Understanding the spatial distribution and factors responsible for cloven hooved foot and mouth disease spread in Umkhanyakude district, South Africa

By

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Dissertation submitted in partial fulfilment of requirements for Master of Science Degree in geography

December 2017

Declaration

I, Khethiwe Ethel Dlamini declare that the dissertation hereby submitted by me for the MSc degree at the University of the Free State is my own independent work and has not previously been submitted by me at another university/faculty. I furthermore, cede copyright of the dissertation in favour of the University of the Free State.

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Abstract

Recent global reports show a continual vulnerability of large livestock populations to transboundary diseases such as cloven hooved foot and mouth disease (FMD) in relation to our environments. Of a particular concern is the spatial distribution of disease occurrences and its association with risk factors. Domesticated animals such as cattle are at risk of contracting the highly contagious FMDV that manifests with different distribution of serotypes across the world. FMD serotypes i.e. South African territory (SAT 1, SAT2, SAT3) are restricted to South African countries. Despite the several reports of FMD in Umkhanyakude district, few reports have utilized GIS (Geographical information system) technology for mapping the environmental factors and the disease concerned. In Umkhanyakude, Jozini and Umhlabuyalingana shoulder the highest FMD burden. In the present study, GIS was used to map FMD occurrences and to identify geographic areas with on-going FMD occurrences for the study period (2011-2015). MCDA was carried out to determine factors with the major influence on the spread of FMD. Weights were then assigned into percentage from 0 to 100% using an evaluation scale of 1 to 5, with 5 being extremely important, and 1 being of equal importance. Correlation analysis was carried out to determine the relationship between spatial occurrence of FMD and factors such as distance, herd size, rainfall, wind and temperature, correlation coefficient ranges from 1 to -1. Results revealed that there is a spatial relationship between FMD occurrences and factors concerned, areas with high vulnerability towards the spread of the disease were identified. Spatial distribution of the environmental factors, and vulnerability maps were derived to characterise the spatial pattern of FMD.

Keywords: Cloven hooved, Foot and mouth disease, Vulnerability, Band Collection Statistics

Acknowledgements

I would like to express my gratitude to my supervisor Dr. Samuel Adelabu for his great support, continuous encouragement and guidance through all my time of study.

I would like to extend my sincere thanks to my co-supervisor, Mr Pululu Mahasa who has given me support and guidance during the time I have spent in the Department of Geography.

I would like to thank Dr. Mtshali and Dr. Ntantiso for providing relevant information about FMD occurrences.

My due thanks to Mr Efosa for the great support in completing my Master degree and considerable contribution to its outcome, this dissertation would not have been successful without his support.

I would like to thank Dr. Kayode Adepoju for his great contribution; this dissertation would not have been a success without his support.

I would like to thank Geography Department staff (Qwaqwa) for their helpful comments during departmental seminars.

I would like to thank my fellow graduate students and friends in University of Free State (Qwaqwa) for making life unforgettable.

Dedication

To my beloved mother, Emily, for all the sacrifices and believe in us.

To my wonderful husband, Bhekumuzi, you are everything for me, without your love and understanding; I would not be able to make it.

To my lovely children, my life and hope, Zamo, Nqobile, Sandile, Sizwe, Ntadoyenkosi and Awande.

To all my sisters and brothers of The Twelve Apostles Church in Christ who prayed for me to succeed

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List of Acronyms

APA	African Protected Areas
ATp	Average Temperature
AR	Annual Rainfall
FMD	Foot and Mouth Disease
FMDV	Foot and Mouth Disease Virus
FAO	Food and Agriculture Organisation
GIS	Geographic Information System
GPS	Global positioning system
HS	Herd size
KNP	Kruger National Park
KZN	KwaZulu Natal
LSE	Landscape Epidemiology
M & E	Monitoring and Evaluation
NGR	Ndumo Game Reserve
NP	National Park
OIE	Office International des Epizooties
RS	Remote Sensing
SAT	South African Territory
SP	Spatial Epidemiology
SSAG	Society for South African Geographers
SZ	Surveillance Zone
TAD	Transboundary Animal Disease
UTM	Universal Transverse Macerator
WMA	Water Management Area
WS	Wind Speed
WOAH	World Organisation for Animal Health
WLC	Weighted Linear Combination
BCS	Band Collection Statistics
MCDS	Multi-criteria Decision Support

CHAPTER ONE: INTRODUCTION

1.1 Background

Foot-and-mouth disease (FMD) is a contagious disease which is caused by foot and mouth virus (FMDV), which affects cloven-hooved animals such as cattle and wild animals (Admassu et al., 2015), specifically South African Buffalos are confined to be the carrier (Jori et al., 2016). However, it is also classified as one of the most economically important infectious diseases of animals according to the Office International des Epizooties (OIE) of the World Organisation for Animal Health: WOAH (OIE, 2012a).

In South Africa, FMD is regarded to be one of the colossal challenges to livestock production and economic development in most of the provinces (Mtshali, 2012). The prevalence of the FMDV in Ndumo game reserve (NGR), for example may affect the international trade in the country (Agriculture, 2012). Also, Umkhanyakude district of KwaZulu Natal (KZN) province is one of those which have been attacked by the outbreaks of FMD in the recent past (Bruckner et al., 2002). As a result, the farming potential of local farmers of Umkhanyakude district was disrupted, their livestock production, food security, and their economy were considerably affected since the livestock serves as the backbone of the rural economy. Nevertheless, the control of FMD within the district of Umkhanyakude is the responsibility of the government, according to the Animal Diseases Act 35, 1984.

Prior to the outbreak of FMD in 2011, South Africa had zones that officially recognised by the OIE as infected zone, being the National Park (NP) and the surrounding game parks, while the protection zone is immediately bordering the infected zone and the free zone being the rest of the country (Admassu *et al.*, 2015) (refence). The north of KZN bordering Mozambique was a protection zone due to Mozambique being regarded as an infected country

(Sikombe *et al.*, 2015). Livestock (adult animals) affected by FMD generally recover, though the morbidity rate is very high in young populations. FMD is characterised by vascular lesions on the lips, hoofs, teats that may result in decreased milk yield, weight loss due to painful grazing, chronic mastitis and permanent hoof damage (Barnett, 2003). However, some animals like young buffalos in South Africa, a loss of the immunity is provided by maternal antibodies (which happens right after the weaning process) is required for FMD infection (Jori, 2015). Further, FDM is difficult to control once it has occurred due to its high contagious nature,

Worldwide, FMD occurs in some countries; however, it has been eradicated from some regions including North America and most of European countries (Mwanandota, 2013;Valarcher *et al.*, 2004;Valarcher *et al.*, 2009). It is reported that the economic importance of the disease is not solely based on the production loss, but also related to the reaction of veterinary services towards the control of the disease. In addition, the occurrence of the disease resulted in restricting the trade of animals and animal products locally and internationally (Knight-Jones and Rushton, 2013).

1.2 Motivation and Research Problem

Domesticated animals such as cattle are at risk of contracting the highly contagious FMDV that manifests with different distribution of serotypes across the world (Olabode *et al.*, 2014). However, FMD viral pool i.e. South African territory (SAT 1, SAT2, SAT3) are restricted to South Africa (Vosloo *et al.*, 2002), and are endemic in the national parks and countries like Mozambique and Swaziland. FMD virus are also responsible for causing long- term unapparent persistent infections which are difficult to diagnose in the field and can as well complicate disease control (Nardo *et al.*, 2015). Persistent infections of African buffaloes has been associated with the capacity to provide an important reservoir for FMD infection (Jori *et al.*, 2016). This has resulted in far more cross-border movements of people, domestic animals and the Buffaloes crossing the game fence (Caron *et al.*, 2013). In these circumstances, the risk of spread of FMD disease is still a challenge.

Restriction of cattle trade to neighbouring countries is one of the control measures for FMD outbreaks and viral transmission to prevent spreading of the disease. It was emphasised that livestock is regarded as the source of income and also source of food (Robinson and Knight-Jones, 2014), in the rural areas like Umkhanyakude district of South Africa and for the whole world. Most African countries including South Africa are ill-equipped to control transboundary animal diseases (TAD) such as FMD because of the lack of infrastructure and financial resources, ineffective animal health authorities, civil unrest, and even military conflict (Mtshali, 2012). Furthermore, government ascribe low priority to the control of animal diseases in the face of many other pressing problems like human health and education (Maree *et al.*, 2015). Despite the considerable information being available about the FMDV and its distribution, the disease remains a major threat to livestock sector globally (OIE, 2012a). This warrants the need for continued investigations of the current situation for the risk factors that influence the spread of the disease. The majority of countries in Asia and Africa, where the disease is endemic, are deficient in knowledge about the circulating subtypes of FMDV due to lack of systematic outbreak samples submission to the laboratories (Saeed et al., 2015).

Traditional understanding of FMD spatial distribution will not provide visual interpretation for spatial distribution of the disease, for describing and determining the factors responsible for FMD spread. Geographic information system (GIS) has been engaged in this study as a paramount technology to determine the distribution of the disease and its association with factors that has influence towards the disease spread in Umkhanyakude district. Unavailability of systematic FMD occurrences records in the study area may partly be overcome by mapping technologies of GIS. The study area is sharing the border with game parks known to be the FMD endemic zone, which poses a risk of disease outbreak to reoccur. A number of studies carried out in countries like Zambia, Nigeria, Botswana, Zimbabwe and

South Africa, provided evidence that the intensity of FMD outbreak was associated with distance to the nearest international border crossing, wetness index, elevation, movement of livestock in search of water and grazing (Dyason, 2010). However, each country or area has its distinctive influential environmental factor different from one area to another. Therefore, it was found very crucial to determine those factors within the study area.

1.3 Research aim

The study aimed at determining and understanding the spatial distribution of FMD within Umkhanyakude district of KwaZulu Natal,South Africa, and to examine the environmental factors that have a link with the spread of the disease.

1.4 Specific objectives

Objective 1: To map FMD incidence in the five years period (2011- 2015) within the Umkhanyakude district of KwaZulu Natal, South Africa.

Objective 2: To explore the relationship between the environmental factors that are responsible for FMD spread in Umkhanyakude district of KwaZulu-Natal, South Africa.

Objective 3: To determine the areas with high FMD vulnerability towards livestock.

1.5 Research Question

1. What is the situation of FMD and which areas mostly affected?

2. Is there a relationship between the occurrence of FMD and its environment?

3. Which environmental factor has a major influence towards the spread of FMD?

1.6 Outline of the dissertation

Chapter 1: This chapter outlines the background, research problem, research aim, research objectives, research questions and structure of the dissertation.

Chapter 2: This chapter contains literature about FMD epidemiology, Distribution of FMD, Spatial epidemiology

Chapter 3: . This chapter outlines and describes the study area. It also describes data used for the study, as well as methods that used to address the aim of the study.

Chapter 4: This chapter presents the results of each objective of the study. Results presentation is in the form of maps, tables and charts and is displayed following this order: Spatial distribution of FMD reported cases; environmental factors such as rainfall, wind speed and average temperature. Subsequently, results showing the locations with greater chances than others of regarded as high-risk areas are also presented.

Chapter 5: -Discussion

Chapter 6: - Conclusion and Recommendations

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The prevalence of FMD varies worldwide and at times only affecting certain districts or local areas predominantly (FAO, 2012). In South Africa, provinces which share the boarder or closer to FMD endemic countries, are likely to be contaminated by the disease. Areas along the national park and game reserves are also at risk. Although it has been noted that FMD cases have been decreasing in South Africa as a of disease control programs, populations who live within or next to FMD endemic areas are at risk of contracting the disease. Jori (2014) states that the occurrence of FMDV in South Africa is normally confined to the free-living African buffalo (*Syncerus caffer*) of KNP and associated with private nature conservancies in the north eastern corner of the country. Ndumo game reserve (NGR) of Umkhanyakude district falls under similar scenario of being regarded as FMD endemic site, due to the containment of African buffaloes. SAT 1, buffaloes efficiently maintain 2 and 3, and vaccination was only practiced in a small region along the western and southern boarders of KNP. Detailed geographic distribution of FMD and fundamental concepts of spatial epidemiology of the disease are therefore to be discussed.

2.2 Nature of FMD as a transboundary disease

Transboundary Animal Disease (TAD) may be defined as those epidemic disease which are highly contagious or transmissible and have the potential for very rapid spread, irrespective of national borders, causing serious socio-economic and possibly health consequences. These diseases can result in high morbidity and mortality in susceptible animal populations, thereby constituting a constant threat to the livelihood of livestock farmers (FAO, 2017).

OIE stated that many countries use the term exotic animal disease to define the disease that has disastrous consequences when entering their territory. From United Nations point of view, the preferred name is TAD. These are diseases of transboundary nature namely: foot and mouth disease, rinderpest, contagious bovine pleuropneumonia, sheep and goats pox, peste des petites ruminants, avian influenza, rift valley fever, Newcastle disease, swine fever and equine encephalitidies.

FMD is a highly infectious disease of cloven hooved animals, it is grouped in List 'A' of transboundary animal diseases according to the office international Epizooties (OIE) of the World Organisation for Animal Health (Mustafa *et al.*, 2016). FMD is a viral disease which belongs to the *Aphthovirus* genus of the family *picornoviridae* in the group of viruses called *picornaviruses*, which means that it is highly contagious (Sei *et al.*, 2016). It is one of the most important livestock diseases in the world. It has the potential to infect all cloven-hoofed animals (i.e. wildlife, cattle, goats, sheep, and pigs) and has major economic impacts on animal trade (Dhikusooka *et al.*, 2015). Nature of the disease symptoms are displayed in figure 2.1 below.

Figure 2.1: Symptoms of foot and mouth disease in cattle showing the clinical symptoms for the disease (Source: www.thecattlesite.com).

FMD is not recognised as a zoonotic disease. However, the disease spreads very quickly if not controlled and because of this, it is a reportable disease. It is characterized by fever, loss of appetite, salivation and vesicular eruptions on the feet, mouth and teats (Tesfaye *et al.*, 2016;Wungak *et al.*, 2016). As class 'A' disease according to OIE disease classifications, the laboratory diagnosis of any suspected FMD case is a matter of urgency (OIE, 2012b). Furthermore, its distribution is described by seven serotypes of FMDV across the globe. Within these serotypes, over 60 subtypes have also been described using biochemical and immunological tests, and new subtypes occasionally arise spontaneously. The importance of subtypes is that a vaccine may have to be tailored to the subtype present in the area in which the vaccine is being used (FAO, 2017).

2.3 FMD Epidemiology

The epidemiology of FMD is influenced by a cycle, in which wildlife plays a role in maintaining and spreading the disease to other susceptible domestic animals.(Brito *et al.*, 2016). Outbreaks of FMD in cattle caused by SAT serotypes are usually associated with wild buffalo known to be the reservoir host (Sikombe *et al.*, 2015). FMDV infections may be maintained in cattle sub clinically by strengthening of the virus through serial passage in the same species and depending on the density of naive cattle, epidemics may occur (Parthiban *et al.*, 2015).

Potential risk factors found to be associated with FMD includes, farming system, age category of animals, breed type, sex and seasonal influence (Sarker *et al.*, 2011). Other risk factors pointed out by Intha (2009) include management of the farm, feed source of the animal, trade of animal and husbandry practices. Therefore, semi-intensive farm systems or smallholder livestock in developing countries are prone to FMD. The reasons might also stem from either the increased contact between animals infected and animals susceptible to the infection.

2.4 Control of FMD spread

The disease is mainly controlled by stamping out approach supported with emergency ring vaccination carried out on the risk territories. In areas with minimal livestock movement restrictions, vaccination is the main option for FMD control (Knight-Jones and Rushton, 2013). Vaccine type is aligned with serotype of a certain territory for its full potential effect (Díaz-San Segundo *et al.*, 2011). Live attenuated or inactivated bi-, tri- or polyvalent vaccine which contains the representative strains of the serotypes that are in circulation in the region must be utilised (Robinson *et al.*, 2014). In Umkhanyakude of KZN, South Africa SAT 1 and SAT 3 were laboratory diagnosed in year 2011 and strict livestock movement is enforced as the main control measure.

2.5 Role of carriers in the epidemiology of FMD

A carrier animal can be defined as the animal in which the live virus can be recovered after 28 days following the infection (Parthiban *et al.*, 2015). The virus can be isolated from the oesophageal pharyngeal area. Fully susceptible animal is a vaccinated or non-vaccinated host, which develops clinical signs of the disease and in which virus persists following the recovery and becomes a carrier. The FMDV persists in African buffaloes between 5 to 24 years, 3 years in cattle, 9 months in sheep and 3-6 months in goats, but the mechanism underlying persistence is not well understood (Wekesa *et al.*, 2015)

Apart from Africa buffalo, FMD can affect number of wild animals namely Impala (Aepyceros melampus), Kudu (*Tragelaphus strepsiceros*), Warthog (*Phacochoerus aethiopicus*) and elephants. Furthermore, the African buffaloes have shown to be the source of infection for cattle under both natural and experimental conditions (Sangare *et al.*, 2001). The transmission of the virus is mainly facilitated by direct contact between the two populations during the acute stage of infection and shedding of virus in large amount. Impala (*Aepyceros melampus*) is the most frequently infected species and act as intermediaries in the disease transmission.

2.5.1 Grazing behaviour of cattle and buffaloes

Little research to date has focused directly on intraspecific age difference related topography or resource selection patterns by livestock. All factors that influence livestock resource selection behaviours are highly interrelated, by which the chances of direct contact between the two population (cattle and buffaloes) is increased. The availability of forage for grazing herbivores in savannah varies spatially and seasonally (Kaszta *et al.*, 2016). Large herbivores i.e. cattle and buffaloes tend to compete for similar type of forage, which sometimes called bottom up process (Gandiwa *et al.*, 2016). Furthermore, crude protein concentration decline and fibre levels increase as the grasses become senescent over the course of the dry season, That also could be a determining factor of grazing behaviour of the two population.

During the dry season there is the depletion of accessible forage, therefore the African buffaloes move towards region with available grass species which can lead to cattle and buffalo to overlap over resource competition (Zengeya *et al.*, 2015). Environmental conditions affect daily energy requirements, i.e. temperature, wind speed and moisture can cause stress by shifting the animal outside of the zone (Macandza *et al.*, 2004). Grazing animals are selective in their eating; the selection is determined by plant morphology, the presence of secondary compounds and experiences. Palatability, preference and species difference plays a fundamental role in species selection. Under temperate grazing conditions, cattle discriminate between temporal states of the veld and graze selectively when confronted with heterogeneous swards.

This is emphasized by outbreaks recorded in the Kafue flats over the past fifty years occurred during dry season as a result of transhumant and resident cattle population congregate on flats for grazing (Sikombe *et al.*, 2015). From April to September, the herds of buffaloes of KNP also migrate in search of better grazing. However, the recurrent of FMD outbreaks in this region believed to be the contact between cattle and migratory buffaloes, as a result of fence permeability as well as where the fence is totally removed (Michel and Bengis, 2012).

2.5.2 FMD in wildlife population

FMD in sub-Saharan African wildlife has been studied since the early 20th century (Jori and Etter, 2016). Both natural and experimental infections have been demonstrated in different species. Subclinical and clinical symptoms have been identified in numerous populations including African buffalo (Wekesa *et al.*, 2015). However, severe outbreaks in Impala have been reported in Kruger national park for decades. Despite all the wildlife species that have been infected with the virus, only African buffalo and Impala of South Africa implicated in the transmission of FMD to cattle (Brito *et al.*, 2016). This situation draws attention to the study area, where these two populations are contained in Indumo and Tembe Game Park.

Several epidemiological studies have shown that the African buffalo maintain the three SAT serotypes in the southern Africa. The ability of African buffalo to harbour a number of pathogens that are transmissible to domestic livestock creates a complex problem for both domestic and wild communities (Kock *et al.*, 2014). Although there is some arguments that African buffaloes are only wildlife species that play a role in maintaining the FMDV (Weaver *et al.*, 2013). This may be supported by the probang samples from African buffalo in Mozambique, Tanzania and Zambia which contained FMDV serotypes SAT 1, 2 AND 3, indicating all the positive maintenance within the buffalo population (Kasanga *et al.*, 2012). A serological study of cattle grazing adjacent to the game park in Zimbabwe and in South Africa also detected seroconversion of cattle to FMD serotypes carried by buffalo, but without showing clinical signs. This warrants the need for close monitoring as part of effective FMD surveillance along these settings (Jori and Etter, 2016). Despite a number of review article on FMD in wildlife, science based information is still lacking (Wekesa *et al.*, 2015). Beyond the valuable experimental infection work performed in a quite number of wildlife species, most of published literature on the subject fail to distinguish between evidence of infection and ability to effectively maintain infection at population level that could result in either persistence or frequent transmission to other species (Maree *et al.*, 2016)

FMD in wildlife has been reviewed and denoted that, origins of outbreaks in livestock are frequently attributed to buffalo, but also suggested that transmission from cattle to buffalo also occurs (Brito *et al.*, 2016). In general, clinical signs in wildlife are similar to what is seen in domestic animals, although the pathogenesis of FMDV in wildlife species has not been studied extensively (Sikombe *et al.*, 2015). However, the transmission of FMDV is pioneered by contact between the two populations. Figure 2.2 depicts possible contact zones between buffaloes and cattle.

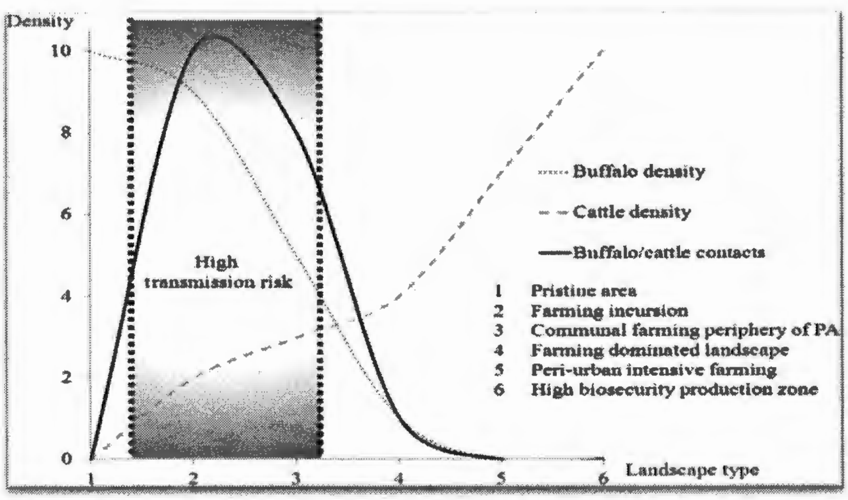

Figure 2.2: Buffalo-cattle contacts in relation to different human-nature interactions in African protected areas (APA) context (Kock *et al.*, 2014)

2.6 Mechanisms of FMD spread

FMD is frequently spread by different mechanism which includes movement of infected animals and aero-genous transmission to susceptible animals of infectious droplets and droplet nuclei, distance, heard size, temperature and precipitation (Donaldson and Alexandersen, 2002). Another very common mechanism of spread is by the movement of contaminated animal products, including meat, milk (Gloster *et al.*, 1982a), etc. In addition, FMDV can be spread by the wind (Donaldson, 1988). In general, integration of factors such as distance, herd size, rainfall, wind speed and temperature in determining the occurrence and the spread of FMD is fundamental. Occurrence of the disease took place in different geographic locations; each factor's level of influence may differ from one place to another. In this study, each factor was examined against the occurrence of the disease for each study year to determine factor with major influence towards the spread of the disease.

2.6.1 Inter-domestic transmission

In the rural areas where extensive farming is practised, it is quite often to keep both cattle and goats. Small ruminants can also play an important role in the epidemiology of FMD (Sinkala *et al.*, 2014). Raising cattle with goats may increase the risk of spreading the disease since goats are highly susceptible to FMDV and spread the virus through aerosol (Chakraborty *et al.*, 2014). This may be the mode of virus transmission to other animals that are raised together in the same area. Once an animal is infected, the virus can be disseminated into the environment including field pastures, water resources and soil (Abbas *et al.*, 2014). Sharing of pasture and water source is common in most communal areas like Umkhanyakude district, where farmers (subsistence farmers) feed their animals by letting the animals roam freely in communal veld. This type exercise can promote the spread and infection of FMD in cattle, as it is mainly transmitted via contact of infected animal and susceptible animals in the same area. Cattle are sensitive to respiratory infections, therefore aerosol transmission can be expected (Kitching and Hughes, 2002).

In Zimbabwe for example, FMD spread seemed to have been perpetuated by domestic animal populations since the initial possible spread from buffalo in

September 2001 (Vosloo *et al.*, 2002). In adult sheep and goats, FMD is frequently mild or unapparent and the cardinal signs mimic other diseases, which makes a clinical diagnosis difficult. However, high mortality can result in young animals (Kitching and Hughes, 2002). Their ability to become carriers represents a reservoir for further infection and spread of disease, and so trade of live sheep and goats present a major risk of entry of FMD to disease free countries (Sikombe *et al.*, 2015).

In Turkey, 18.5% of the total FMD cases reported in 1996 were associated with small ruminants (FAO, 2017), and in Greece, during the 1996 FMD epidemic, 5,000 sheep and goats were destroyed (OIE, 2012b). In the 2001 epidemic in Great Britain, the first species infected on the affected farms was almost always sheep (53%) or cattle (45%) rather than pigs (Ferguson *et al.*, 2001).

2.6.2 Meteorological transmission of FMD

Under favourable climate conditions of low temperature, high humidity and moderate wind speed (Admassu *et al.*, 2015), aerosolized FMDV can travel a significant distance (up to 300 kilometres), as was documented in the United Kingdom. More frequently, there is shorter airborne spread (approximately 20 kilometres), particularly downwind (Admassu *et al.*, 2015). However, the highest concentration is likely expected in stable, low wind conditions where there is a minimal mixing (Mikkelsen *et al.*, 2003). Airborne FMDV is usually the result of a large number of infected pigs, resulting in plumes of aerosolized virus in the atmosphere, and can produce large quantities of aerosolized virus (Zaher and Ahmed, 2014). Cattle, because they inhale more air they are likely to be easily infected through respiration.

It has been demonstrated that humans can harbour FMDV in their nasal passages and throats for short periods of time, up to approximately 28 hours (USDA, 2016).Under experimental conditions, personnel did transmit infection to naive animals. Animals infected with FMD exhale virus in their breath as droplets and droplet nuclei at various levels depending on the virus strain (Aiki-Raji *et al.*, 2016), disease stage, and animal species. For instance, pigs infected with certain strains of virus can emit more than three orders of magnitude more airborne virus than cattle or sheep (Fakai *et al.*, 2015).

The corresponding air concentrations downwind can vary by over two or three orders of magnitude, depending on the prevailing atmospheric conditions. The highest concentrations can be expected in stable, low-wind conditions, where there will be low levels of turbulence and hence minimal mixing (Klausner *et al.*, 2015). FMDV can be found in all secretions and excretions from acutely infected animals, including expired air, saliva, milk, urine, faeces and semen, and can shed FMDV for up to four days before the onset of clinical signs (OIE, 2012a). The virus can also be transmitted on fomites including vehicles, as well as mechanically by animals and other living vectors.

2.7 Global geographic distribution of FMD

FMDV has a global distribution, with the exception of North America, Western Europe and Australia. Three serotypes namely 'O', 'A' and 'C', are endemic in most of the countries (Ranjan *et al.*, 2016). Serotypes 'A' and 'O' are widespread throughout Sub-Saharan Africa, whilst type 'C' appears to have disappeared from the world as a whole, with exception of Kenya.

However, the different serotypes also have different epidemiological behaviours (Onono *et al.*, 2013). The three SAT serotypes, SAT1, 2, and 3, are generally restricted in distribution to Africa, but occasionally found in the Middle East (Admassu *et al.*, 2015). Even within Africa, the SAT2 virus has a wider distribution and is more frequently found in cattle than the other two strains (Robinson *et al.*, 2014). All three strains are found routinely in the African Buffalo. On the other hand, Asia virus never found outside of Asia, except for a brief excursion into Greece in year 2000. Type 'C' is characterised by a long disappearance from the circulating virus pools, the most recent of which gave optimism that it had completely died out from the globe (Mwanandota, 2013).

There are many enigmas surrounding the behaviour of different FMDV serotypes, most of which cannot yet be explained. The tendency by those unfamiliar with the virus is to assume that all strains and serotypes behave in the same fashion, which leads to significant errors of judgement. Despite the propensity and opportunities for the spread of the FMDV into new regions, there is a tendency for the virus to recur in the same parts of the world (Jamal and Belsham, 2013). This presumably reflects some degree of either ecological isolation or adaptation. The epidemiological patterns of FMD in endemic area can be defined by ecosystem based approach, which was originally described in South America, and can be applied to other parts of the world (Rweyemamu *et al.*, 2008). The distribution and the status of the disease across the world are clearly displayed by means of the figure 2.3 below. Umkhanyakude district is inclusively presented as high risk area since South African game parks are classified as FMD endemic (Grover, 2016).

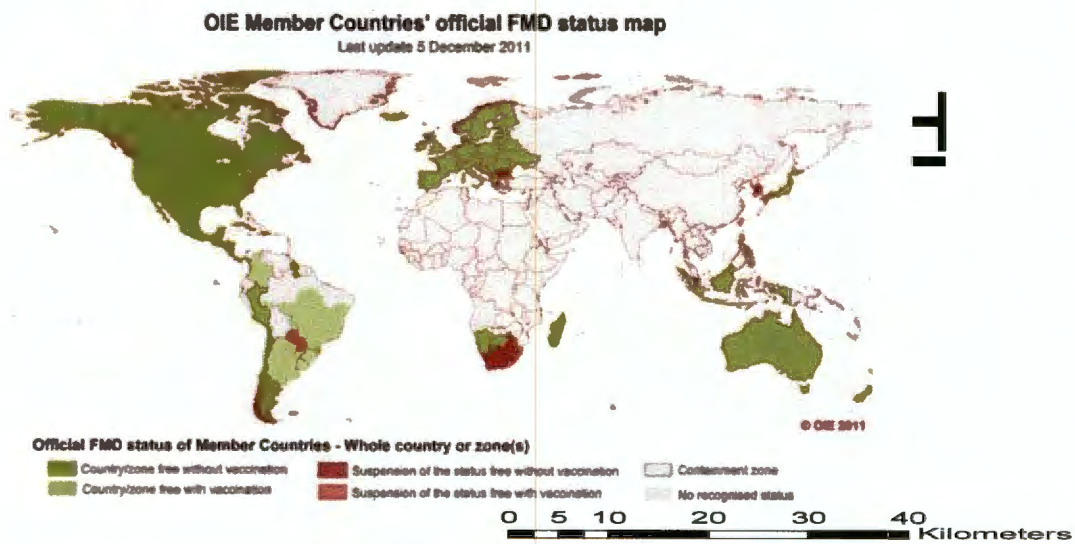

Figure 2.3: Map reflects the global distribution status of foot and mouth disease updated in 2011 (OIE, 2011)

2.8 Distribution of FMD in Africa

In the Central Africa, serotypes O, A, SAT1 and SAT 2 have been responsible for most outbreaks. FMD in Zambia was first reported in 1933 in a place called Barotseland (now Western Province) (Sikombe *et al.*, 2015). Currently FMD is endemic in some parts of Northern and Muching province along areas bordering Tanzania and in the Southern boarders between Zambia and Zimbabwe, Botswana and Namibia and along Kafue and Zambezi flood plains which is also bordered by parts of Kafue National Park (Genchwere and Kasanga, 2014). These areas are densely populated with domestic and game animals coming in contact for most parts of the year. Transhuman grazing is a factor that influences the contact of domestic and wild population in search of water and grazing in this region.
Interaction of buffalo and cattle may pose a risk of FMDV spread that has been seen in Mbeya region of Southern Tanzania where two populations tends to share same serotype of FMD outbreak with Zambia (Sikombe *et al.*, 2015). Outbreaks in these areas tend to occur at the same time, suggesting that there is a likelihood of transmission of the disease between these two countries. Similarly, outbreaks of FMD between Zambia, Zimbabwe, Botswana and Namibia tend to follow trans-border transmissions. In 1976 SAT 3 was recorded once in Malawi, while serotype 'C' also occurred only once in Zambia in 1981.

OIE (2014) reported that, in West Africa, only serotypes 'O', 'A', SAT 1 and SAT 2 were recorded between 1958 and 2001. Most outbreaks were caused by serotype 'A', followed by 31 outbreaks confirmed to be caused by SAT 2, 15 outbreaks by SAT 1 and 13 outbreaks attributed to serotype 'O'. However, SAT 1 has been recorded only in Niger, Nigeria and Ghana. In North Africa, serotype 'A' and 'O' were recorded regularly since 1958, while serotype 'C' occurred in Tunisia only during 1965, 1967 and 1969.

In East Africa SAT 3 was recorded once in Uganda in 1970 within the buffalo population, serotype 'C' occurred in Ethiopia in 1971 and in Uganda between 1970 and 2000. This appears to be the only region of the world where this serotype has been found in recent times (FAO, 2012). The serotype 'C' virus have disappeared elsewhere in the world, it has been postulated that the occurrence of this serotype in East Africa may be vaccine related. Areas located along the international borders and along the borders of game conservancies are at high risk of FMD outbreak (Sinkala *et al.*, 2014).

It was also highlighted that, areas between South West Chad and North East Democratic Republic of Congo boarders with South Sudan. Spatial range which overlaps with Aouk Aoukale Faunal Reserve in Chad, the Monovo Gounda St. Floris and Bangoran National Parks in the Central African Republic have the same ecological areas where the FMD prevalence has been reported (Di Nardo *et al.*, 2011). However, the persistency of the disease occurrence may be the result of inadequate epidemiological understanding and the ineffective control measures.

According to OIE, it was found that in 1892 Hutcheon recorded the first official outbreak of FMD in South Africa, followed by outbreak in Griqualand West. According to the information obtained from the inhabitants, FMD have been prevalent. After the great rinderpest occurrence in1896 to 1905, FMD disappeared from Southern Africa until it reappeared in Zimbabwe in 1931 (Bruckner *et al.*, 2002). At that time, the reintroduction of the disease believed to be imported by animals or animal products, since the ability of African buffalo to provide a reservoir of the virus was unknown.

In South Africa, the FMDV is endemic in the KNP where African buffalo provides the principal reservoir of infection (Kock *et al.*, 2014). However, according to the OIEKNP and the surrounding game parks were defined as the infected zone, the areas immediately adjacent to the KNP constitutes buffer zone (BF), while the surveillance zone (SZ) is situated to the west of the buffer zone, and the rest of country as a free zone (Jori and Etter, 2016).

South Africa lost its FMD free status after the outbreak which occurred on the 14th September 2000 in Camperdown in KZN (Jamal and Belsham, 2013). This outbreak was recorded to have been caused by the serotype 'O' virus. This was followed by an outbreak that occurred in cattle feedlot in Middelburg district of Mpumalanga Province on the 29th November 2000. With this outbreak, it was believed that the disease originated from buffalo-cattle contact within the SZ of Nkomazi bordering the southern KNP (Dyason, 2010).

On the basis of clinical signs of the disease, the diagnosis of the disease was done on the 15th of December 2000 and confirmed by virus isolation and serological testing (Jamal and Belsham, 2013). In Limpopo Province, bordering the KNP lesions caused by serotype SAT2 were detected at the dipping tank in Mhala district (Jori *et al.*, 2009). The situation of FMD in South Africa is displayed in figure 2.4 below.

Figure 2.4: Map showing categorical distribution of FMD in South Africa (Source: DAFF, 2014)

2.9 FMD situation in Umkhanyakude district of KZN, South Africa

FMD control measures in Umkhanyakude district of KZN, South Africa include the separation of wildlife from communal livestock population using high impact fence and movement control of susceptible livestock through quarantine. Serological and virological surveillance is being instated in accordance with the current FMD contingency plan. Cattle presumed to have developed maternal antibodies may be vaccinated after 3 to 4 months against the disease. Nevertheless, this is not strictly practiced in the field. Red line fence was erected to control the contact and movement of livestock of high surveillance zone and of free zone.

2.10 Spatial epidemiology

Spatial epidemiology (SP) has been described as the study of disease occurrences or risk (Ostfeld *et al.*, 2005). It is also described as a sub discipline of medical epidemiology which uses environmental conditions as an explanatory variable in the study of disease health phenomena, also known as landscape epidemiology (LSE) (Young *et al.*, 2013). Ecological studies reveal that pathogen dispersal can be highly localised, and pathogen reservoirs might be spatially clustered. It is also suggested that integration of landscape ecology with disease epidemiology would be fundamental (Emmanuel *et al.*, 2011).

Infection uses various modes to disperse from infected to an uninfected host. Some modes involve direct contact, and indirect contact, whereas others on vectors. However, the probability of transmission declines if the infected host is at a distance. Spatial epidemiology is regarded as a principal scientific subject to provide understanding of the causes and consequences of spatial heterogeneity in infectious disease like FMD (Dion *et al.*, 2011). Pavlovsky, (1966) first coined the concept of landscape epidemiology encompassing three basic observations:

1. Disease tends to be limited geographically.
2. There exists spatial variation of the underlying factors in the physical and biological conditions that support the pathogens and its disease reservoirs.
3. Abiotic and biotic conditions can be delimited on maps, and then both contemporaneous risk and future change in risk should be predictable (Emmanuel, 2011).

Furthermore, vitality of considering the link between environmental factors and disease occurrences is diagrammatically displayed in Figure 2.5 below.

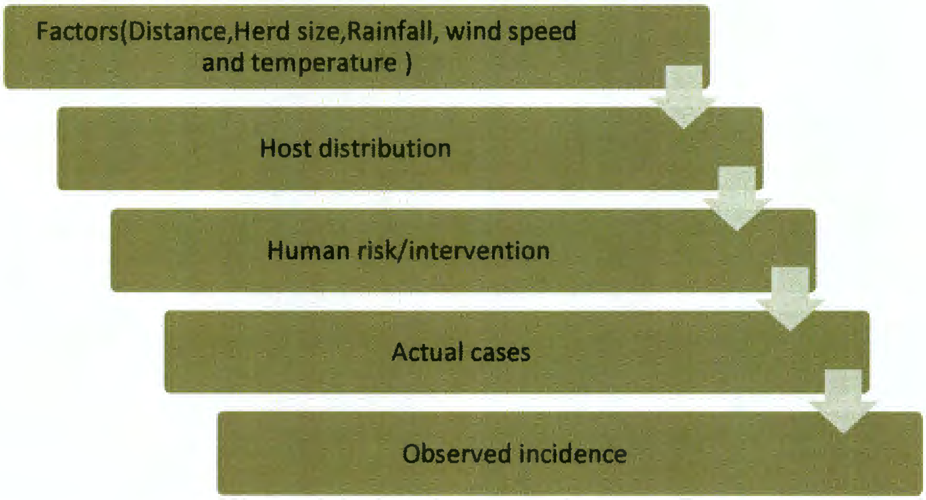

Figure 2.5: Link between factors that influence FMD occurrence (created by the author)

2.13 Mapping of the disease using GIS

GIS is the most popular software in the basic mapping of the disease epidemiology (Carpenter, 2011). However, representation of epidemic data in the form of a map simplifies interpretations, synthesis and recognition of disease clusters and frequencies. Representation of disease maps can be qualitative or quantitative. Qualitative maps illustrate the location of the disease without specifying the amount of its infection. An example is the point distribution map generated in which Dicrocoelium dendriticum in sheep was shown in the area of Southern Italy, whereas quantitative maps display number of disease cases, population at risk and prevalence and intensity (Woolhouse, 2011).

The need for using this system in the field of veterinary services has been emerging during the last decade with many disease reporting systems and projects. Application of GIS is to produce descriptive maps and it has been included in decision support system for control of infectious diseases in animals (Amin et al, 2012).GIS functions are useful in animal disease surveillance, recording and reporting disease information, disease incidence, prevalence at local, regional and national levels can be visualised by mapping process.

For example, in Brazil, Amaral employed the GIS-MCDA methodology not to generate estimates of absolute risk, but rather describe variation in absolute risk map. Amin conducted the study in 2012 where buffer process was done around outbreak areas to determine the proximity to the risk factors responsible for disease outbreak. In Zambia Sinkala conducted spatial analysis to create map of FMD within the study. In Kwara State-Nigeria Olabode carried out spatial analysis based on proximity analysis of closeness of animal herds to water sources and roads, which were potential means of disease spread.

Spatial epidemiology can be divided into three main areas namely: disease mapping, surveillance and geographic correlation (Jerrett *et al.*, 2003). Each of the these spatial epidemiology types are reviewed as follows:

2.11.1 Mapping spatiotemporal dynamics of disease

Livestock diseases epidemiology mapping have been used for specified distinct purposes, i.e. involvement of retrospective analysis of spatiotemporal dynamics of epidemics to understand what factors influence the spatial pattern and rate of disease spread (Dion *et al.*, 2011).

Spatiotemporal approach was used in UK to investigate FMD in cows and sheep. Spatial clustering and spread of FMD were used to model local and long distance transmission rate (Keeling *et al.*, 2001). These results were used to predict how different control strategies would impact FMD epizoitics. Moreover, spatiotemporary dynamic analysis requires a highly precise data of disease incidence. It was emphasised by Young *et al.*, (2013) that studies have shown the effectiveness of using landscape epidemiology approach with environmental variables, especially when GIS employed.

2.11.2 Geographic correlation studies

Geographic correlation studies are aimed at examining geographic and demographic dynamics in exposure to environmental variables and socioeconomic measures, or lifestyle factors in relation to health outcomes measured on a geographic scale (Haaga, 2007). This area can be explored in two subdivisions: spatial statistics and ecological analysis

2.11.2.1 Ecological analysis

Ecological analysis in spatial epidemiology refers to the relationship between spatial distribution of the disease and environmental factors and their analysis. There are a number of studies in which the relationship between disease indicators such as prevalence, environmental and climatic variables have been explored e.g. (Bastos et al., 2000; Bestbier, 2016; Donaldson et al., 1988).

2.11.2.2 Spatial statistic

Spatial statistic comprises a set of techniques for describing and modelling spatial data. In many ways, it extends what the mind and eyes do, intuitively, to assess spatial patterns, distributions, trends, processes and relationships. Unlike traditional statistical techniques, it uses space, area, length, proximity, orientation, and spatial relationship in mathematical way (Scott and Getics, 2008).

2.11.3 Disease surveillance

Disease surveillance system is regarded as the set of planned epidemiological activities, aimed at identifying and preventing new cases of the disease (Rinaldi *et al.*, 2006). However, spatial surveillance system is based on the presence of non-natural cluster of the disease in the area. Several infectious diseases like FMD have re-emerged during the recent years, the most important factors causing the re-emerge of the disease are climate change, habitat changes, water sources, pollution, resistance to drugs and illegal international trades (Di Nardo, 2014).

2.12 Multi-criteria decision analysis (MCDA)

MCDA is concerned with structuring of decisions and planning of multiple criteria problems, with the purpose of supporting decision-makers facing such problem (East *et al.*, 2013;Martínez-López *et al.*, 2014). Pertaining to health needs and accelerating technological developments an ever-increasing demand on limited health budgets. Policy makers need to make important decision on the use of public funds, to focus on question such as which disease areas with which intervention. The underlying problem is that decisions on the choice of health intervention. Prioritisation of interventions can be done through MCDA (Hongoh *et al.*, 2011;Linkov *et al.*, 2006), i.e. high priority may be given to areas which are highly vulnerable to FMD MCDA is a structured tool that allows for the evaluation of alternatives based on multiple, possibly conflicting or even incommensurate criteria in a decision problem.

Key strength of MCDA is the ability to incorporate multiple stakeholders' perspectives as well as uncertain, subjective and qualitative information into an explicit and transparent decision-making process (Dominiak, 2006). MCDA based approaches begin with an intelligence phase where the problem definition, decision constraints and evaluation criteria are defined.

This followed by a design phase where the list of possible alternatives and decision maker's preferences are made explicit. The final phase consists of applying the decision rules and sensitivity analysis to produce a recommendation.

The applicability of MCDA was observed when determining the factor with prominent impact in the vector borne diseases (Hongoh *et al.*, 2011). Clement *et al.*(2009) used MCDA to create a knowledge-driven model of disease risk. Relationship between environmental drivers and rift valley fever (cattle disease) risk was examined, used MCDA to integrate technical spatial information on climate, landscape and livestock density (herd size) along with data from published literature (Stewart, 2005). Santos *et al.* (2017) engaged MCDA to create a FMD model that integrates data from diverse source to identify FMD risk areas.

2.13. Disease risk mapping

In this regard, disease clusters are explored through the use of space, time and space-time pattern detection methods (Meliker and Sloan, 2011). The term cluster indicates an excess of cases above background rate in relation to time and space. Risk mapping and spatial data modelling in epidemiology is aimed at predicting the occurrence of the disease. There is an interrelationship between disease spread and the characteristics of the environment which could be identified using geographical correlation methods (Dhama *et al.*, 2013). Spatiotemporal data such as temperature, humidity, wind speed etc. could be used together with epidemic data to develop predictive model, data set that can be processed using the spatial analysis methods to generate risk maps (Bergquist and Rinaldi, 2010; Tran et al., 2013). Rouche et al, (2014) produced a map that illustrates the predicted FMD outbreaks in Australia, New Zealand, USA, UK and Netherlands.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Introduction

The aim of the present study was to analyse the spatial distribution of FMD incidence in Umkhanyakude district of KZN, South Africa. This chapter outlines and describes the study area. It also describes data used for the study, as well as methods that used to address the aim of the study.

3.2 Description of the study area

Umkhanyakude district is in the north eastern (27.2719° S, 32.5373°E) part of KZN, extending from the Umfolozi river up to Mozambique border. Greater St Lucia Wetland Park forms the coastline of Umkhanyakude district onto the Indian Ocean. Umkhanyakude encompasses the whole of former Uphongolo sub-region and part of Umfolozi sub-region. Umhlabuyalingana and Jozini are both one of the municipalities selected as a focus area for the study as outlined below:

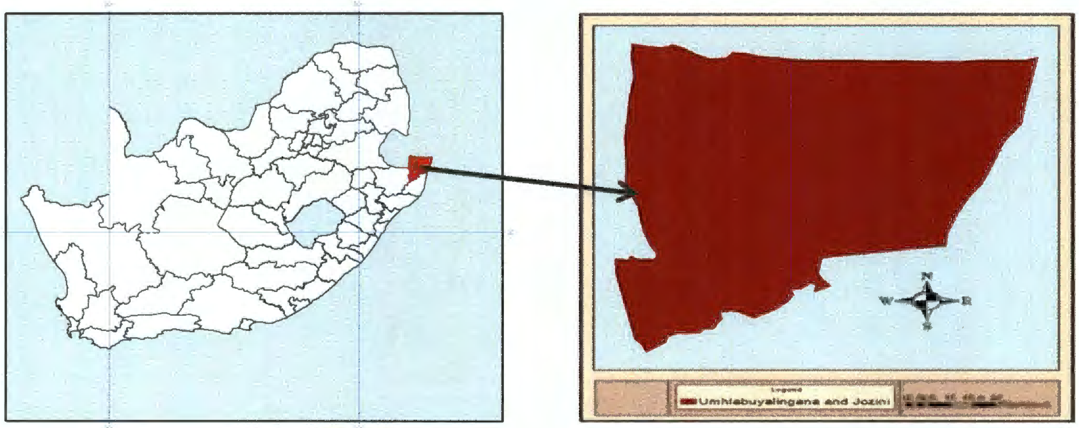

Figure 3.1: The location of the study area in KwaZulu-Natal province, South Africa (created by the author)

3.2.1 Demographic description of the study area

Population was estimated to be 625846 (45.2% male and 54.8% female) in 2011, spreading over the entire five local municipality of Umkhanyakude. Umkhanyakude has an average of 45.17 people per km^2 and total area of 13855.35 km^2 (STATSSA, 2011), 67% of this area is arable as far as the development of pastures, and livestock and game farming are concerned. Cattle and goats estimated to be 234500 (49% cattle and 51% goats). Ndumo game reserve has the population of approximately 145 African buffaloes that are kept inside the park. Only 10.8% of the area has high potential soils suitable for crop production, the main commercial agricultural activities are sugarcane and timber production while a small proportion of the land is under sisal, livestock farming, pineapple and vegetable production (COGTA'REPORT, 2014).

3.2.2 Climate

The southern and north eastern parts of the study area fall within the humid subtropical region, whereas the north western part is in the semi-arid rainfall region. It is characterised by a temperate climate to hot summer and mild winter. The district is situated at an altitude of approximately 203m above the sea level. Average summer maximum temperature varies between 29^{0}C to 30^{0}C. The highest mean annual rainfall (1000mm) occurs in the southern part of the district, the north and the central parts receive a mean annual rainfall of 801 – 1000mm (COGTA'REPORT, 2014).

3.2.3 Catchment and vegetation characteristics

Several studies reveal that water source can serve as a FMDV mode of transmission from one population to another i.e. buffalo-cattle or cattle-cattle. Umkhanyakude falls within Mfolozi/Pongola primary catchment, which is being shared between two FMD endemic countries i.e. Swaziland and Mozambique. The area also falls within the Usuthu-Mhlathuze water management area (WMA). Mhlathuze water provided a supportive management for the DWA since 1980 for the catchment area by establishment of Usuthu-Mhlathuze catchment. Vegetation is summarised as follows: clay thornveld i.e. acacia nilotica and cissus rotundifolia and coastal sandveld i.e. panicum maximum and themeda triandra (Morgenthal *et al.*, 2006).

3.3 Study design

This study involved both prospective and retrospective approaches in data collection. Prospective study was conducted to gather information from key informants and sample population on awareness of FMD in Umkhanyakude by using interview, questionnaire administration and Global Positioning System (GPS) as key survey instruments. The data on awareness and knowledge of occurrence were collected by visiting each homestead (sampling point) for interviewing of herd owners. Coordinates of each sampling point of each study village were taken and recorded making use of *E*trex handheld GPS unit.

3.3.1 Sampling and data collection

Convenient sampling method was used in selecting study villages, which includes physical accessibility of the villages and roads during the period of the study. Ten villages namely: Jozini, Mbodla, Songwana, Esomisweni, KwaNyawo, Endlondlweni, Emagogogweni, Mbangweni, Bhekabantu and Mtikini of Umkhanyakude district were selected. Systematic sampling was conducted to select 60 homesteads including three local leaders (indunas). This was done by reviewing livestock census obtained from the local veterinary office. The aim was to identify and select cattle owners with a minimum of ten cattle. This was resulted in identifying 600 cattle owners, participants were selected using an interval of 10, i.e. 600 (cattle owners) was divided by 10(interval).Total sample size of 60 participants obtained. Out of 60 participants, 10 provided insufficient information than what was required for the study objectives. It was therefore suggested that 10 participants' responses be removed from the study. The spatial distribution of the sampling points is shown in figure 3.2. Willingness to co-operate also considered as criteria for enrolment of respondents. To draw sample size *n*, selection of random number between *1* and *k*.

- select the first unit whose serial number is *i*

- select every k^{th} unit after i^{th} unit

- sample contain i, i+k,1+2k,....i+(n-1)k

In August to September 2016, interviews were conducted using a structured questionnaire. The investigation was based on the following questions: FMD awareness evaluation, farming system and herd size, maintenance of the herd to access the involvement of animal in measures of controlling FMD spread which, knowledge and experience of FMD occurrence among the herd for the last five years, awareness of major clinical signs, disease morbidity, mortality, vaccination and management practices. FMD cases were also investigated among each respondent for each year of the study period. Local veterinary services conducted physical and serological diagnosis within the study area and supplied the cattle owners with information confirming the existence and non-existence of the disease within their herds. The researcher did not conduct any physical or serological examination of the cattle. GPS points for interviewed cattle owners recorded with acquired information about FMD reported (positive cases) and non- reported (negative cases.

Wildlife conservationist of Ndumo Game Reserve and FMD specialist from veterinary services also interviewed. The use of comprehensive questionnaire survey provided data that were useful for addressing the study objectives. Responses of each participant were then organised quantified, coded, entered, and stored into the spreadsheet for further processing. Those with insufficient and missing information were omitted and excluded from the study.

Retrospective study conducted by reviewing the weather records to generate information on the weather variables such as rainfall, temperature and wind in the past five-year period (2011-2015). These weather data were obtainable from the local agriculture research center (ARC) stations namely: Tembe, Makhathini, Harrison, ST Lucia, Woodlands, Bushlands, and Mkuzi. Exact sample points are displayed in figure 3.2 below.

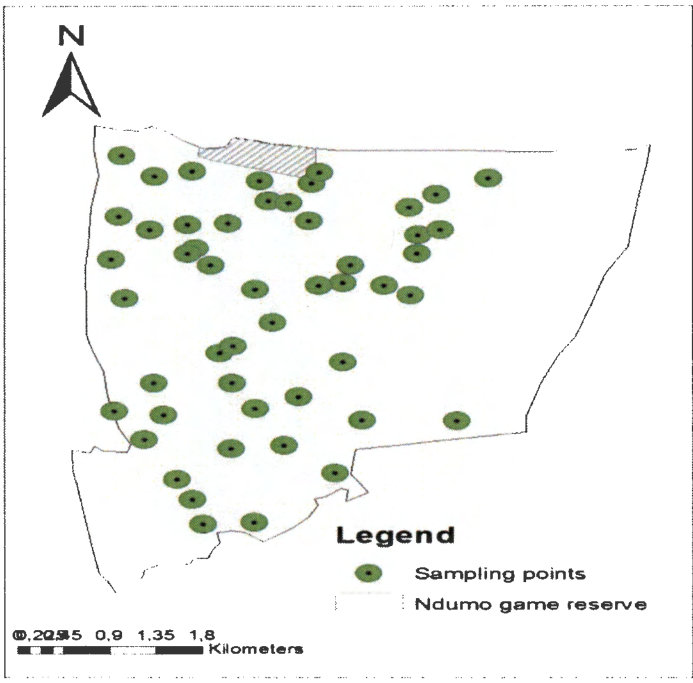

Figure 3.2: Map of Jozini and Umhlabuyalingana municipalities showing the known source of FMD i.e. Ndumo game reserve and specific areas where FMDV samples were obtained.

3.3.1 Conceptual Framework

The first step in applying this framework is to describe linkages between FMD and environmental factors. It highlights factors in the natural environment that impact vulnerability by creating conditions of susceptibility. Figure 3.3 identifies key components that can be used to populate the vulnerability model. The following subtopics describe the methodology carried out for each study objective.

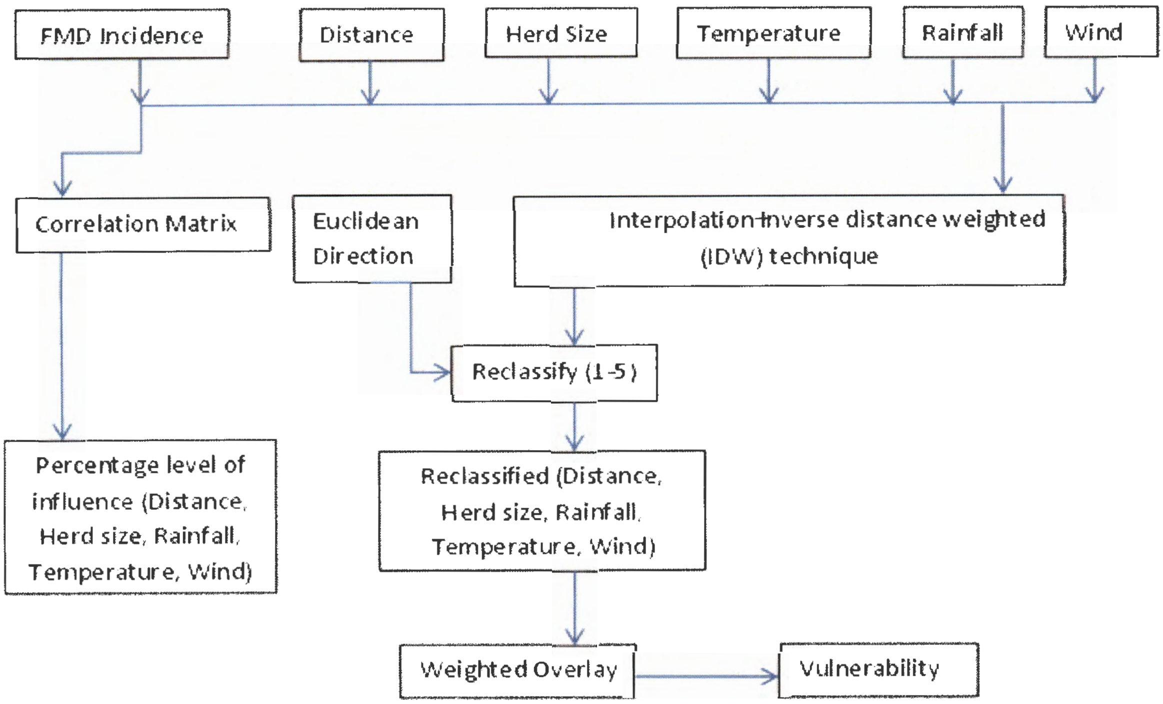

Figure 3.3: Vulnerability model include factors like distance from FMD source, herd size, average temperature, annual rainfall and wind speed, which were correlated with FMD incidences.

3.5 Data processing

3.5.1 Assessing the FMD spatial distribution

Spatial pattern of the disease occurrences is also clearly displayed to observe number of disease cases within the proximity of the known source of FMD (Ndumo Game Reserve) and to compare the number of incidents of each study year. Spatial analyst tool box in ArcGIS software was used to create dot density maps. This method was used to create spatial distribution maps of FMD occurrences. The study area shapefile and FMD occurrences data (sampling points coordinates, FMD incidences for each sampling point and for each year of the study 2011 – 2015) was coded as 1=FMD reported as 'YES' and 0= FMD reported as 'NO'. The outputs maps were transferred to a layout view mode for embellishment and final production.

3.5.2 Assessing factors responsible for FMD spread

Mapping of factors using IDW: IDW explicitly implements the assumption that values that are close to one another are more alike than those are farther apart. This method was used to predict values of unmeasured locations within the study area. It was therefore employed to this study to compute values of factors such as (herd size, rainfall, wind speed, average temperature), were used as input in the interpolation process to generate continuous surface maps for each study year (2011-2015). Data that were stored in an excel spread sheet were entered into the ArcGIS 10.2 software for further processing and analysis. Shapefiles of the study area and of each parameter for each study year (2011-2015) were also created. This formula was used to calculate IDW.

Equation 3.1 $\hat{Z}(S_0) = \sum_{i-1}^{N} \lambda_i Z(S_i)$

- $\hat{Z}(S_0)$ is the value we are predicting
- N is the number of measured sample points surrounding prediction location that is used in prediction
- λ_i are weights assigned to each measured point
- $Z(S_i)$ is the observed value at a location S_i

Euclidean distance mapping: Considering distance when analysing the role of all other factors towards the spread of the disease is very crucial. GIS software was employed to assess number of FMD incidences lie within a specific distance away from the known source of FMD i.e. Ndumo Game reserve. Euclidean distance analysis was conducted, as it provides distance between two values (Khokher and Talwar, 2012). Hence the study is focusing on distance from the source of FMD and each actual incident. Distance map was created with a minimum distance of 10km and maximum distance of 100km. Euclidean distance between point p and q is the length of the line segments connecting them (pq). In Cartesian coordinates, if p = (p*1, p2,...,pn*) and q = (*q1, q2,....,qn*) are two points in Euclidean n – space, then the distance (d) from p to q, or q to p is given by the following Pythagorean formula:

Equation 3.2 $d(p, q)=d(q, p)=\sqrt{(q1-p1)+(q2-p2)+\cdots+(qn-pn)^2}$

$$= \sqrt{\sum_{i=1}^{n}(qi-pi)^2}$$

- p and q is length of the line
- *n* is dimension space

Categorisation and counting of FMD cases: The output maps (distance from the source, herd size, rainfall, wind and temperature) showing the relative likelihood of disease occurrences on each factor. According to FMD information acquired from FMD expert in Umkhanyakude, existing demarcation in Umkhanyakude, categorised the area into two zones i.e. northern zone (NZ) and southern zone (SN). NZ is categorised to be 40km away from international border to red line fence erected as FMD boundary and SZ starts after the redline fence. These demarcations were used to categorise environmental maps for FMD spread determination over multiple factors. Dots representing FMD cases were counted on each map zone over study period. Zone with highest cases for each variable per study year was identified. Overall distribution count conducted by adding the FMD cases of each factor per zone dividing by total FMD cases.

Correlation analysis: Arc Map 10.4 utilized to analyze the factors or criteria influencing the spread of FMD, which includes temperature, rainfall patterns, heard size, wind speed and distance from the known source of FMD. Raster surface from sample points at the weather stations was interpolated using an IDW technique. Each interpolated criterion was re-classified into five classes based on the level of influence and then aggregated using the weighted linear combination (WLC) procedure. The importance weights of each criterion were developed using band collection statistic (BCS) to carry out a correlation analysis test between FMD incidence and selected factors. The equation to calculate the correlation in ArcGIS spatial Analyst is as follows:

$$Corr_{ij} = \frac{Covij}{s_i s_j}$$

Where ij – are layers of a stack

s – standard deviation product

Correlation coefficient ranges from 1 to -1. A positive correlation indicates a direct relationship between two layers, such as when the cell values of one layer increase, the cell values of another layer are also likely to increase. Negative correlation means that one variable changes inversely to the other. Correlation of zero means that two layers are independent of one another. The results of the correlation analysis were then scaled to 100%. Overall correlation coefficients were calculated by consecutively adding each value of each factor for the study period (2011 – 2015).

3.5.3 Assessing the vulnerability of livestock to FMD

GIS based multi-criteria decision support (MCDS) analysis in ESRI ArcGIS 10.4 utilised to analyse all factors or criteria of each study year influencing the spread of FMD. These factors include temperature, rainfall patterns, heard size, wind speed and distance from FMD source. MCDS process entails that the data for each factor is in a raster format, therefore a raster surface from points was interpolated using an inverse distance weighted (IDW) technique. Each criterion was then re-classed into five classes based on the level of influence and then aggregated using the weighted linear combination. The importance weights of each criterion was developed using a correlation analysis. Weights were attached to each criterion, with numerical scores (percentage) of each annual calculation of criteria was conducted. Weights were then assigned into percentage from 0 to 100% using an evaluation scale of 1 to 5, with 5 being extremely important, and 1 being of equal importance. Vulnerability maps (aggregating the influence of each variable in 2011, 2012, 2013, 2014 and 2015) were derived with weighted overlay spatial analyst tool in ArcGIS. The Overall vulnerability map was derived by overlaying all the maps from 2011-2015 using the weighted overlay tool. Output map was reclassified into classes; 1 as low vulnerability and 3 was highly vulnerable.

3.6 Validation of Vulnerability model

Geographically Weighted Regression (GWR) has been applied to capture the average strength and significance of relationships between dependent (FMD cases) and independent variables (selected factors). Interpolation maps of both dependent and independent variables was created and reclassified. It was found optimal to use 2011 (highest FMD cases) and 2015 (lowest FMD cases) reclassified maps. Furthermore map algebra was conducted with 2011 and 2015 maps. The areas with cumulative cases of FMD over the study period thereafter displayed by means of the map. The output map was reclassified into three classes to produce a comparative view of FMD cases. The disease cases were defined and rated according to the number of cases on a particular area and labelled as high, medium and low. Further analysis was conducted to study the linear relationship between 2011 – 2015 FMD reported cases and 2011 - 2015 predicted vulnerability cases.

The coefficient of determination R^2 was further used as a validation measure for estimating the validity of the predicted models and for studying the relationships among the dependent Y (i.e. FMD cases) and independent X (i.e. environmental factors) variables. R^2 provides a measure of how well the observed FMD cases are replicated by the model, based on the proportion of total variation (%)in the FMD cases explained by the model.

CHAPTER FOUR: RESULTS

4.1 Spatial distribution of FMD

Figure 4.1 shows FMD spatial distribution maps in the study area, where each dot represents the actual locations of the incidence. Red dots represent number of FMD cases reported in each year of study, while the yellow dots for FMD non-reported cases. Based on the dots count there is a relatively strong spatial association between FMD occurrence and proximity to Game Reserve areas (known source). It is suspected that in Figure 4.1(a) disease outbreak occurred by looking at the number of positive cases (FMD reported). In Figure 4.2(b) negative cases began to appear, whereas in Figure 4.1(c, d, e) positive cases drastically decreased. Even so, within the proximity of Ndumo Game reserve positive cases usually kept in numbers. Attention is drawn to the fact that African buffaloes are the carries of FMDV, direct or indirect contact may serve as the transmission mode of the disease.

Dot count in northern and southern zone for 2011-2015, determines the spatial distribution of FMD cases. Highest disease cases are found in the northern part of the study area. Table 4.1 shows the details of the actual number of FMD cases.

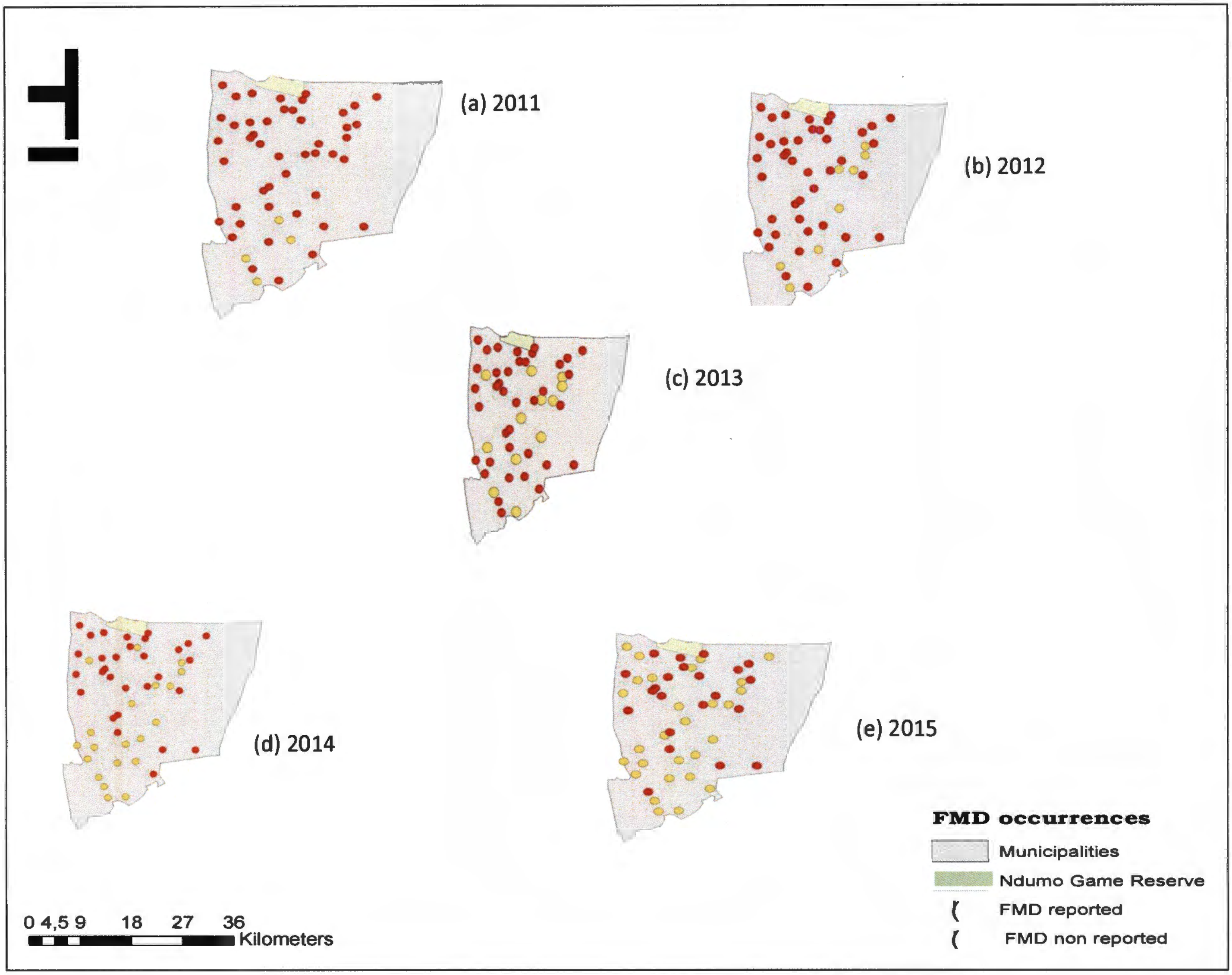

Figure 4.1: Spatial distribution of FMD occurrences derived from reported cases for each year (2011 – 2015) in the Umkhanyakude district of KwaZulu-Natal province, South Africa.

Table 4.1: 2011-2015 FMD cases for each study area zones in the Umkhanyakude district of KwaZulu-Natal province, South Africa

Dot count of FMD positive cases					
Zones	**FMD 2011**	**FMD 2012**	**FMD 2013**	**FMD 2014**	**FMD 2015**
North	34	28	24	24	17
South	14	14	13	6	5

4.3 Factors responsible for FMD spread

Figure 4.2 displays the situation of all factors for the year 2011. FMD occurrence data of respective year were overlaid on each factor map. Table 4.2 presents the correlation of 2011 FMD and environmental variables results. This table reveals the correlation coefficients and their level of influence towards FMD spread; rainfall holds highest level (24%) of influence.

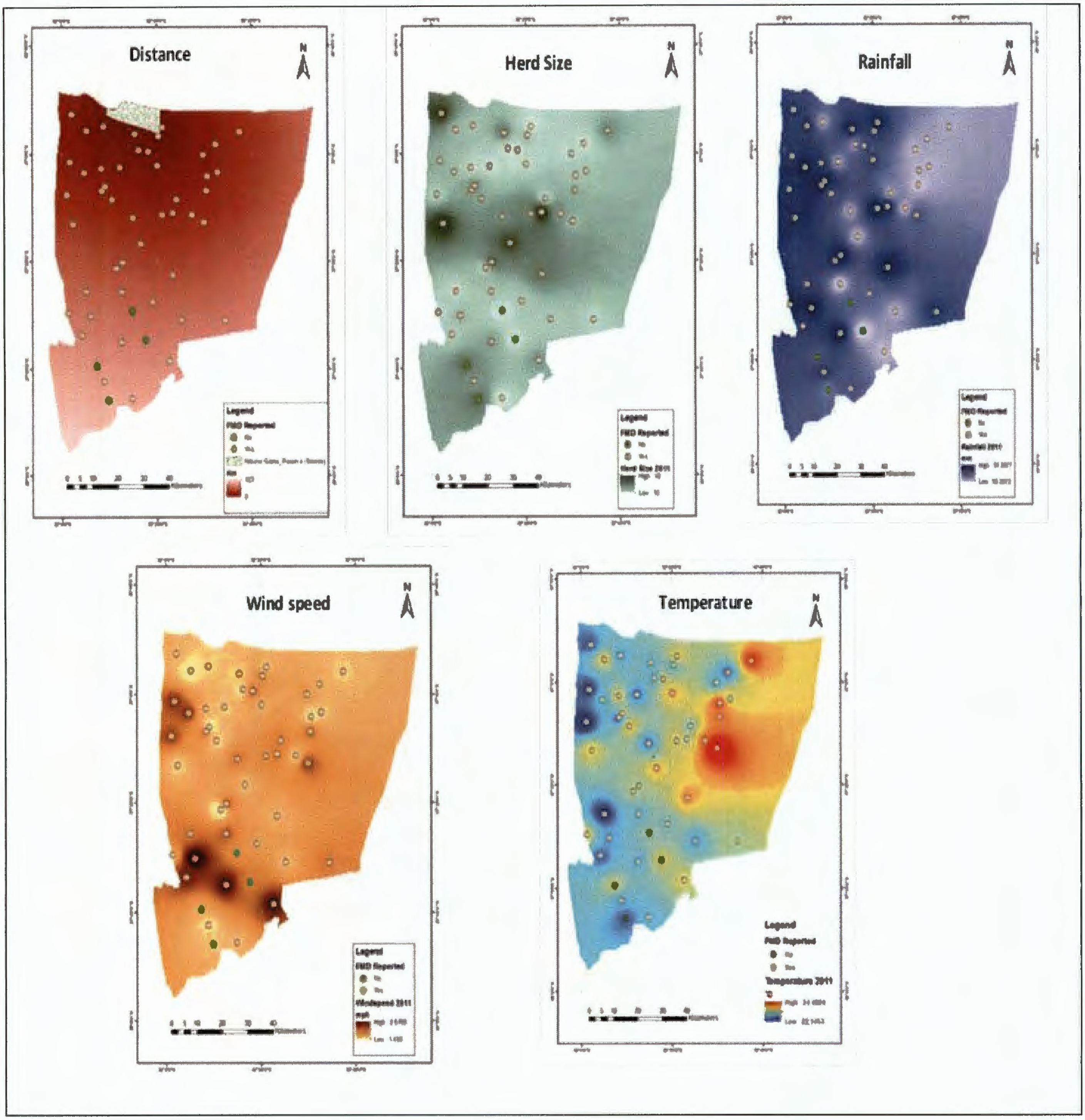

Figure 4.2: Shows 2011 maps of all factors with FMD reported cases overlaid on each map for each study year

Table 4.2: Correlation coefficient (r) and the level of influence for each factor impose towards the spread of FMD in 2011 in the Umkhanyakude district of KwaZulu-Natal, South Africa

Correlation of influence scaled to 100%			
Factor	**r-value**	**Percentage**	**%**
Distance	0.1739	24.0	24
Herd size	0.09368	13.0	13
Rainfall	0.2341	32.4	32
Wind speed	0.15051	20.8	21
Average temperature	0.0712	9.8	10
Total	**0.72339**	**100**	**100**

Figure 4.3 displays the situation of all 2012 environmental factors. FMD occurrence cases of respective year were overlaid on each factor map. Because it is not simple to conclude the relationship of factors and FMD spread, correlation of variables are presented in Table 4.3. This table displays 2012 correlation coefficient and their level of influence towards FMD spread. Results revealed that distance from the FMD source has the highest level of influence (31%) and temperature showed the lowest influence of 6%.

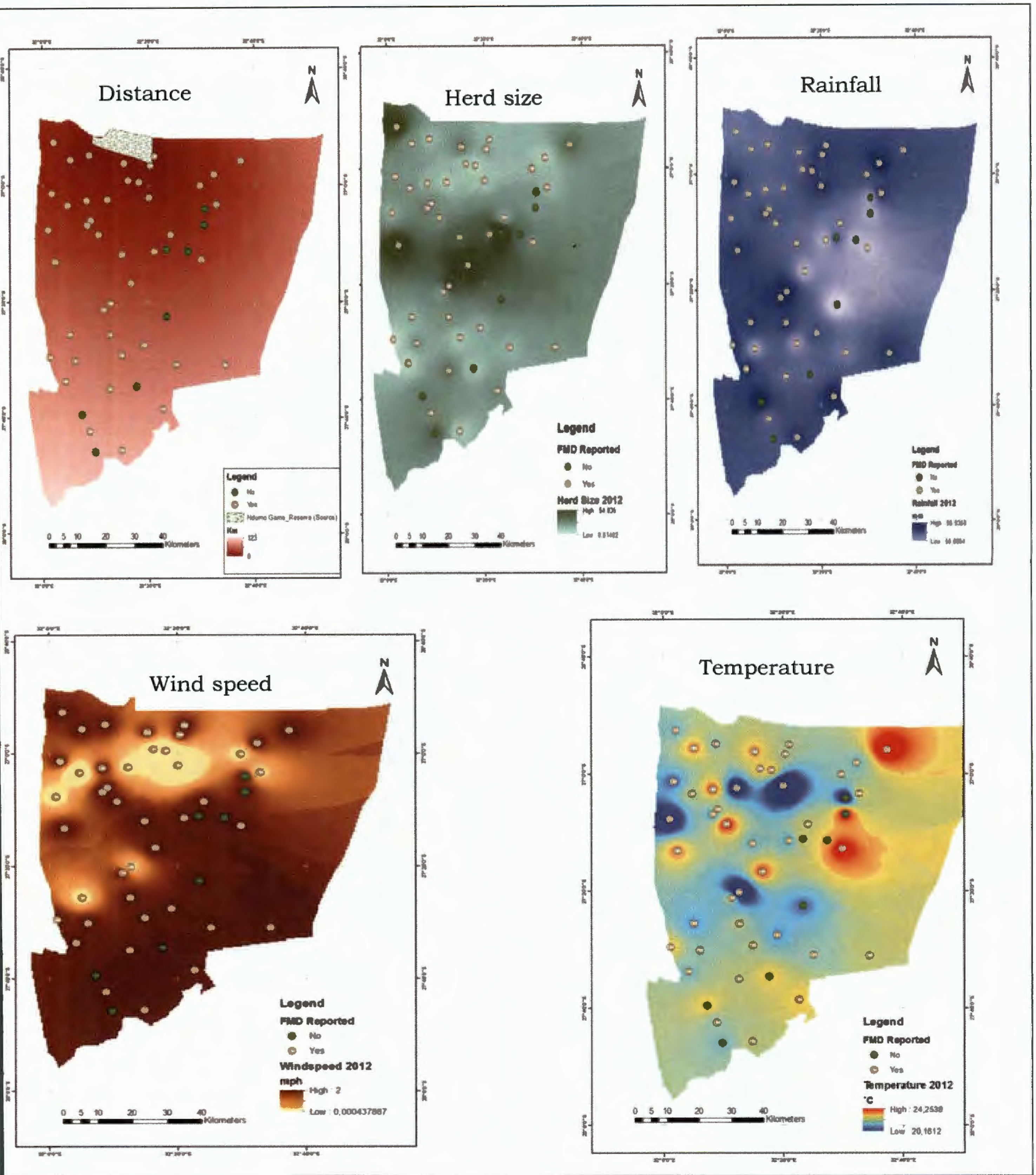

Figure 4.3: Shows 2012 maps of all factors with FMD reported cases overlaid on each map for each study year

Table 4.3: Show the correlation and the level of influence each factor impose towards the spread of FMD in 2012.

2012 Correlation of Influence scaled to 100%			
Factor	**r-value**	**Percentage**	**%**
Distance	0,35835	30,72353	31
Herd size	0,13666	11,71669	11
Rainfall	0,33642	28,84333	29
Wind speed	0,2694	23,0973	23
Average temperature	0,06554	5,619143	6
Total	**1.16637**	**100**	**100**

Figure 4.4 s displays the situation of all factors for 2013. FMD occurrences of respective year were overlaid on each factor map and are displayed in maps below. Table 4.4 displays 2013 correlation coefficient and their level of influence towards FMD spread. Results showed that Herd size has the highest level of 47% and distance being the least influential factor (6.2%).

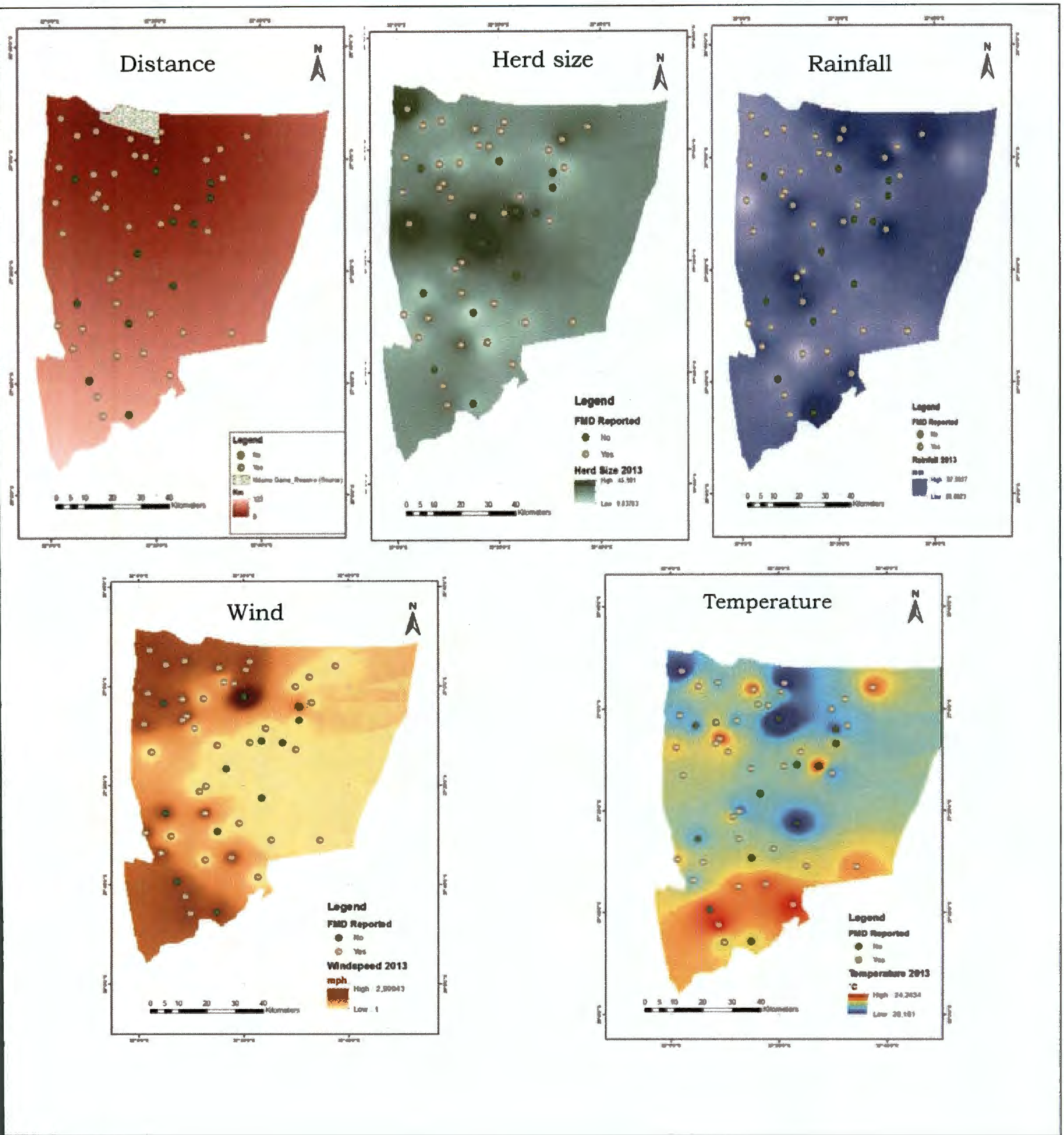

Figure 4.4: Shows 2013 maps of all factors with FMD reported cases overlaid on each map for each study year

Table 4.4: Show the correlation and the level of influence each factor impose towards the spread of FMD in 2013.

2013 Correlation of Influence scaled to 100%			
Factor	**r-value**	**Percentage**	**%**
Distance	0,04727	6,216383	6,2
Herd size	0,35675	46,91548	47
Rainfall	0,02571	3,381071	3,4
Wind speed	0,09152	12,03561	12
Average temperature	0,23916	31,45145	31,4
Total	**0,76041**	**100**	**100**

Figure 4.5 visually display the situation of all factors for 2014. FMD occurrences of respective year were overlaid on each factor map and are displayed in maps below. Table 4.5 presents the 2014 correlation of variables results, this table reveals correlation of factors and their level of influence towards FMD spread. Results displayed that distance has the highest influence of 40%.

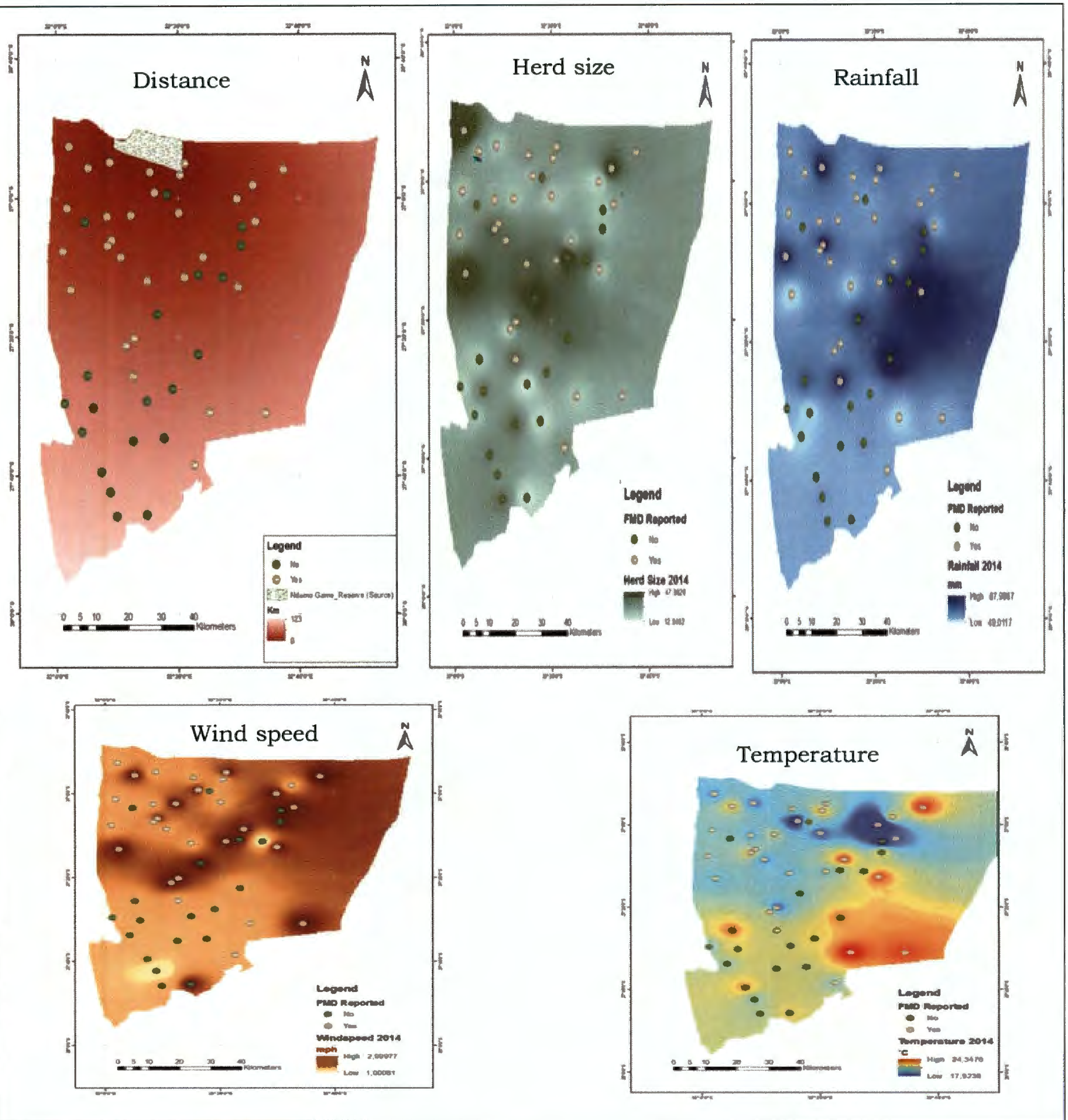

Figure 4.5: Shows 2014 maps of all factors with FMD reported cases overlaid on each map for each study year

Table 4.5: Show the correlation and the level of influence each factor impose towards the spread of FMD in 2014.

2014 Correlation of Influence scaled to 100%					
Factor	**r-value**		**Percentage**		**%**
Distance	0,67277		39,79239		40
Herd size	0,00838		0,495653		0
Rainfall	0,1548		9,155971		9
Wind speed	0,56823		33,60916		34
Average temperature	0,28652		16,94683		17
Total	**1,6907**		**100**		**100**

Figure 4.7 visually display the situation of all factors for 2015. FMD occurrences of respective year were overlaid on each factor map and are displayed in maps below. Table 4.6 presents the 2015 correlation results to describe relationship of variables. This table reveal correlation of factors and their level of influence towards FMD spread, distance has the highest level of influence of 67% and temperature the lowest of 2%.

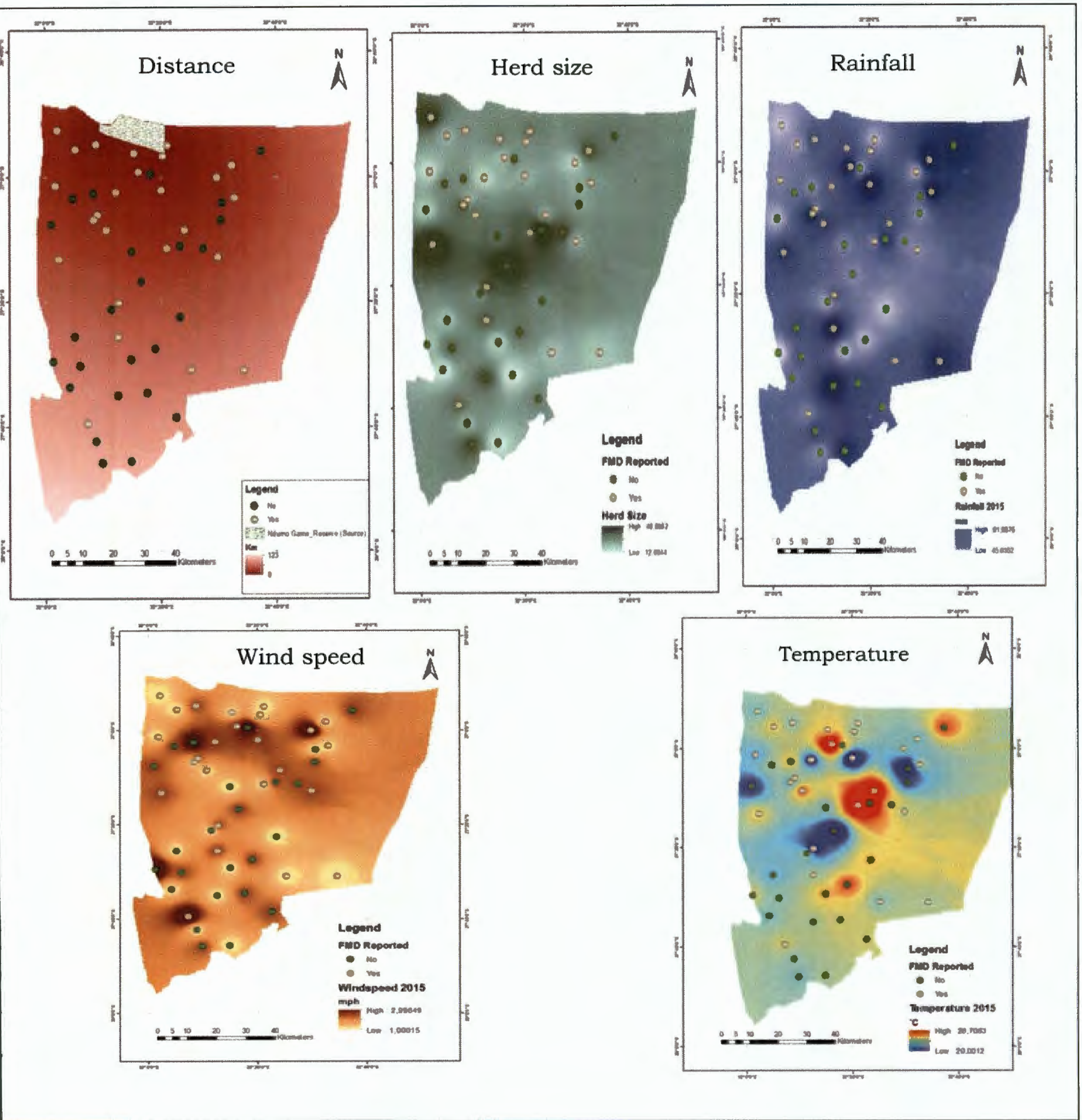

Figure 4.6: Shows 2015 maps of all factors with FMD cases overlaid on each map of each study year.

Table 4.6: Show the correlation and influence level of each factor impose towards the spread of FMD in 2015.

2015 Correlation of Influence scaled to 100%				
Factors	**r-value**		**Percentage**	**%**
Distance	0,51237		59,49489	67
Herd size	0,05848		6,790525	5
Rainfall	0,15213		17,66489	14
Wind speed	0,12218		14,18718	12
Average temperature	0,01604		1,862517	2
Total	**0,8612**		**100**	**100**

Figure 4.8summarises the relationship of environmental factors displayed in Figure 4.2, 4.3, 4.4, 4.5 and 4.6, with FMD cases. The results showed that the factors level of influence differ from one year to another and from one variable to another.

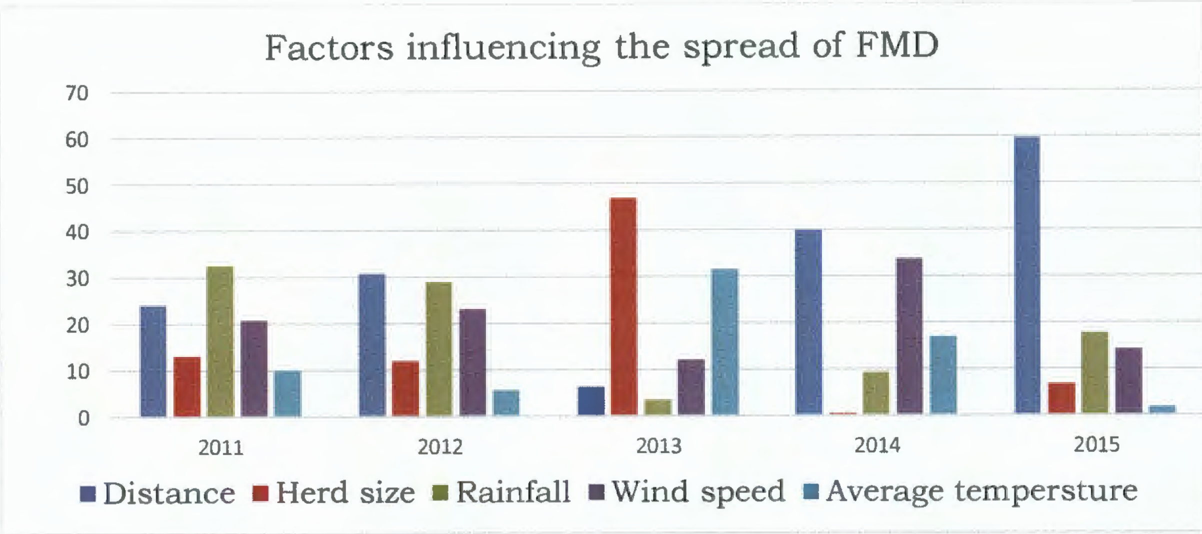

Figure 4.7: Influential level of each factor towards the spread of FMD in the Umkhanyakude district of KwaZulu-Natal province, South Africa (2011 – 2015).

Table 4.7 is a summary of overlaid FMD cases displayed. The highest percentage ranges between 70% to 74% is observed in the northern part of the study area. On the other hand, the lowest range of 26% to 29% was observed in the southern zone.

Table 4.7: Total number and percentage of FMD cases for 2011 to 2015 categorised as northern (NZ) and southern (SZ) zones of the Umkhanyakude district of KwaZulu-Natal province, South Africa, for each factor

Variable	**FMD(NZ)**	**FMD(SZ)**	**NZ%**	**NZ%**
Distance	140	50	74	26
Herd size	133	50	72	27
Rainfall	124	51	70	29
Wind	127	48	72	27
Temperature	139	50	73	26

Table 4.8 shows that the highest mean herd size was in 2011, whereas the lowest mean was in 2012, 2013 the lowest. The highest rainfall mean was observed in 2012, and the lowest in 2014. The highest wind speed mean was

observed in 2013 and the lowest in 2012. Whereas, the highest maximum mean temperature was observed in 2015.

Table 4.8: Mean of each factor's records for the data collected in each study year (2011 – 2015) in the Umkhanyakude district of KwaZulu-Natal province, South Africa.

Factor	**2011 Min**	**2011 Max**	**2012 Min**	**2012 Max**	**2013 Min**	**2013 Max**	**2014 Min**	**2014 Max**	**2015 Min**	**2015 Max**
Herd size	10	52	8	55	9	46	12	48	12	49
Rainfall(mm)	50	90	50	99	50	88	49	88	45	92
Wind speed(mph)	1.48	2.88	0.2	2.47	1.17	2.99	1.1	2.91	1.22	2.9
Temperature(°C)	22.1	23.9	20.16	24.22	20.16	24.25	17.9	24.35	19.9	26.7
Distance	Ranged from 10 to 120km and remained constant for each study year									

Tables 4.9 and 4.10 displays the summary of correlation results for all the studied variables in the study period (2011 – 2015). The tables also portray the overall level of influence of each variables for FMD spread. It is shown that the distance from the FMD source, ranked as the most influential (32%) factor for FMD spread and temperature being the least influential factor (13%).

Table 4.9: Overall correlation coefficient of the studied variables for the spread of FMD in the Umkhanyakude district of KwaZulu-Natal province, South Africa during 2011-2015.

Factors	r-value
Distance	1.76466
Herd size	0.65395
Rainfall	0.90316
Wind speed	1.20184
Average temperature	0.67846

Table 4.10: Level of influence of the studied variables scaled to 100% for the spread of FMD in the Umkhanyakude district of KwaZulu-Natal province, South Africa during 2011-2015

Factors	2011	2012	2013	2014	2015	Total	Scaled to 100%
Distance	24	31	6	40	59	160	32
Herd size	13	12	47	0	7	79	16
Rainfall	32	29	3	9	18	91	18
Wind speed	21	23	12	34	14	104	21
Average temperature	10	6	31	17	2	66	13
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**500**	**100%**

4.4 Areas with high FMD vulnerability

Vulnerability model assisted in analysing multiple factors of the study as it allowed the combination, weight and ranking of factors level of vulnerability. Figure 4.8 displays of the vulnerability information rendered by the model generated in this study. Levels of influence displayed in tables 4.2, 4.3, 4.4, 4.5 and 4.6) were used to create this vulnerability map (Figure 4.8). The figure shows areas with high vulnerability, meaning that the model predicts high-risk areas. These areas are regarded as highly vulnerable FMD sites, because the influence of all the focus factors was relatively high.

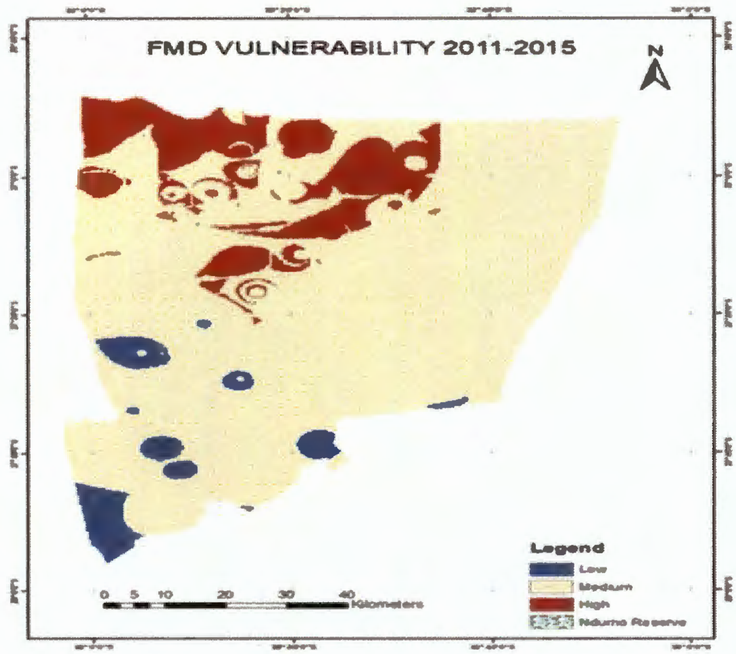

Figure 4.8: FMD vulnerability map in the Umkhanyakude district of KwaZulu-Natal province, South Africa. Areas with both FMD high exposure and susceptibility resulted in the highest overall vulnerability; represent priority areas for intervention planning.

Observations carried out on figure 4.9 present visual and actual spatial situation of FMD for the study period. Green part of the study area experienced cases of FMD consecutively and constantly throughout the period of study. They may be regarded as FMD high prevalent areas. Areas with blue colour had inconsistent cases in some years, whereas khaki colour had fewer cases. In comparison with vulnerability map, it is revealed that the northern part of the study area has the characteristics of being FMD endemic. In addition, this is applicable to both maps i.e. FMD reported cases and Vulnerability map.

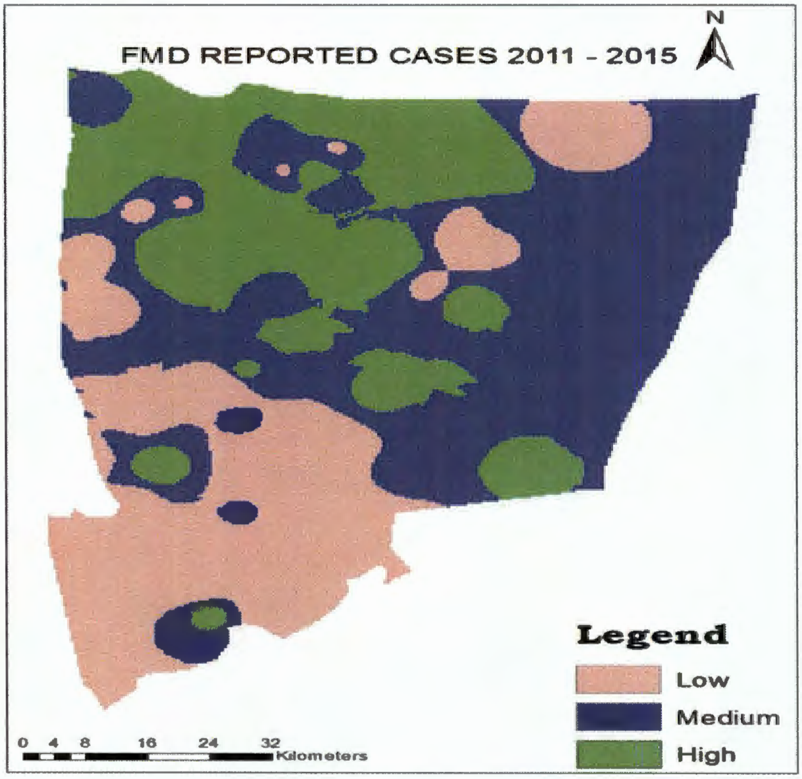

Figure 4.9: Reclassified map showing the cumulative 2011 – 2015 FMD reported cases in the Umkhanyakude district of KwaZulu-Natal province, South Africa.

Vulnerability model encompasses all the environmental factors, which were suggested to provide conditions of the disease to occur. The actual occurrence was examined against what the model implies. Results revealed that there is a positive correlation (r = 0.935952) between the actual FMD situation and the predictive cases of the model, with 87.6% association between the actual reported FMD and predicted modelled cases (Figure 4.11). This significant association indicates the importance of the explanatory factors as determinants of FMD occurrence.

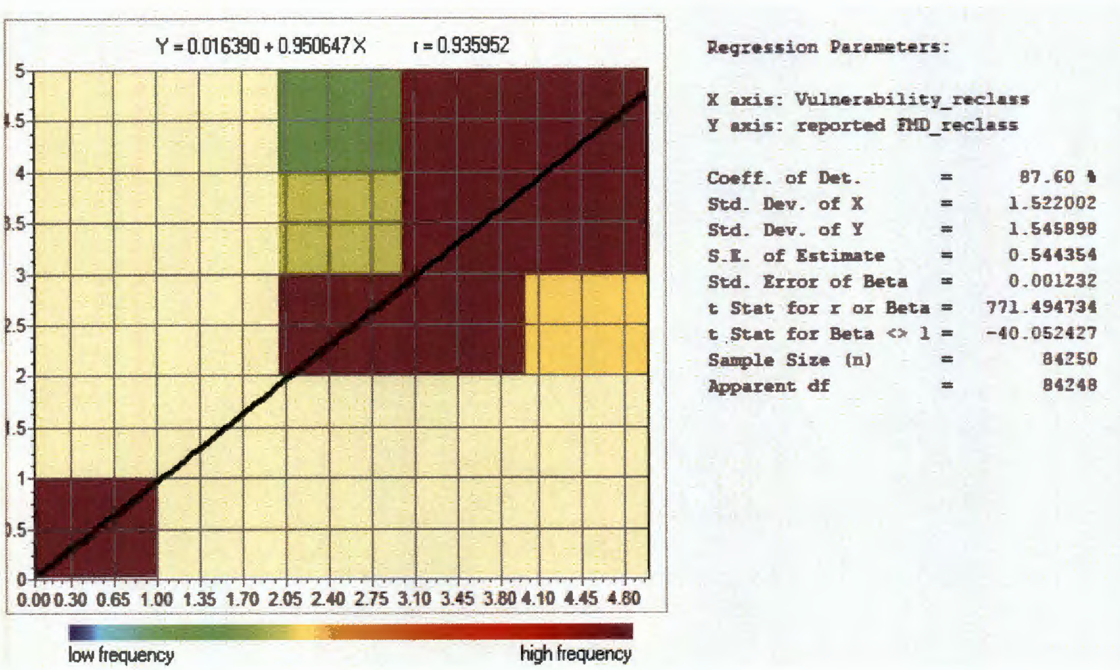

Figure 4.10: Relationship between actual reported and predicted modelled FMD cases in the Umkhanyakude district of KwaZulu-Natal province, South Africa (2011 – 2015). The predicted FMD cases were produced by the vulnerability model

CHAPTER FIVE: DISCUSSION

The aim of this study was to determine the spatial distribution of FMD, and to analyse and map factors responsible for its spread within the study area. GIS rendered significant benefit to analyse spatial data, however it is usually taken into low consideration for either epidemiological or management purposes in the veterinary services of Umkhanyakude district of the KwaZulu-Natal, South Africa. GIS considerably increases the efficacy of communication, and it can also improve management and veterinary services, tasks and decision making during emergencies (Norstrøm, 2001). With aid of GIS analysis, the results of the present study showed large number of FMD cases (342) in 2011 as opposed to other years (2012–2015). These findings coincide with the information received from the veterinary services (VET) that there was recorded outbreak during 2011(VET.'S REPORT, 2011). Mapping of spatial distribution of FMD cases and illustration of highly prevalent areas for each year during the study period (2011 – 2015) appeared to be at the proximity distance from the Ndumo Game Park. This result corroborate the findings of previous studies that demonstrated areas along nature conservancies are likely to have number of FMD occurrences (Kock et al., 2014; Michel and Bengis, 2012;Sinkala et al., 2014;Sutmoller et al., 2000). Proximity distance influences the distribution of FMD indirectly through its effect on contact between the susceptible and the infected animal. This fact is supported by the finding in the present study that FMD cases rate increased with the decrease of distance away from the Indumo game park. In the other words, as the distance increases, disease cases of FMD decreases. This may be derived from the point that chances of contact between two populations become lean. The matter also applies to wind borne transmission, as the virus is transmissible within certain distance (Wright, 1969). It is stated that virus densities decline with the increase of distance (Gloster *et al.*, 1982b). FMD cases were concentrated in areas along the game reserve; this may be attributed to the fact that African buffaloes are the carrier of FMDV. Direct or indirect contact between cattle and African buffaloes is possible. Comparing our findings with available literature, a number of studies have used serological survey to determine the spatial distribution that environmental factors (Sikombe *et al.*, 2015;Sutmoller, 1999).

However, many of recent studies concentrated more on advanced technique of GIS in performing advanced spatial statistical analysis, to georeferenced and geocode FMD data. It used for combining them with molecular epidemiology (DNA and virus transmission) to identify areas of FMD transmission and to map areas of cluster and or hotspot (Genchwere and Kasanga, 2014; Olabode *et al.*, 2014; Sinkombe *et al.*, 2015).

Further, the results of the present study demonstrated that the distribution of FMD could be attributable to the prevalence of favourable environmental conditions like rainfall, temperature and wind speed. These results are supported by the a finding of a study that environmental factors were influential determinants of FMD occurrences (Khan *et al.*, 2016). Transmission intensity of FMD changes with climate, in particular the temperature which affects FMDV lifespan (Kamolsiripichaiporn *et al.*, 2007). Possible explanation for this is that at higher temperature the FMD transmission is interrupted. Another possible explanation is that FMD incidences are relatively higher where minimum temperature prevails (Bestbier, 2016). According to the previous study on Malaria, it found that the variation between day/ night temperature could have a significant effect on the disease incidence in Umkhanyakude. The range of night temperature is between 8^0C to 30^0C, the optimum temperature for the virus to survive and spread is less than 27^0C (Bhunia *et al.*, 2013;Carvalho et al., 2015). This gives an assumption that the virus transmission can take place during the night.

The findings of the study could be useful in achieving the Umkhanyakude district plan of controlling and eradicating the FMD. Also, the study can raise the awareness of the affected personnel to formulate a FMD control program. The level of awareness about q relevant disease is one of the most important factors for preventing and controlling the disease (Garland, 1999; Leforba and Gerbier, 2002). The success of any control and eradication program in Umkhanyakude is dependent upon the combined efforts of all involved personnel including veterinary services, herd owners, and traders. To involve this diverse group, a clear understanding of spatial epidemiology of the disease and as its spread is required. It was suggested that to control the spread of FMD more effectively in endemic areas, vaccination should be adopted in conjunction with animal movement controls (quarantines) together with compulsory culling of clinically affected animals. All these efforts will help prevent or reduce the replication of virus and thereby dramatically reduce the amount of virus released into the environment. Vaccinated animals present a barrier to further spread of the disease. It is a fundamental to investigate the spatial distribution of the disease, so as to identify predisposing factors for disease occurrence, and control plans can therefore be developed, implemented and evaluated (Carpenter, 2001).

Although there is a substantial difference between the level of influence among each study year, but distance from FMD source remained remarkably the highest in terms of its role towards the spread of the disease. This may be due to the movement of livestock across borders, whereby infected animal travel and transmit the disease to the surrounding non-infected animal. This has been previously documented (Davies, 2002; Donaldson and Sellers, 2000; Grubman and Baxt, 2004). The crucial point revealed in this study is that very few herd owners were able to correctly explain how FMD spread. This evidently supported by intentional NGR fence breakage by the community for illegal farming practices.

Martinez-Lopez et al., (2013) presented multi-disciplinary decision support tool, which includes geostatic, mapping and spatial stochastic spread model for evaluation of sanitary and socioeconomic of FMD under diverse epidemiological scenarios. The multivariable analysis conducted as part of this study demonstrated that areas with higher livestock density were at risk of having animals with FMD. This was probably due to the increased level of animal contact amongst ruminants, in which they act as one of potential source of infection (Alexandersen *et al.*, 2003; Barnett and Cox, 1999). These findings are supported by the results of other studies (Al-Majali *et al.*, 2008; Maddur *et al.*, 2009) that keeping small stock together with cattle increased number of FMD cases

MCDA used to create a FMD model that integrates data from diverse sources to identify FMD risk areas within the study area. The MCDA has already been employed in other countries (dos Santos *et al.*, 2017; Martínez-López *et al.*, 2014) like Brazil to help target animal surveillance and identify risk areas (Amaral *et al.*, 2016). The model structure provides methodology for guiding decision makers throughout the critical process of FMD control. Unregulated animal movements across international game park borders are considered a risk associated with FMD introduction. High ruminant density could improve the likely contact with the FMD virus (Fevre *et al*, 2006).The final FMD vulnerability map represented by the likelihood of FMD occurrence also showed areas along the Ndumo game park interfaces were areas with the highest FMD cases. Therefore, an operational veterinary service (OVS) plan with FMD target surveillance in these zones would be indicated. The model considered FMD high-risk areas as areas with a likelihood of FMD occurrence within the top 70% among the categorised zones because this cut-off threshold resulted in higher zonal values. However, decision makers and the OVS, who may extend or reduce this limit, should carry out the best categorisation and selection of limits. Given that, the improvement of surveillance in large areas needs material and human resource, which are often scarce, the OVS could relocate these resources from lower FMD risk areas to higher risk areas.

Limitations of the proposed method

Lack of reliable data likely limited the scope of analysis i.e. lack of prior research within Umkhanyakude district. Reviewing of literature should have laid the foundation of understanding of their local problem. Data which was used was self-gathered data, is limiting factor by the fact that it is rarely can be independently verified i.e. FMD case data.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The predicted FMD risk maps demonstrated how environmental factors could be utilised in disease forecasting. The prediction (vulnerability) model was able to display or locate the hotspots in Umkhanyakude district of KwaZulu-Natal, South Africa where incidence rates are the highest. The study did not include the illustration of the seasonal variation in transmission of the FMDV, thus further investigation may be carried out on this area. This information would be crucial to FMD control programmes, as it would know the time of the year where efforts should be targeted. It is important to monitor non-climatic factors in determining FMD spread, especially in areas of Umkhanyakude, according to the information obtained from local quarantine, number of imported FMD cases exceeds and contributes to transmission more than local cases.

The prediction model successfully demonstrated the value of developing robust statistical models that can predict future risk. Global climatic change is also another important contemporary issue to consider where such climatic/environmental prediction models can be used to detect future spatial patterns of the disease. According to OIE, intergovernmental panel on climatic change stated that FMD have been linked to climatic change as warming of the climate is expected to increase latitudinal and altitudinal temperature. The spatial and temporal changes in rainfall, temperature and wind that are expected to happen because of global warming may affect the biology and ecology of hosts differently and could consequently alter the risk of the disease transmission

In analysing spatial distribution of FMD cases, number of livestock affected by FMD during the study period was the most relevant variables considered. The study also investigated the FMD high-risk areas. Northern part of the study area was found to be a high-risk area, the FMD surveillance performance could be aligned with the study findings. Animal surveillance system is associated with stakeholders and their participation in the surveillance process is very important. Although commutation tools such as the internet and mobile phones are abundantly available, physical presence and proximity of veterinary offices are important to herd owners, especially for disease notification.

A lack of tools and data resources for vulnerability assessment and mapping has been identified as a key gap in the field. This is especially recognised in animal health, health impacts are primarily examined through risk models, which calculate the probability of disease transmission. Predictions from early warnings system provide critical information for immediate on the ground actions such as vaccination and quarantines. However, in many contexts predictive models are limited because the use of early warning system relies on large inputs of financial, human and data resources as well as adequate public animal health infrastructure (Racloz *et al.*, 2012).

6.2 Recommendations

- Temporal components could be useful with disease spatial distribution determination combined with risk model to improve the results, it is possible that there are events (droughts and floods) of the year when FMD virus is more likely to survive and spread.
- Environmental attributes such as forest areas, hills and valleys could be considered natural in investigating their role towards the spread of the FMD.
- Natural barriers to FMD introduction and dissemination can be contemplated to improve the precision of the model.

- Further studies may focus on land use and land cover change to investigate its role towards FMD occurrence.

Annexures: Questionnaire

Questionnaire Survey: Umkhanyakude district

Name of the researcher: Ms Khethiwe Dlamini

Institution: Free State University (QwaQwa campus)

Purpose of the questionnaire. The purpose of this research is to identify number of cattle affected by the foot and mouth disease for the past five ~~past~~ years and its spatiotemporal distribution, as well as its impact toward the farming potential of Umkhanyakude.

Section A: Details of the farmer

Province		District	

Locality		Grid Reference	Lat		Long	

Date	Year		Month		Day		Farmer name	

Gender	M	F	Age	

Level of education	Primary	High School	Tertiary

Language	Speak		Read		Write	
Zulu	Good		Good		Good	
English	Moderate		Moderate		Moderate	
Afrikaans	Poor		Poor		Poor	

Village:		Male	Female	1-6 months	6months-1year
No. cattle					
No. sheep					
No. goats					
No. poultry					

Number of years in farming	1-5 years	6-10 years	Above 10

Are you: Cattle Owner / Farm worker / Vet / Other: __________
Are you the person responsible for the majority of management decisions?
Yes / No / Partially

Section B: Details of the disease

Disease/Diagnosis		Differential Diagnosis	

Nature of Diagnosis	Suspected	Clinical	Smear	PM	Laboratory

SPECIES:			AFFECTED POPUL-ATION (mark the correct word)	SEX	AGE	SYSTEM	
NUMBER Cases (total affected)				male	neonate	dairy	beef
NUMBER Dead				female	juvenile	mixed	trad
NUMBER at Risk				castrate	subadult	intensive	
				all	adult	extensive	
				?	all	other	
					?	?	

Mark with X where Appropriate

Year of incidence	2011	2012	2013	2014	2015

MEASURES ADOPTED		MAIN CLIN. SIGNS	MAIN PM LESIONS	EPIDEMIOLOGY
Treatment				(source, rate of spread, vectors, reservoirs, sporadic, continuous etc.)
Vaccination				
Dip				
Quarantine				

About grazing pattern

Do the cattle graze on controlled camps: Yes / No

If no, how far do they graze: 2-5 km/5-10km/above 10km

Where do they stay after grazing: always in kraal/ sometimes in kraal/always in veld

Your understanding of FMD

I feel I understand the risks FMD poses to my herd
Strongly disagree 1 2 3 4 5 6 7 *strongly agree*

I do not believe my herd is infected with FMD
Strongly disagree 1 2 3 4 5 6 7 *strongly agree*

I take measures to protect my herd from FMD
Strongly disagree 1 2 3 4 5 6 7 *strongly agree*

I do not know how to protect my herd from FMD
Strongly disagree 1 2 3 4 5 6 7 *strongly agree*

I know where to find clear information on FMD
Strongly disagree 1 2 3 4 5 6 7 *strongly agree*

Your awareness of FMD

Please answer true or false to these statements. This is not a test! Just a survey of your knowledge.

Do you know about the disease: Yes/No

if yes where do you think the disease is sourced ______________

Do you know the symptoms of disease: Yes/No

FMD can be passed between animals with mild or no signs of disease	True/False/Don't know
An animal which has previously been infected will be protected from FMD for life	True/False/Don't know
FMD can cause reduced reproduction and production rates	True/False/Don't know
Persistently infected cattle spread large amounts of virus and infect large numbers of other cattle	True/False/Don't know
Persistently infected cattle can be cured	True/False/Don't know
Vaccination will prevent persistently infected animals spreading FMD	True/False/Don't know
Persistently infected cattle often have a greatly reduced life span	True/False/Don't know
Persistently infected cattle can appear normal and healthy	True/False/Don't know
FMD does not affect profitability unless there are signs of disease	True/False/Don't know

Your interest in controlling FMD

I believe FMD is a serious disease
Strongly disagree 1 2 3 4 5 6 7 *strongly agree*

I believe FMD is relevant to me
Strongly disagree 1 2 3 4 5 6 7 *strongly agree*

I am concerned about FMD in my herd
Strongly disagree 1 2 3 4 5 6 7 *strongly agree*

I am interested in testing my cattle for FMD
Strongly disagree 1 2 3 4 5 6 7 *strongly agree*

I would be interested in a free FMD control program
Strongly disagree 1 2 3 4 5 6 7 *strongly agree*

I would be interested in a FMD control program at a small cost
Strongly disagree 1 2 3 4 5 6 7 *strongly agree*

I would be interested in a FMD control program at a small cost, if I can be shown that the long term benefits outweigh the short term costs
Strongly disagree 1 2 3 4 5 6 7 *strongly agree*

I am interested in learning more about FMD
Strongly disagree 1 2 3 4 5 6 7 *strongly agree*

Name : ______________________________
Postal Address: ______________________________
____
Contact Phone Number: ______________________________
Email Address: ______________________________

Any further comments?
About FMD:
____
____
____

About this survey:
____
____

Thank you for

your participation!

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