Committee.
3. The researcher(s) will conduct the study according to the methods and procedures set out in the approved application.
4. Any changes that can affect the study-related risks for the research participants, particularly in terms of assurances made with regards to the protection of participants' privacy and the confidentiality of the data, should be reported to the Committee in writing, accompanied by a progress report.
5. The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study. Adherence to the following South African legislation is important, if applicable: Protection of Personal Information Act, no 4 of 2013; Children's act no 38 of 2005 and the National Health Act, no 61 of 2003.
6. Only de-identified research data may be used for secondary research purposes in future on condition that the research objectives are similar to those of the original research. Secondary use of identifiable human research data require additional ethics clearance.
7. No field work activities may continue after the expiry date. Submission of a completed research ethics progress report will constitute an application for renewal of Ethics Research Committee approval.

Note:

The reference number ***2018/CAES/003*** *should be clearly indicated on all forms of communication with the intended research participants, as well as with the Committee.*

Yours sincerely,

Prof EL Kempen
Chair of CAES General Research ERC
E-mail: kempeel@unisa.ac.za
Tel: (011) 471-2241

Prof MJ Linington
Executive Dean : CAES
E-mail: lininmj@unisa.ac.za
Tel: (011) 471-3806