A RETROSPECTIVE ANALYSIS OF THE EPIDEMIOLOGY OF RIFT VALLEY FEVER IN NAMIBIA

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B. Summary

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Rift Valley fever (RVF) is a peracute or acute disease of domestic ruminants and humans in sub-Saharan Africa, caused by a mosquito-borne virus. It is a high priority pathogen because of its potential to cause severe economic harm to the livestock industry and to cause life threatening haemorrhagic disease in humans. The disease was first recorded in southern Africa when a large epidemic occurred in the South Africa in 1950, and the first recorded outbreak in Namibia was in 1957. Since then, occasional large epidemics have occurred in southern Africa, with long interepidemic periods. The epidemiology of RVF is complex and many questions regarding the movements of the virus and its survival during the interepidemic period remain unanswered.

The aim of this study was to compile a comprehensive description of the history of RVF in Namibia and to describe its epidemiological characteristics. This was accomplished using information available in the scientific literature, annual reports, disease reports and reports to the OIE. The geographical location and temporal occurrence of each outbreak was recorded as accurately as allowed by available records. Also recorded were suspected RVF outbreaks, defined as those outbreaks in which samples were not collected for laboratory analysis or RVF was not confirmed on submitted samples but where the clinical picture was suggestive of the disease. Serological surveys done in humans and animals were also included in the study.

The collected data were analysed descriptively, by risk mapping and by cluster analysis. The relatively low number of recorded outbreaks and the poor spatial resolution of much of the data prevented more detailed multivariable analysis. Maps were produced to show the districts affected for the outbreaks with

no coordinates and the exact location of the outbreaks which had coordinates. This was then followed by a detailed description of each outbreak showing the species affected and the mortalities caused.

Risk mapping was done to identify areas of the country which are at high risk of having outbreaks. A quarter degree square grid was used to show the cumulative number of confirmed outbreaks occurring from 1957 to 2011. The accuracy of this was, however, limited due to the poor spatial resolution of data prior to 1986, which recorded only the district(s) affected. The risk map was visually compared with maps of sheep and cattle density and rainfall.

A space-time permutation model, using case-only data, was used to detect space-time clusters with high rates, using SaTScan software on all the confirmed outbreaks with GPS coordinates. The objective was to detect areas of significantly high rates of RVF in Namibia, testing whether the outbreaks were randomly distributed over space and time. Space time permutation requires the use of precise geographic coordinates; therefore the only confirmed outbreaks that could be used for this analysis were those occurring during 2010 and the 2011.

A total of six years had outbreaks of RVF in Namibia, the major outbreaks occurring in 1957, 1974, 1984, 2010 and 2011. Rift Valley fever was confirmed in the Karas, Hardap, Khomas, Erongo, Otjozondjupa, Omaheke and Oshikoto regions, with suspected outbreaks occurring in the Kavango and Caprivi regions. SaTScan analysis showed that there were two statistically significant outbreak clusters observed, one in the Hardap region in 2010 and the other in the Oshikoto region in 2011. The south-eastern part of the country was shown to be predisposed to RVF outbreaks; this correlated with sheep population density. The southern part of Namibia receives less rainfall and is hotter than the north, with colder winters, factors which may reduce vector and virus survival and therefore limit continuous viral circulation. This likely renders livestock highly susceptible to infection and if there is an introduction of the virus a severe epidemic may occur. In the Northern Communal Areas and adjacent Etosha National Park the positive serological results in humans and wildlife show that there is continuous or intermittent low level circulation of the virus. This could be leading to high levels of herd immunity and hence no confirmed outbreaks recorded in these areas to date. Nevertheless, all suspected cases should be tested for RVF to avoid misdiagnosis and under-reporting of cases.

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F. Abbreviations

AGID	Agar gel immunodiffusion
CVL	Central Veterinary Laboratory
DVS	Directorate of Veterinary Services
ELISA	Enzyme linked immunosorbent assay
ENSO	El Niño/Southern oscillation
GPS	Global positioning system
NCA	Northern Communal Areas
NDVI	Normalized difference vegetation index
OIE	World Organization for Animal Health
RT-PCR	Real time polymerase chain reaction
RVF	Rift Valley fever
RVFV	Rift Valley fever virus
SOI	Southern oscillation index

Chapter 1: Literature review

1.1 Background

Rift Valley fever (RVF) is a peracute or acute disease of domestic ruminants and humans in Africa and Madagascar, caused by a mosquito-borne virus and characterized by necrotic hepatitis and diffuse hemorrhages. It is most severe in sheep, cattle and goats, occurring in the form of large, sporadic epidemics producing high mortality in new-born animals and abortions in pregnant animals (Swanepoel and Coetzer, 2004). Rift Valley fever virus (RVFV) is a high priority pathogen because of its potential to cause severe economic harm to the livestock industry and its ability to cause life threatening haemorrhagic disease in humans. It is an emerging pathogen whose range has recently expanded from East and southern Africa across sub-Saharan Africa to North Africa and the Arabian Peninsula (Bird *et al*, 2009).

Rift Valley fever transmission is known to be both focal and episodic in nature and closely tied with flooding rainfall events but there may be sporadic transmission in endemic areas that helps perpetuate and or extend the range of RVFV transmission areas (Swanepoel and Coetzer, 2004). Rift Valley fever is one of the most threatening of all tropical viral infections because it can infect a number of animal species and can be carried by many vectors (Swanepoel and Coetzer, 2004). Indirect evidence suggests that RVFV is transmitted at low levels in inter-epidemic years, a process that may act to provide a continuing reservoir of infection in high risk areas and semi-arid regions (Swanepoel and Coetzer, 2004).

The study was aimed at investigating the epidemiology of RVF in Namibia through the establishment of the full history of the occurrence of the disease in the country by collecting information on outbreaks from the Central Veterinary Laboratory (CVL), the Epidemiology Section of the Directorate of Veterinary Services (DVS), scientific literature and other relevant sources of data.

The project aims to expand the knowledge of the epidemiology of RVF in Namibia by describing the epidemiological features of the disease and identifying high-risk regions of the country. RVF is a disease of both economic and public health importance hence knowing its epidemiology helps policy makers to implement effective control measures to prevent outbreaks and further spread of the disease in case of outbreaks. Countries that have had RVF outbreaks are always at high risk of outbreaks in the future, (Gerdes, 2004) therefore establishing the possible causal factors helps control future disease incursions. Certain environmental factors are associated with RVF outbreaks. It is therefore crucial to assess if the outbreaks which occurred in Namibia were influenced by environmental factors. Collating information on

historical outbreaks and compiling a database on the temporal and spatial occurrence of outbreaks provides a valuable resource for future epidemiological studies on the disease in Namibia.

1.2 Disease definition

Rift Valley fever is a viral zoonotic disease of ruminants transmitted by mosquitoes of various genera. The most common effects in animals are fever, abortion and mortalities in young animals especially lambs, with occasional deaths in adults (Swanepoel and Coetzer, 2004). Humans become infected from contact with tissues of infected animals or, less commonly, from infected mosquito bites. Human infection is usually associated with mild to moderately severe influenza-like illness, but severe complications such as ocular infection, encephalitis and haemorrhagic disease occur in a small proportion of patients and can lead to death (Swanepoel and Coetzer, 2004).

Rift Valley fever typically occurs as outbreaks interspersed with long periods of absence during which the virus is thought to survive by transovarial transmission in *Aedes* spp. mosquitoes and/or by low level circulation between animal hosts and vectors (Swanepoel, 2009). New outbreaks are triggered by an explosion in vector numbers as a result of water abundance. This might be due to increased rainfall, flooding or even human activity such as dam building (Gerdes, 2004).

1.3 History of Rift Valley fever

Rift Valley fever is found primarily in sub-Saharan Africa. It was first reported among livestock in Kenya around 1915 (Daubney *et al*, 1931) but the virus was not isolated until 1931 (Daubney *et al*, 1931). The largest outbreaks in Kenya occurred in 1930-1931, 1968 and 1978-79. In Kenya the virus claimed the lives of over 400 people during the 1998 outbreak (Swanepoel and Coetzer, 2004).

The disease was first recorded in southern Africa in the 1950s when a large epidemic occurred in the western Free State, southern Gauteng and adjacent North West and Limpopo provinces of South Africa. The disease was only recognized as RVF early in 1951 when humans became ill after assisting at a necropsy on a bull near Johannesburg (Alexander, 1951; Mundel and Gear, 1951). Major outbreaks in South Africa occurred in 1950-51 and 1974-76; less major outbreaks were recorded in 1952-53, 1955-59, 1969-71 and 1981 (Pienaar and Thompson, 2013). The most recent major epidemic was in 2010 from February to June, which started in the Free State (Bulfontein and Brandfort) and eventually affected all

provinces except KwaZulu-Natal (Pienaar and Thompson 2013; Métras *et al.*, 2013). Sheep were primarily affected but goats, cattle and a variety of wildlife were also affected. This was then followed by a smaller epidemic in 2011 which involved mostly the Eastern Cape but some outbreaks also occurred in Western and Northern Cape provinces (Pienaar and Thompson 2013).

The first recorded outbreak of RVF in Namibia was in 1957 (Schneider, 1994) with subsequent outbreaks occurring in 1974-76, 1984, 2010 and 2011. There were suspected outbreaks in 1986, 2001, 2006 and 2009 but they were not confirmed by laboratory testing. In 2010 the epidemic affected Namibia mainly the sheep rearing southern part of the country (Hardap and Karas regions) and extended to Erongo region. The next outbreak occurred in 2011 affecting Oshikoto and Otjozondjupa regions.

Extensive outbreaks in Southern Africa occurred in areas dominated by cattle farming in Zimbabwe in 1955, 1957, 1969-70 and 1978. In Mozambique it occurred in 1969 and Zambia in 1973-74, 1978 and 1985 (Swanepoel and Coetzer, 2004). In Egypt during the 1977-78 outbreaks an unprecedented number of human infections occurred and thousands died during the epidemic (Swanepoel and Coetzer, 2004).

In 2000 and 2001 RVFV escaped from the African region to cause a major outbreak of disease on the Arabian Peninsula (Shoemaker *et al*, 2002), with outbreaks reported in Saudi Arabia and Yemen (Ahmad, 2000).

1.4 Aetiology

Rift Valley fever virus is an enveloped, negative sense, slightly pleomorphic single stranded RNA virus belonging to the genus Phlebovirus in the Bunyaviridae family (Grobbelaar *et al*, 2011). The bilipid layer envelope is host derived and has glycoprotein spikes projecting through it. The viral genome is divided into three segments namely S (small), M (medium) and L (large), the smallest segment being ambisense RNA, meaning it can be coded in both directions. The virus is 80 to 120 nm in diameter (Grobbelaar *et al*, 2011). Experiments showed that the virus was stable at 27°C in buffered solutions within the pH range 6.9-7.3 for at least 24 h. The virus can survive at ambient temperature and also when frozen or lyophilized. It is resistant to alkaline environments but inactivated by pH 6.3 or less and is inactivated by lipid solvents. The virus survives in freeze dried form and aerosols at 23°c and 50-85% humidity (Swanepoel and Coetzer, 2004).

1.5 Epidemiology

Rift Valley fever is a vector borne disease of sheep, cattle and goats. It usually presents in an epizootic form over large areas following heavy rains and substantial flooding (Pienaar and Thompson, 2013). In sub-Saharan Africa outbreaks have usually been associated with above average rainfall and there are long inter-epidemic periods during which no disease is reported (Swanepoel and Coetzer, 2004). Although there is a correlation between high rainfall and RVF outbreaks, not all wet periods are associated with RVF outbreaks (Swanepoel and Coetzer, 2004).

Rift Valley fever regularly circulates in endemic areas between ruminants and haematophagus mosquitoes. Certain *Aedes* spp. act as reservoirs for RVFV during inter-epidemic periods and increased precipitation in dry areas leads to an explosive hatching of mosquito eggs many which may be harboring the virus (Swanepoel and Coetzer, 2004). The frequency at which transovarial transmission of RVF occur appears to be low as numerous attempts to isolate the virus failed from mosquitoes which were collected during years where no known outbreaks had occurred. Experiments were conducted in South Africa and elsewhere to demonstrate transovarial transmission but they were not successful (Swanepoel and Coetzer, 2004). Other mosquito species such as *Culex* spp in which transovarial transmission does not take place but which are still able to transmit RVF feed on infected animals thus propagating the outbreak and amplifying virus numbers (Gerdes, 2004). Low level circulation of virus between animals (wild and domestic) and vectors without clinical signs or severe outbreaks, and the presence of reservoir animals could also be important for the epidemiology of RVF. Another important possibility in the epidemiology of RVF is the spread of the virus over long distances mostly by movement of infected animals through trade or illegal transboundary animal movements (Pienaar and Thompson, 2013).

The virus is capable of inhabiting a variety of different bioclimatic conditions including wet and tropical, hot and arid and irrigated areas. It can circulate at low levels without severe or even detectable disease in humans and animals and this explains why many African countries have recorded positive serological results in sheep, goats and cattle without clinical disease. Most outbreaks occur simultaneously in adjacent territories and this could be because climatic conditions tend to occur over large areas (Pienaar and Thompson, 2013). The presence of vectors and their population dynamics are strongly linked to land cover patterns and with suitable climatic conditions there is an increase in vector population and subsequent outbreaks (Pienaar and Thompson, 2013).

Although vaccination is effective in preventing disease, the long inter-epidemic period leads to vaccination relaxation, since farmers and veterinary officials tend to forget the disease, resulting in the

lowering of herd immunity. When suitable climatic conditions prevail there may be a sudden increase in mosquitoes carrying the virus and severe outbreaks may occur.

The vectors are divided into two groups namely the endemic vectors and the epidemic vectors. The endemic vectors are the flood water breeding *Aedes* spp. in which transovarial transmission takes place and the epidemic vectors are the Culicine mosquitoes and biting flies which propagate the virus (Swanepoel, 2009; Pepin *et al*, 2010). Infection rates in vector populations may be quite low even during epidemics, usually below 0.1%, but enormous numbers of aedines emerge from flooded dambos or pans and vertebrates are then subjected to a high mosquito biting frequency (Jupp *et al*, 1984). Infected livestock and possibly wild herbivores serve as a source of virus for mosquitoes and once infection is amplified in vertebrates, secondary or epidemic vectors such as *Culex* spp. and anopheline mosquitoes may become involved in transmission.

Rift Valley fever was first reported in southern Africa when an epidemic occurred in South Africa in 1950 affecting the western Free State, southern Gauteng adjacent to North West and Limpopo provinces (Pienaar and Thompson, 2013). This was followed by numerous sporadic outbreaks and occasional severe epidemics with the last recorded being in 2010 (Pienaar and Thompson, 2013). A severe outbreak involving mainly sheep occurred in Namibia in 1957 and this was followed by outbreaks in 1974, 1984, 2010 and 2011 with numerous suspected outbreaks (Schneider, 1994). Further outbreaks were recorded in Zimbabwe in 1955, 1957, 1960-70 and 1978 and these outbreaks mainly affected cattle (Swanepoel and Coetzer, 2004). Thus far there is only serological evidence for the presence of the disease in Mozambique and Botswana. The disease then spread to Madagascar and further to west and north Africa before crossing into the Arabian Peninsula in the year 2000 (Barnard, 1997, Anderson and Rowe, 1998).
Figure 1.1 shows the countries with endemic disease and the years when major outbreaks occurred, however outbreaks which occurred in Namibia in 2010 and 2011 and South Africa in 2011 are not indicated in the map below.

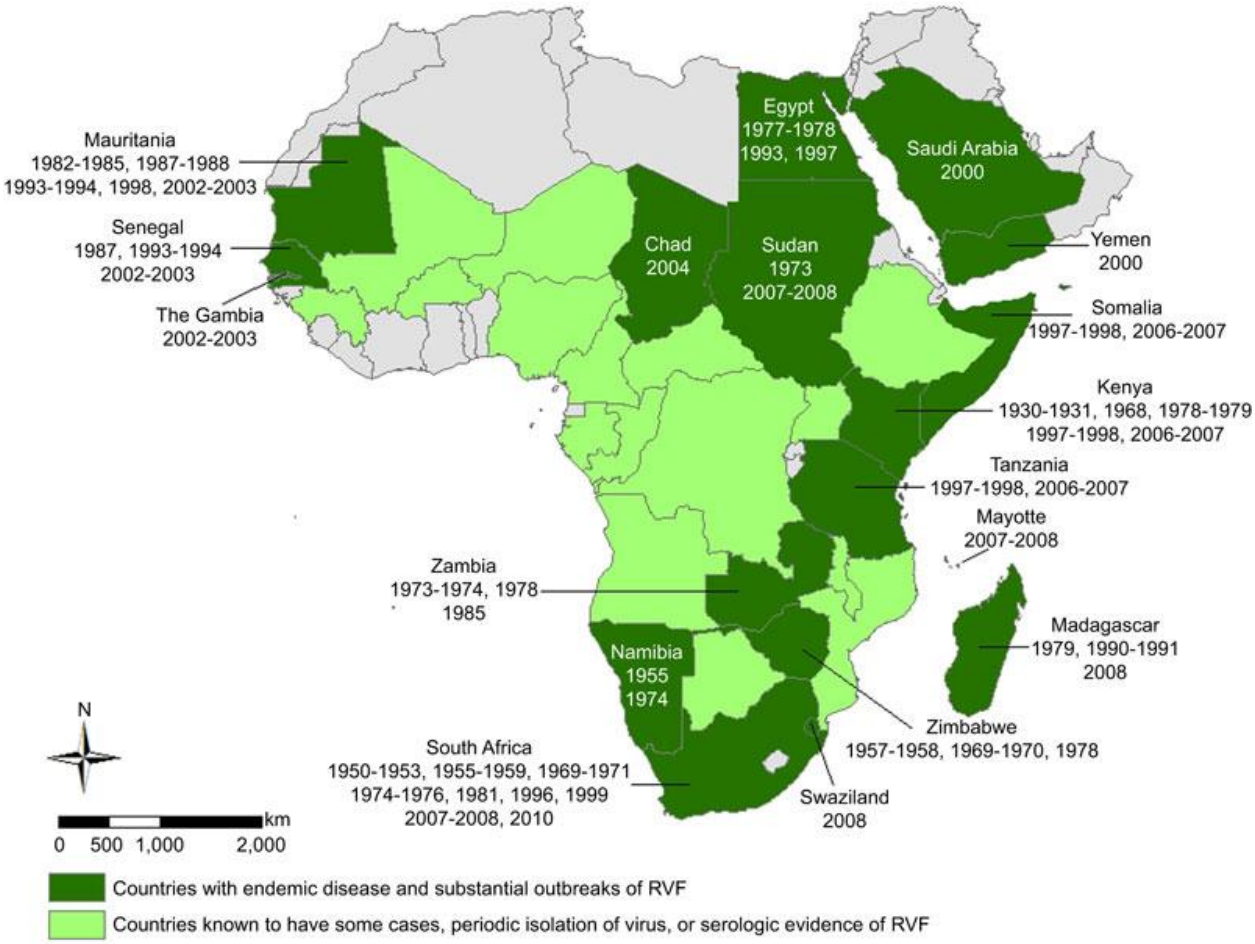

Figure 1.1 Countries which have had Rift Valley fever and the years when the outbreaks occurred. The map was adapted from Professor P. N. Thompson`s presentation on unlocking mysteries of RVF in southern Africa through integrated spatial and molecular analyses.

Rift Valley fever forecasting and climatic models can predict climatic conditions that are frequently associated with an increased risk of outbreaks and may improve disease control. In Africa, Saudi Arabia and Yemen RVF outbreaks are closely associated with periods of above average rainfall but not all high rainfall events or years had outbreaks (Anyamba *et al*, 2010). The response of vegetation to increased levels of rainfall can be easily measured and monitored by remote sensing imagery, i.e. the satellite normalized difference vegetation index (NDVI), and used to predict RVF outbreaks. In addition RVF outbreaks in East Africa are closely associated with the heavy rainfall that occurs during the warm phase of the El Niño/ Southern Oscillation (ENSO) phenomenon (Anyamba *et al*, 2010). These findings have enabled the successful development of forecasting models and early warning systems for RVF using

satellite images and weather/climate forecasting data. Early warning systems such as these could be used to detect animal cases at an early stage of an outbreak enabling authorities to implement measures to avert impending epidemics. The forecasting and early detection of RVF outbreaks together with a comprehensive assessment of the diffusion to new areas are essential to enable effective and timely control measures to be implemented (Anyamba *et al*, 2010).

Rift Valley fever outbreaks in Kenya were shown to positively correlate with high rainfall events associated with the warm phase of El Niño/Southern Oscillation Index (SOI) (Pienaar and Thompson, 2013). EL Niño is the warming of the central and eastern Pacific Ocean while Southern Oscillation is the atmospheric changes associated with El Niño and the SOI is a measure of these atmospheric changes (Pienaar and Thompson, 2013). In South Africa (Southern Africa) El Niño has an opposite effect compared to Kenya (West Africa). A positive SOI causes normal or higher rainfall and a negative SOI is associated with below normal rainfall or drought (Anyamba et al, 2010). The epidemiology of RVF in West Africa differs from that in southern Africa, with outbreaks occurring during periods of average or below average rainfall. In Senegal, Gambia, Mauritania and Mali RVF outbreaks are not associated with climatic features but rather with cyclic patterns of herd immunity (Chevalier *et al*, 2004).

The onset of winter is the major factor contributing to the abatement of epidemics as the cold weather suppresses vector activity. In southern Africa outbreaks tend to terminate abruptly soon after the first frosts of winter occur (Weiss, 1957), although a low degree of mosquito activity and disease transmission persisted through the relatively mild and exceptionally humid winter conditions which prevailed during the 1974-76 epidemic in South Africa (Swanepoel and Coetzer, 20024). Similarly, virus activity may persist in parts of Africa which experience warmer winters, however, the onset of cooler winter weather largely suppressed vector activity during the 1977-78 epidemics in Egypt (Hoogstraal *et al*, 1979). A further factor which may influence the course of epidemics is the natural succession of arthropods in breeding sites, including species that are predacious on mosquitoes (Linthicum *et al*, 1985).

Humans become infected mainly from contact with animal tissues, although there are instances where no such history can be obtained and it must be assumed that infection has resulted from mosquito bites. Generally, people who become affected are involved in the livestock industry, such as farmers who assist in dystocia of livestock, farm laborers who salvage carcasses for human consumption, veterinarians and their assistants, and abattoir workers. Human infection presumably results from contact of virus with abraded skin, wounds or mucous membranes, but aerosol and intranasal infection have been demonstrated experimentally and circumstantial evidence suggests that aerosols have been involved in some human

infections in the laboratory, and in the field during the Egyptian epidemic (Swanepoel and Coetzer, 2004). According to Grobbelaar *et al*. (2011), there are numerous lineages of the RVFV and these have caused outbreaks in Africa and beyond as single lineages or in combination. The different RVFV lineages which have been isolated in Africa since 1951 are shown in Table 1.1.

Table 1.1 Rift Valley fever virus lineages recorded in Africa from 1951 to 2010 (data modified from Grobbelaar *et al*, 2011).

Country	**Rift Valley fever lineages**														
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**
Mauritania			x											x	
Senegal							x							x	
Burkina Faso														x	
Guinea							x								
CAR				x	x		x								
Egypt	x											x			
Saudi Arabia			x												
Somalia			x												
Uganda											x		x		
Kenya		x	x								x	x			
Tanzania			x												
Madagascar	x		x												
Angola			x												
Zambia					x										
Zimbabwe	x		x		x		x			x	x	x			
Namibia								x							
South Africa			x			x		x	x		x	x	x		x
Mozambique			x												

1.6 Pathogenesis

Upon entry into the body RVFV replicates at the site of infection and then spreads to other organs such as the liver, spleen and brain. It attaches to receptors on susceptible cells, is endocytosed into the cell and replicates in the cytoplasm (Swanepoel and Coetzer, 2004). It takes 16 hours post-infection for the virus to be detected in lambs, the virus then persists for the duration of the illness and may cause death in 36-42 hours. In adult cattle, sheep and goats viremia is detected 1-2 days post infection, reaches a peak after 2-5 days and persists up to 7 days (Peters *et al*, 1989). In *in vitro* cultures, RVFV replicates in cells derived from almost all tissues except primary macrophages and lymphoblastoid cell lines, *in vivo* macrophages are infected and there is selectivity for certain other tissues. It can persist in the spleen and other visceral organs of sheep for up to 21 days. RVFV causes hepatic necrosis, vasculitis, lymphoid necrosis and

haemorrhagic disease, and abortions occur in pregnant cattle, sheep and goats due to febrile illness and foetal death.

Lesions in target organs in the acute form of the disease are produced by the direct lytic effect of the virus on infected cells. In the liver of new-born lambs, there is initial cloudy swelling and hydropic degeneration of randomly scattered hepatocytes, these then become necrotic and are characterised by acidophilic cytoplasms and pyknotic nuclei. The lesions then progress to form necrotic foci resulting from cytolysis and infiltration of neutrophils. As the primary lesions enlarge numerous degenerated and necrotic hepatocytes and acidophilic bodies appear throughout the parenchyma (Coetzer and Ishak, 1982). Clinical pathology reveals severe leucopenia, elevated blood enzyme levels (associated with liver damage) and thrombocytopenia.

1.7 Clinical signs

Morbidity and mortality due to RVF is determined by the virulence of the strain of virus and the susceptibility of the vertebrates involved (Swanepoel and Coetzer, 2004). Susceptibility of livestock was suggested to be high in exotic sheep and cattle than in indigenous breeds and this could be due to low level circulation of the virus during inter-epidemic periods. The disease has been inconsistently reported in goats but mortalities in kids were recorded in Kenya in 1930, Sudan in 1973, South Africa and Namibia in 1974-75, and in West Africa in 1987. However, goats were considered to be resistant to the disease in the Egyptian outbreak of 1977-78 (Swanepoel and Coetzer, 2004).

Signs of the disease tend to be non-specific, rendering it difficult to recognize individual cases, however, the presentation of numerous abortions and mortalities among young animals together with influenza-like disease in humans is indicative of RVF (Pienaar and Thompson, 2013).

Sheep and goats

Lambs are extremely susceptible, with an incubation period of 12-36 hours. They develop a biphasic fever of 40-42°C which subsides just prior to death (Bird *et al*, 2009). The major signs include anorexia, weakness, listlessness, abdominal pain and rapid abdominal respiration prior to death within 24-36 hours. Lambs and kids older than 2 weeks, mature sheep and goats are significantly less susceptible to RVFV and may develop inapparent, acute or peracute disease. Under field conditions animals develop the acute form in which the incubation period is 1-6 days after which there will be a fever of 40-41°C,

mucopurulent nasal discharge, vomiting/regurgitation, anorexia, listlessness, diarrhoea and icterus. Pregnant animals may abort at any stage of gestation due to the febrile reaction and/or infection of the foetus. Aborted foetuses are usually autolysed. Mortality and abortion rates vary between and within epidemics (Swanepoel and Coetzer, 2004). Abortion storms with rates approaching 100% can occur (Bird *et al*, 2009). The case fatality rate in lambs less than 1 week of age may be as high as 100%, while in those more than 1 week of age it is as high as 20% and in adults it is 20-30% (Bird *et al*, 2009).

Cattle

Calves are highly susceptible, the disease resembling that in lambs, with an incubation period of 1-6 days. They develop fever of 40-41°C, inappetance and depression and there is blood and fetid diarrhoea with more icterus than in lambs (Bird *et al*, 2009). Adult cattle are moderately susceptible and often have inapparent infection but sometimes have acute disease. They develop fever lasting for 24-29 hours, dry and or dull coat and lacrymation. Some of the clinical signs include nasal discharges, excessive salivation, anorexia, weakness, blood or fetid diarrhea and a fall in milk yield are some of the clinical signs. The abortion rate may reach 85% in the herd (Bird *et al*, 2009).

Humans

Rift Valley fever causes influenza like syndrome with a fever of 37.8-40°C, headaches, muscle pain, weakness, nausea and epigastric discomfort and photophobia (Bird *et al*, 2009). Recovery mostly occurs within 4-7 days. Complications may occur in a minority of cases which includes retinopathy and blindness, meningoencephalitis, haemorrhagic syndrome with jaundice, petechiae and death (Pepin *et al*, 2010; Swanepoel and Coetzer, 2004). A small proportion of infected individuals develop the complicated form and the haemorrhagic syndrome is more fatal causing death. After the 1974-76 epidemic which occurred in South Africa estimates showed that ocular complications occurred in up to 20% of infected humans (Mcintosh *et al*, 1980), however estimates following the 1977-78 Egyptian outbreak ranged from less than 5% to less than 1% (Laughlin *et al*, 1979).

1.8 Pathology

Gross pathology

The virus causes focal or generalized hepatic necrosis (white necrotic foci about 1 mm in diameter), congestion, enlargement and discoloration of the liver with sub-capsular haemorrhages and there is

brown-yellowish colour of the liver in aborted foetus (Daubney *et al*, 1931; Wood *et al*, 1990). There is also widespread petechial to echymotic haemorrhages on parietal and visceral serosal membranes. Lymph node changes include enlargement, oedema, haemorrhages and necrosis (Wood *et al*, 1990). There is also congestion and cortical haemorrhages of kidneys and gall bladder with haemorrhagic enteritis and icterus.

Histopathology

The virus causes severe necrosis which is characterized by dense aggregates of cellular debris and also by the presence of fibrin and inflammatory cells. Necrosis also show eosinophilic, rod shaped intranuclear inclusion bodies in hepatocytes. Liver examination reveals characteristic cytopathology and immunostaining enables specific identification of RVFV antigen in infected cells (Wood *et al*, 1990).

1.9 Zoonosis

The most important mode of transmission of RVF to humans is by direct contamination which occurs by handling of infected animals (nasal discharges, blood and vaginal secretions after abortions) or infected carcasses. Transmission can also occur through mosquito bites, aerosol in the laboratory environment or possibly consumption of raw milk (Swanepoel and Coetzer, 2004; Sissoko *et al*, 2009). It is an occupational disease with farmers, farm workers and veterinary personnel being most at risk. It causes influenza-like illness with fever, joint and muscle pain and headache (Meegan *et al*, 1981). It most often results in a mild febrile illness, but the complicated form occurs in a small percentage of patients (less than 8%) (Madani et al, 2003; Meegan and Bailey 1988). Severe complications including retinitis, haemorrhagic syndrome, meningoencephalitis or even death can occur (Mcintosh *et al*, 1980; Pepin *et al*, 2010).

1.10 Diagnosis

Suspicion of RVF should be aroused when heavy rains are followed by the occurrence of abortions in sheep, cattle and goats together with fatal disease, particularly in young and in pregnant animals, which is marked by necrotic hepatitis and widespread haemorrhages. Frequently there is also influenza-like illness in farm workers but samples should be submitted for laboratory confirmation. Definitive diagnosis is through the isolation and identification of the virus or the serological demonstration of a significant rise in specific neutralizing antibody titer between acute and convalescent sera (Wood *et al*, 1990).

Samples

Samples to be collected include heparinised or clotted blood and plasma or serum (OIE, 2005a). Tissue samples of the liver, spleen, kidney, lymph nodes, heart blood and brain from dead animals or aborted fetuses (OIE, 2005a). Specimens should be submitted preserved in 10% buffered formalin and in glycerol or saline and transported at 4°C (OIE, 2005a).

Agent identification procedures

- Culture

Primary isolation is usually performed on hamsters, infant or adult mice or on cell cultures of various types. The virus can also be detected by immunofluorescence carried out on impression smears of the liver, spleen and brain (Pepin *et al*, 2010).

- Agar gel immunodiffusion

Agar gel immunodiffusion (AGID) test is useful in laboratories without tissue culture facilities. Approximately 1 gram of tissue, preferably liver, is homogenized and made up to a 10–20% suspension in borate saline buffer, pH 9.0. The material is centrifuged at 1000 g and the supernatant is used in the test. Micro-AGIDs are performed on standard microscope slides covered with 3 ml of 1% agarose in borate saline (OIE, 2008).

- Polymerase chain reaction

Polymerase chain reaction (PCR) is used for rapid diagnosis based on antigen detection and detects RVFV in mosquito pools and diagnostic samples (Pepin *et al*, 2010).

Serological tests

Samples collected from animals for antibody testing may contain live virus and appropriate inactivation using either heat or chemical methods should be in place. Several assays are available for detection of anti-RVFV antibodies and the most widely used techniques are enzyme linked immunosorbent assays (ELISA) for the detection of IgM and IgG. Virus neutralisation tests have been used to detect antibodies against RVFV in the serum of a variety of species (OIE, 2014).

- Virus neutralization

Virus neutralization is the gold standard test, although it is laborious, expensive and requires days for completion (Pepin *et al*, 2010). This may be used to determine the presence of antibodies in naturally infected or vaccinate animals and it is the test prescribed by the World Organisation for Animal Health (OIE) for international trade (OIE, 2014). It is highly specific and can only be performed with live virus; therefore it is not recommended for use in non-endemic areas or in laboratories without appropriate biosecurity facilities and vaccinated personnel (Pepin *et al*, 2010). The test is also generally used to test vaccine efficiency and can be used to test the serum of any species with high specificity (OIE, 2014).

- Enzyme linked immunosorbent assay

Enzyme linked immunosorbent assays can be done with inactivated antigen and therefore are recommended for use in non-endemic areas. Cross reaction with other phleboviruses can occur. Use of inactivated whole virus or mouse liver antigen has recently been replaced by recombinant neucleocapsid (N) protein as antigen (OIE, 2014). Immunoglobulin M capture ELISA allows diagnosis of recent infection (Pepin *et al*, 2010).

- Haemagglutination inhibition

Haemagglutination inhibition can be done with inactivated antigen. However, sera from individuals previously exposed to other phleboviruses other than RVFV can be positive (OIE, 2014).

1.11 Prevention and control

The main preventive measure in endemic areas and to control epidemics is vaccination. Commonly used is a live vaccine derived from the Smithburn strain which is attenuated through serial intracerebral inoculation (Pepin *et al*, 2010). One inoculation produces protection in 6-7 days and confers immunity for 3 years. However, the vaccine causes abortion in pregnant ewes and is pathogenic to humans. Inactivated vaccines have also been developed for use in both animals (Clone 13 vaccine and MP12) (Pepin *et al*, 2010) and humans. The vaccines have been shown to be safe and effective but require two inoculations, which have limited their utility in outbreak control (Pitman *et al*, 1999; Pepin *et al*, 2010).

RVF outbreaks in livestock populations can be difficult to control but vaccination with the live attenuated vaccine can provide lifelong immunity. However due to the long inter-epidemic years there is usually vaccination relaxation as there will be no new cases and this lowers herd immunity. Farmers should

vaccinate all new and all replacement stock and there must be no relaxation since in most countries there are no early warning or prediction systems. Restriction of animal movement during epidemics by quarantining the affected areas is also another important control measure. This reduces the possibility that viraemic animals can be moved therefore preventing the spread and amplification of disease transmission (Chevalier *et al*, 2004).

Remote satellite sensing and monitoring of environmental conditions have been used to predict RVF epidemics. These predictions allow implementation of measures aimed at reducing mosquito vectors before epidemics occur (Anyamba et al, 2010).

1.12 Namibia

1.12.1 Introduction

Namibia (Fig 1.2) is a southern African country measuring 824 292 km², has a human population of 2.3 million and it has more than 300 days of sunshine. The winter (June to August) is generally dry and there is a minor rainy season between September and November and a major rainy season between February and April. Humidity is low and average rainfall varies from almost zero in the coastal areas to more than 600 mm in the Caprivi. Rainfall is variable from year to year and droughts are common.

The Namibian landscape consists generally of five geographical areas with very scanty vegetation. These five areas are the central plateau, the Namib Desert, the great escarpment, the bushveld and the Kalahari Desert. The central plateau runs from north to south and its borders are the Skeleton Coast to the northwest, the Namib Desert and its coastal plains to the southwest, the Orange River to the south and the Kalahari Desert to the east. It has the highest Namibian human and animal population and economic activity. The summer temperatures in the central plateau can reach 40°C.

The Namib Desert is composed of hyper-arid gravel plains and sand dunes along the entire coastline. It has the largest sand dunes in the world with little vegetation in the dry river beds. The great escarpment is rocky with poorly developed soils but is significantly more productive than the Namib Desert. Average temperature and temperature ranges increase as one moves further inland from the Atlantic Ocean. Vegetation varies in both form and density from woodlands to shrubby areas and some scattered trees.

The bushveld is found in north-eastern Namibia along the border with Angola and in the Caprivi. This area receives a greater amount of precipitation than the rest of the country, averaging around 400 mm per year. The temperature is cooler with approximate seasonal variations of between 10 to 30°C. The soils are

sandy and adjacent to this bushveld in the north central is the Etosha Pan, a dry saline pan which forms a shallow lake in the wet season covering more than 600 km². The Kalahari Desert is shared between Namibia, Botswana and South Africa. It has a variety of localized environments including hyper-arid sandy desert, *Acacia* trees and lots of grass.

Figure 1.2 The location of Namibia on the African continent (adapted from the world atlas http://www.worldatlas.com).

Namibia has a semi-desert climate with the southern part of the country drier than the Northern Communal Areas (NCA) hence the disparities in the farming practices in these areas. The southern part is associated more with small stock farming while the northern part is more large livestock production. Namibia has 13 regions and these are shown in Figure 1.3, in each region is at least one state veterinary office and the regions are further divided into constituencies.

The NCA is separated from the south by the veterinary cordon fence. This fence separates the foot-and-mouth disease free zone (south) from the infected zone (Caprivi region) with the rest of the NCA serving as protection and surveillance zones. There are no movements of cattle from the north to the south for farming purposes; the only movement allowed is from the surveillance zones through quarantine camps and direct to the abattoirs. The cattle are quarantined for 21 days while sheep and goats are quarantined

for 90 days in the camps and a further 30 days on the farm of destination. In the quarantine camps there are sentinel animals so that foot and mouth disease can be easily detected. There are no restrictions for animal movements south of the veterinary cordon fence as the area is foot and mouth disease free; however, a permit system is used to control these movements. The regions of Namibia and the veterinary cordon fence are shown in Figure 1.3.

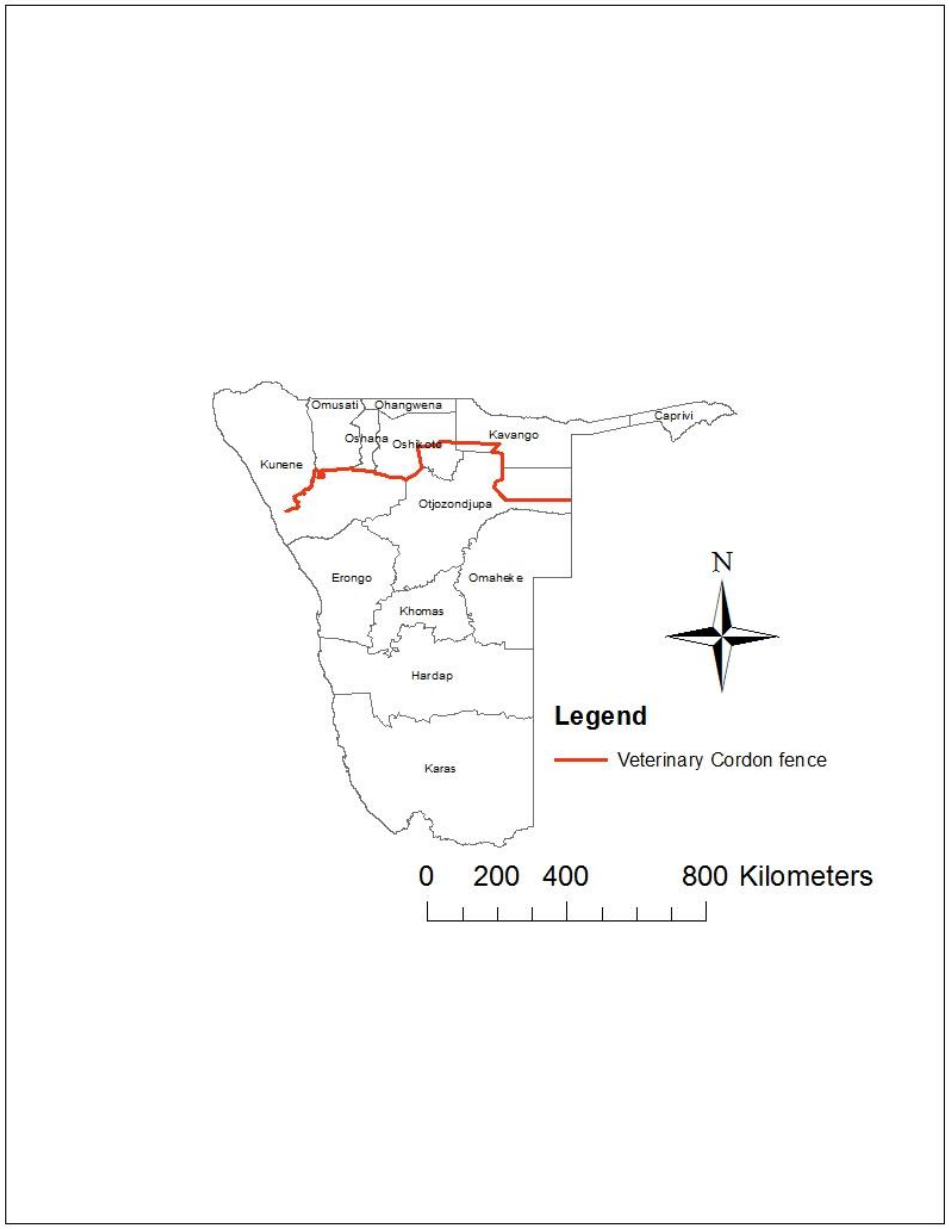

Figure 1.3. The regions of Namibia and the veterinary cordon fence.

1.12.2 Rift Valley fever in Namibia

Rift Valley fever is endemic in Namibia affecting mostly sheep with cattle, goats and people also affected. It is characterized by explosive epidemics of 10-15 years intervals and in all cases it is associated with high rainfall in more arid areas of the country (Schneider, 1994). It was first recorded in Mariental district in 1957 where high numbers of abortions and mortality occurred in sheep (Schneider, 1994). This outbreak was confined to Mariental district and was followed by the 1974 outbreak which spread affecting the Southern regions (Hardap and Karas) including Khomas and Otjo. Mortalities during this epidemic reached approximately 15000 sheep and 8000 abortions. During this outbreak goats and a few cattle were also affected (Schneider, 1994).

The 1976 outbreak occurred in Hardap region in the Mariental district on a Karakul farm killing 300 sheep and this was followed by the 1984 outbreak which occurred in Khomas region in the Windhoek rural district (Noden and Van Der Colf, 2013). Rift Valley fever was suspected in the following years; 1986 in Oshikoto region, 1989 in Karas region, 2001 in Kavango region, 2006 in Hardap and Otjozondjupa regions and 2009 in Caprivi region at Katima Mulilo. Rift Valley fever was again confirmed in 2010 where it affected mostly sheep and a few goats in the Hardap, Karas and Erongo regions. The H virus lineage was responsible for the outbreak (Monaco *et al*, 2010); this lineage was first isolated in 2004 in a human case in Caprivi region and it was also responsible for the earlier outbreak in South Africa in 2010 (Grobbelaar *et al*, 2011). In 2011 the same lineage H (result obtained from CVL) was detected in Otjozondjupa region at one focus where it affected cattle and in Oshikoto region at 4 foci where it affected goats.

The impact of the disease in Namibia includes loss of local and international trade. Namibia is a net exporter of livestock and livestock products and loss of trade due to the disease has serious economic consequences. There is also movement restrictions imposed within the country if there are outbreaks. The disease has a serious effect on rural people's food security and household nutrition and causes direct and indirect losses to livestock producers in the country. Psycho-social distress that communities go through is enormous, considering the loss of their livestock production and fear of infection.

Chapter 2: Research design and methodology

2.1 Research questions

There are several epidemiological factors with regards to the Rift Valley fever virus which are not yet fully understood. It is not yet fully known how the RVF virus survives inter-epidemic years. Questions have been raised as to whether the virus is introduced before each epidemic or whether transovarial transmission in vectors is the main mode of survival between epidemics. Although abnormally high rainfall has been associated with outbreaks, not all high rainfall years had RVF outbreaks.

RVF is a notifiable disease in Namibia because of its zoonotic potential, the severe economic impact due to abortions and deaths in livestock and its effects on international trade. However, little is known of the spatial and temporal occurrence of the disease, the potential risk factors and areas which are at high risk of outbreaks in Namibia.

For further research on RVF in Namibia, and in order to better manage, control and possibly predict the disease, it is important to have a full record of where and when the outbreaks occurred in the country. The epidemiology of RVF is not well understood, hence forecasting outbreaks and carrying out efficient and timely control measures remains a challenge. Improved knowledge of the epidemiology of RVF in Namibia, including potential risk factors, will help in the upgrading of current control strategies and the development of new strategies.

2.2 Objectives of the study

1. To compile a complete temporal and spatial history of the occurrence of RVF in Namibia, including all confirmed and suspected RVF outbreaks as well as serological evidence of RVFV presence.

2. To identify the areas of the country that is at higher risk of RVF outbreaks.

3. To describe the features of the spatial and temporal distribution of RVF in Namibia.

4. To identify the potential risk factors associated with the occurrence of RVF outbreaks in Namibia.

2.3 Materials and methods

2.3.1 Study design

This was a retrospective, descriptive study in which it was attempted to obtain all possible information regarding the occurrence of RVF in Namibia. All available sources regarding confirmed and suspected occurrences of RVF in Namibia were consulted and the spatial and temporal features of each occurrence fully described. Annual reports prepared by the Directorate of Veterinary Services (DVS); disease report forms compiled and kept at the Epidemiology Section of the DVS; laboratory reports from the CVL on suspected and confirmed cases; scientific publications and books on RVF in Namibia and reports submitted to the OIE by Veterinary Services were used to compile RVF outbreak data.

2.3.2 Data collection

All the data describing the RVF outbreaks and laboratory confirmation results from 1986 to 2011 were collected from the CVL and the Epidemiology section of the DVS. This information was in disease report forms sent to the laboratory with samples and also disease report forms sent directly to the Epidemiology section with no samples collected. The disease report forms both sent directly to the Epidemiology section and those sent via CVL were entered in a central database at the Epidemiology section in Windhoek and that data in form of spreadsheets was collected.

Scientific literature and publications with regards to the outbreaks in Namibia and neighbouring countries was consulted as well as reports sent by the national directorate to the OIE regarding outbreaks from 1957 to 1985, which were not in the records at Veterinary Services. The following databases were searched: Medline, PubMed, CAB abstract, Zoological records and Science direct. Some of the search terms used were: (Rift Valley fever OR arbovirus) AND South West Africa, (Rift Valley fever OR arbovirus) AND Namibia, (Rift Valley fever OR arbovirus) AND southern Africa, and (Rift Valley fever OR arbovirus) AND South Africa. This literature included a book published by H.P. Schneider in 1994 on animal health and veterinary medicine in Namibia and publications on RVF and other arboviruses both in Namibia and other African countries.

In addition, data on other cases which could have been RVF but were not confirmed were also collected and these were referred to as suspected cases. These suspected cases were defined as those which exhibited clinical signs of RVF such as abortions and death in young animals but were not confirmed due to samples not being collected or not confirmed at the laboratory.

2.3.3 Data analysis

2.3.3.1 Descriptive analysis

Simple mapping was done using ArcMap 10.2 (ESRI Corporation 2013), all the outbreaks were displayed on a map showing the region or district affected for outbreaks between 1957 and 1984 and specific coordinates of foci affected from 1986 to 2011. The maps also shows factors that have a correlation with RVF outbreaks such as annual average rainfall, sheep and cattle density, vegetation cover and average annual temperature for Namibia. This was then followed by a detailed description of each outbreak showing the species affected and the mortalities caused. All the serological surveys done in humans and animals were also included to show where and when these surveys were done and their outcomes.

2.3.3.2 Risk mapping

This was done to identify areas of the country which are at high risk of having outbreaks. The whole country was divided into quarter-degree squares (15′ grid) and the cumulative number of outbreaks occurring in each square since 1957 was calculated. For outbreaks occurring from 1986 onwards it was possible to precisely allocate each outbreak to a specific square. However, for outbreaks before 1986 only the districts affected could be obtained from literature; therefore, all squares contained within those affected districts were designated as having an outbreak. An attempt was made to somewhat refine the spatial allocation of these outbreaks by excluding squares without sheep or cattle. This was done by overlaying cattle and sheep distributions obtained from (Mendelsohn *et al*, 2002). The assumption was that cattle and sheep distribution has not changed over time and that RVF could not occur where there were no animals. Despite this, using the whole district affected for the outbreaks without coordinates grossly overestimated the extent of these outbreaks, but that was the only option with the available data.

This was done for each year in which RVF occurred in Namibia, and a cumulative total for each cell of the number of confirmed outbreaks since 1957 was obtained. The resultant map outlined the areas which are considered to be at high risk of having outbreaks.

2.3.3.3 Cluster analysis

A retrospective space-time analysis for clusters with high rates was done using SaTScan (http://www.satscan.org/) on all the confirmed outbreaks with GPS coordinates. SaTScan analyses spatial, temporal and spatio-temporal data through a scan statistic quickly scanning for potential clusters (Kulldorff, 1997). The objective was to detect areas of significantly high or low rates of RVF in Namibia, to test whether it was randomly distributed over space, over time and over space and time, and to see if

the clusters were statistically significant. Space time permutation requires the use of geographic coordinates for case data therefore in this study only outbreaks which had a precise spatial location and time of occurrence were used, that is the 2010 and the 2011 outbreaks. The software calculates the p-values for the detected clusters using computer simulations generating a number of random replications of the data set under the null hypothesis. The resultant statistically significant clusters were the shown on a map.

2.3.3.4 Risk factor analysis

Due to the small number of confirmed outbreaks ultimately included in the dataset, it was not possible to attempt multivariable analysis to identify risk factors for the occurrence of outbreaks. In addition, the poor spatial definition for outbreaks up to 1984, resulting in overestimation their geographic extent, made it unwise to attempt such analysis. Instead, visual comparisons between the risk map and maps of livestock and rainfall distribution were done in order to identify any correlations.

Chapter 3: Results

3.1 Introduction

The study was aimed at investigating the spatial and temporal occurrence of RVF in Namibia from the first to the last recorded outbreak. Sources of information on the occurrence were annual reports, scientific literature, disease reports to the OIE, published books and laboratory reports.

The process of data collection did not go as expected since most of the information which was available on the outbreaks was just general and lacked the precise spatial and temporal location of the cases. The data which was collected from the epidemiology section was most useful since they had a compilation of disease cases reported directly to the section and disease reports with laboratory results from the CVL. There were very few publications with specific reference to RVF in Namibia but Schneider 1994 had a general overview on confirmed and suspected RVF outbreaks that occurred from 1957 to 1986. Attempts were made to locate animal disease reports from South West Africa / Namibia which may have been sent to South Africa prior to Namibian independence, by enquiring at the library of the Department of Agriculture, Forestry and Fisheries, Pretoria, and the library of the Agricultural Research Council – Onderstepoort Veterinary Institute, Onderstepoort. However, attempts to locate such reports were unsuccessful. References cited by Schneider 1994 with regards to RVF in South West Africa/ Namibia were also followed up. A search was done on the South African National Archives and Records Services for annual DVS reports referenced by Schneider 1994 dating from 1957 to 1992 and all the references with regards to RVF in Southern Africa. The following link was used to search for the records but unfortunately the search yielded no results: http://www.national.archives.gov.za/index.htm.

The first recorded RVF outbreak in Namibia was in the year 1957 and the latest was in 2011; however, the annual reports at the Epidemiology section in the DVS started from 1986 to date. The information on outbreaks between 1957 and 1986 was obtained from scientific literature and books but lacked the exact coordinates of the foci affected.

Suspected outbreaks which occurred between 1986 and 2009 were detected by clinical presentation. They were not confirmed by the laboratory tests because diagnostic samples were either not sent to the laboratory for confirmation or the laboratory did not carry out the tests due to inappropriate samples delivered. Table 3.1 shows a summary of the years in which RVF was confirmed or suspected in each

state veterinary region, number of foci affected and the total cumulative number of years (both suspected and confirmed) in the history of Namibia.

Table 3.1 Summary of all the recorded RVF outbreaks in Namibia

Region	Year confirmed	Year suspected	Number of foci confirmed	Number of foci suspected	Cumulative years suspected and confirmed
Hardap	1957, 1974, 1976 and 2010	2006	15	1	5
Karas	1974 and 2010	1989	3	1	3
Khomas	1974 and 1984	No record	2	0	2
Erongo	2010	No record	1	0	1
Otjozondjupa	1974 and 2011	2006	2	1	3
Kavango	Never confirmed	2001	0	2	1
Caprivi	Never confirmed	2009	0	1	1
Oshikoto	2011	1986	5	1	2
Omaheke	1974	No record	1	0	1

A total of six years had outbreaks of RVF in Namibia from the first outbreak to the latest. The geographic distribution of these outbreaks and the cumulative number of outbreaks in each quarter degree square are shown in Figure 3.8. The reports on outbreaks that occurred before 1986 lacked the exact geographical location as only either state veterinary regions or districts were shown to be affected. This limited the data analysis to only descriptive mapping, cluster analysis and risk mapping with no determination of the possible risk factors. The major RVF outbreaks in Namibia occurred in 1957, 1974, 1984, 2010 and 2011. The regions which had at least one confirmed or suspected outbreak in Namibia are shown in Figure 3.1.

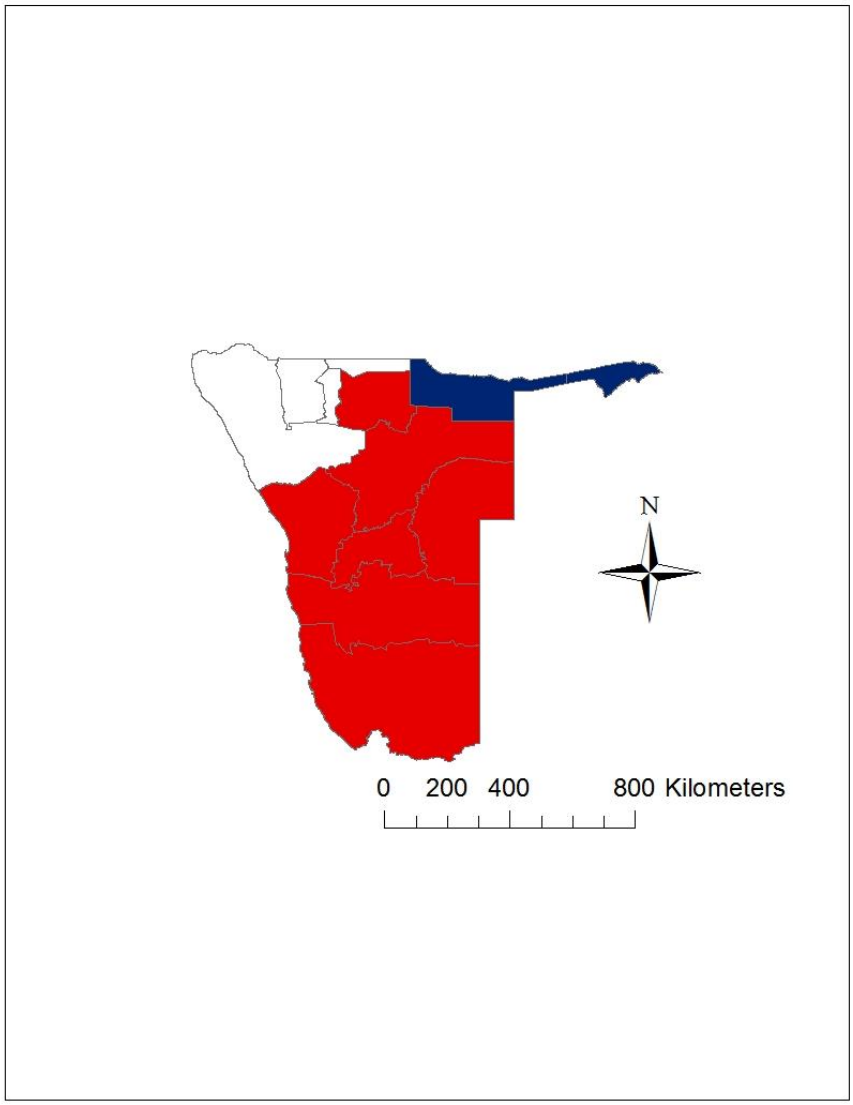

Figure 3.1 Regions with at least one confirmed or suspected outbreak of RVF in Namibia from 1957 to 2011.

Regions shaded in red indicate the regions which at least one confirmed outbreak and those in blue only had suspected outbreaks. The outbreaks were confirmed by laboratory testing and those not tested or not confirmed were suspected based on the clinical picture i.e. abortion storms and death of lambs and kids.

3.2 Individual outbreaks

3.2.1 Confirmed outbreaks

1957

This was the first major epidemic to occur in Namibia in the Mariental district resulting in high mortalities and abortions in sheep. This outbreak was confined to the Mariental district in Hardap region and never spread to other regions (Schneider, 1994). During this epidemic goats and cattle were also affected and this outbreak was confirmed by laboratory testing. Figure 3.2 shows the affected district since there was no information recorded on the exact location (farms affected) in Mariental district, the whole district was highlighted encompassing Mariental urban, Mariental rural and Gibeon constituencies. This is however an overestimation of the extent of the outbreak. This coincided with an outbreak in Zimbabwe in 1957 in the cattle farming areas (Swanepoel and Coetzer, 2004) and it also occurred after an outbreak in South Africa in 1955-1956 which affected twenty-eight foci in the Free State Province (Pienaar and Thompson, 2013).

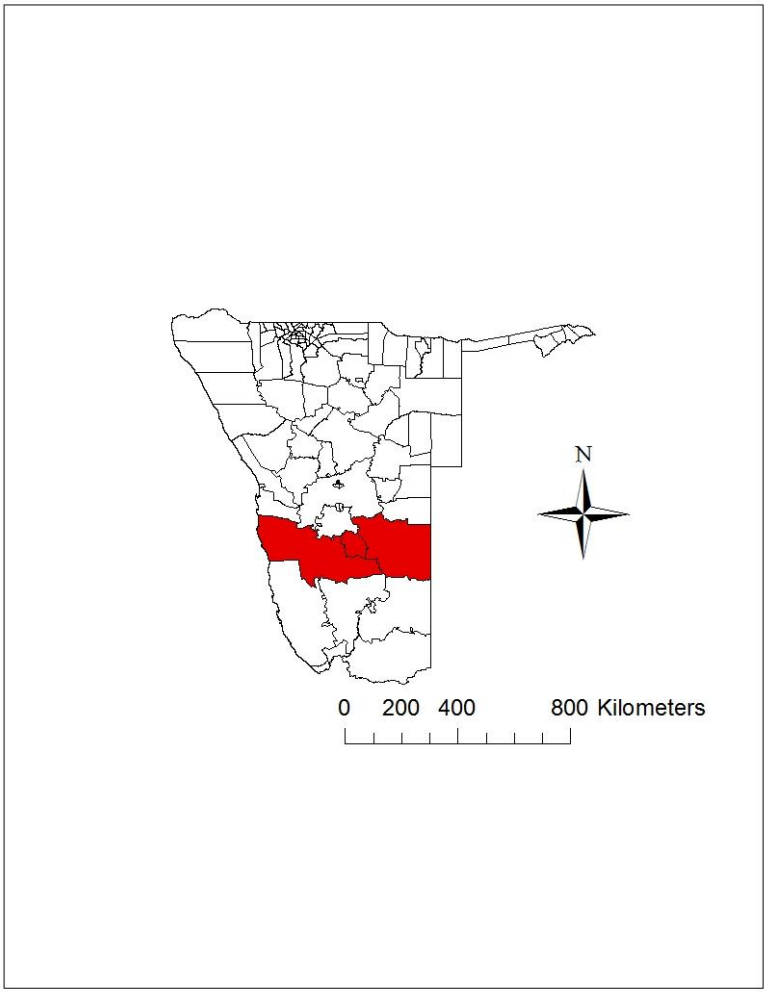

Figure 3.2 Mariental district and Gibeon constituency affected by the first RVF outbreak in Namibia.

1974

This was the second RVF epidemic in Namibia and it affected Hardap, Karas, Khomas and Erongo regions. The outbreak was first reported in the Mariental and Keetmanshoop districts and later spread to Karasburg, Maltahohe, Rehoboth, southern Gobabis Windhoek and Outjo (Schneider, 1975) resulting in very high mortality of approximately 15000 sheep and 8000 abortions, it also affected goats and a few cattle (Schneider, 1994). The economic loss of this outbreak was estimated at R250 000 and several farmers and farm workers were also infected with deaths recorded. This severe epidemic coincided with the very large South African epidemic which had started in 1973 and lasted for three years. There was also an outbreak in Zambia in 1973-1974 (Swanepoel and Coetzer, 2004).

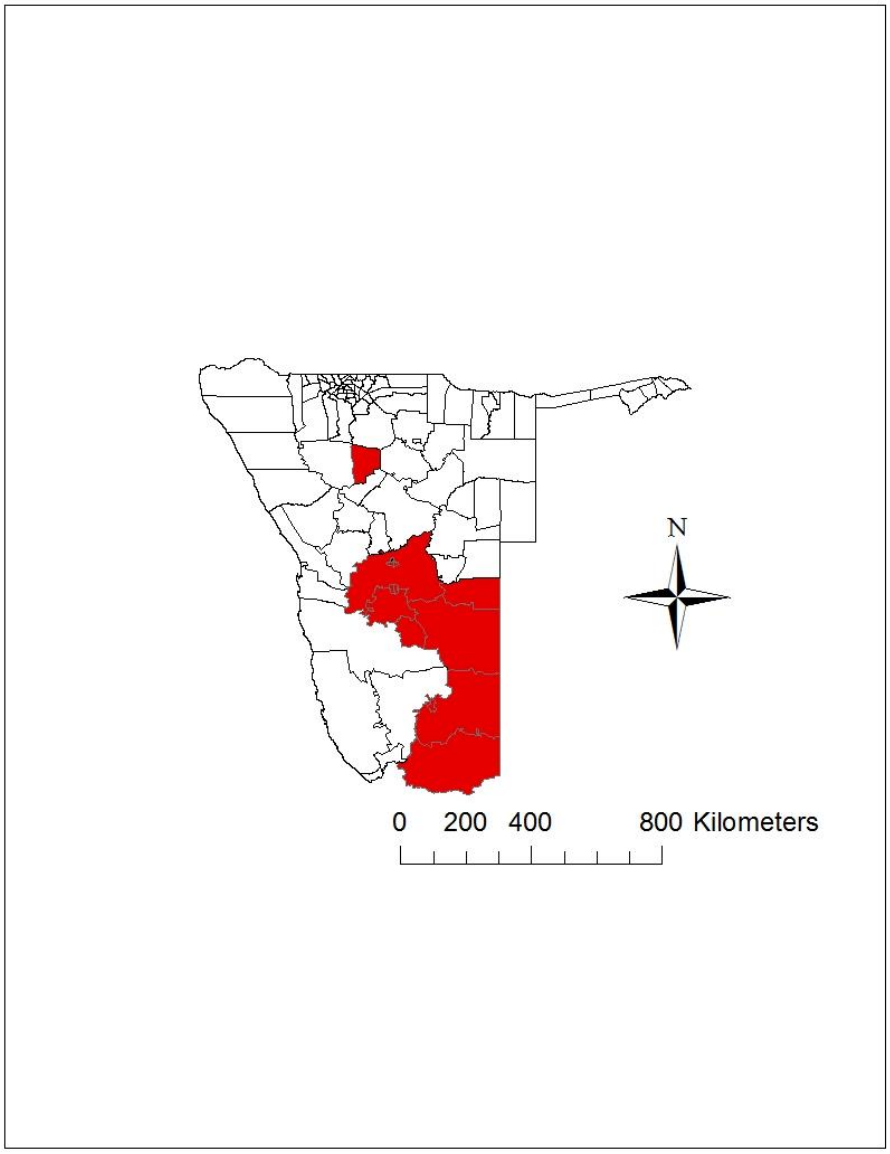

Figure 3.3 Constituencies affected by Rift Valley fever in 1974.

1976

There was a single outbreak in Hardap region in Mariental district on a stud farm which killed 300 stud karakul sheep (Schneider, 1994). The exact location was not mentioned but the district affected is highlighted in Figure 3.2 above.

1984

This outbreak affected the Khomas region, specifically Windhoek district, but there was no specific location given. During this outbreak farmers were forced to vaccinate pregnant animals and it resulted in

2-5% abortions and 22-50% of the lambs had malformations (Schneider, 1994). The area affected is shown in Figure 3.4.

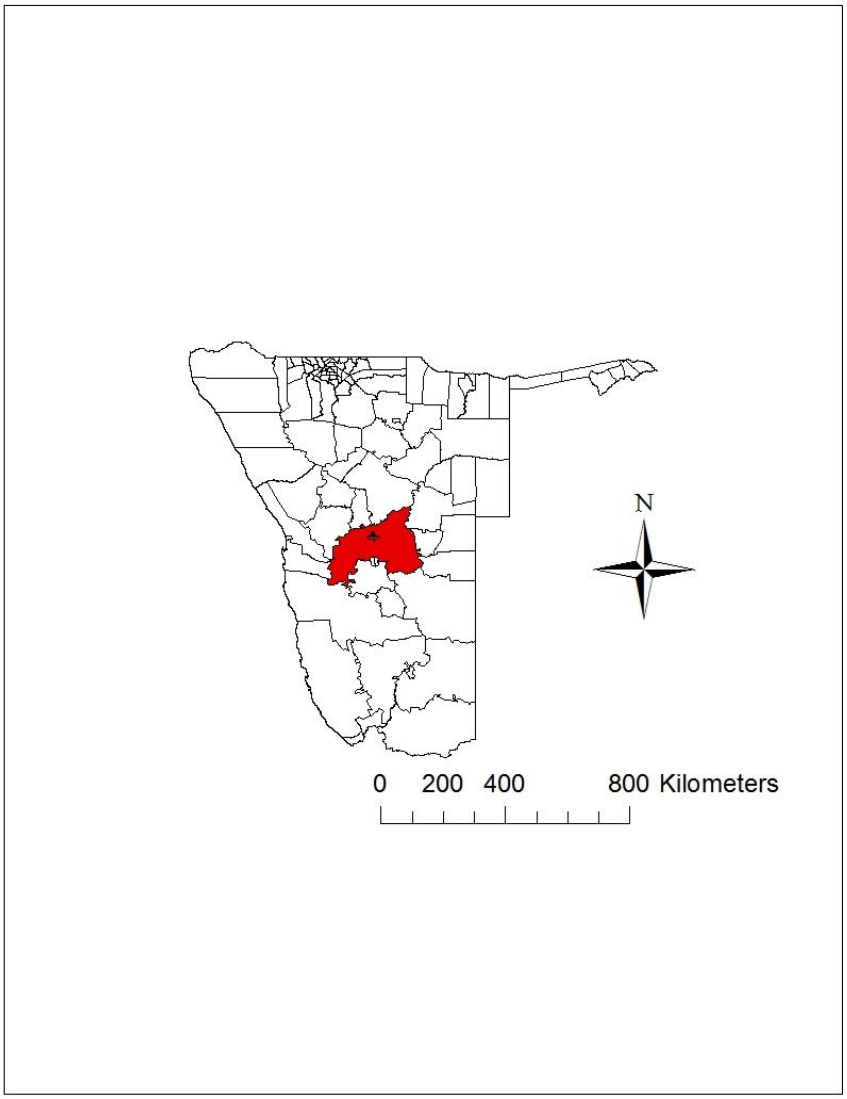

Figure 3.4 Windhoek district affected by the 1984 Rift Valley fever outbreak.

2004

A single human case exposed to the virus in the Caprivi region was confirmed in Windhoek to be suffering from RVF and lineage H was responsible for the infection (Grobbelaar *et al*, 2011). There was no confirmed or suspected outbreak in livestock during 2004 hence the possibility that the virus was transmitted via mosquito bites. This was the first serotype documented in Namibia and this serotype was

responsible for the South African outbreak in 2010 (Grobbelaar *et al*, 2011) and the outbreak in livestock in Namibia in 2010 (Monaco *et al*, 20100 and 2011 (results from CVL).

2010

This was a laboratory confirmed outbreak which affected 15 foci, in Hardap (12 foci), Karas (2 foci) and Erongo (1 focus) regions. The outbreak was first diagnosed at an export abattoir in Hardap region. This outbreak subsequently spread to other regions but the mechanism of spread was never established. The farms affected in Hardap region were Hebron, Toelop, Marienthal, Karris, Donkerhoek, Dassiesfontein 1 and 2, Hardap plot, Aranos townlands, Driedoring, Brynard and Orion. In Karas region the farms affected were Graswater and Ramansdrift and in Erongo region the farm Omatjette was affected. The first recorded case was in Hardap region in May 2010 and all the cases in both Hardap and Karas occurred between May and June 2010 while the recorded cases in Erongo occurred in October 2010. On all the affected farms in 2010 sheep were affected, with cases in goats at Omatjette and Aranos townlands. The reported clinical signs varied from abortions, stillbirth, death in young lambs and kids to weakness and sudden death. Rift Valley fever lineage H was the virus isolated from this outbreak and was similar to the one which had caused earlier outbreaks in South Africa in 2010 (Monaco *et al*, 2010). The South African outbreak occurred during the first half of 2010 coinciding with the Namibian outbreak. The outbreak in South Africa started in the Free State Province and went on to affect all the provinces except KwaZulu-Natal. A total of 484 outbreaks were reported affecting mostly sheep followed by cattle then goats and some indigenous and exotic wildlife species (Pienaar and Thompson, 2013).

The source of the virus was never confirmed; it could have been an introduction from South Africa which had an outbreak earlier that year or it could possibly have been a virus which was present and maintained by low level circulation. The mechanism of spread of the virus from the initial foci to distant regions such as Erongo was never established; possibilities include animal and vector movement.

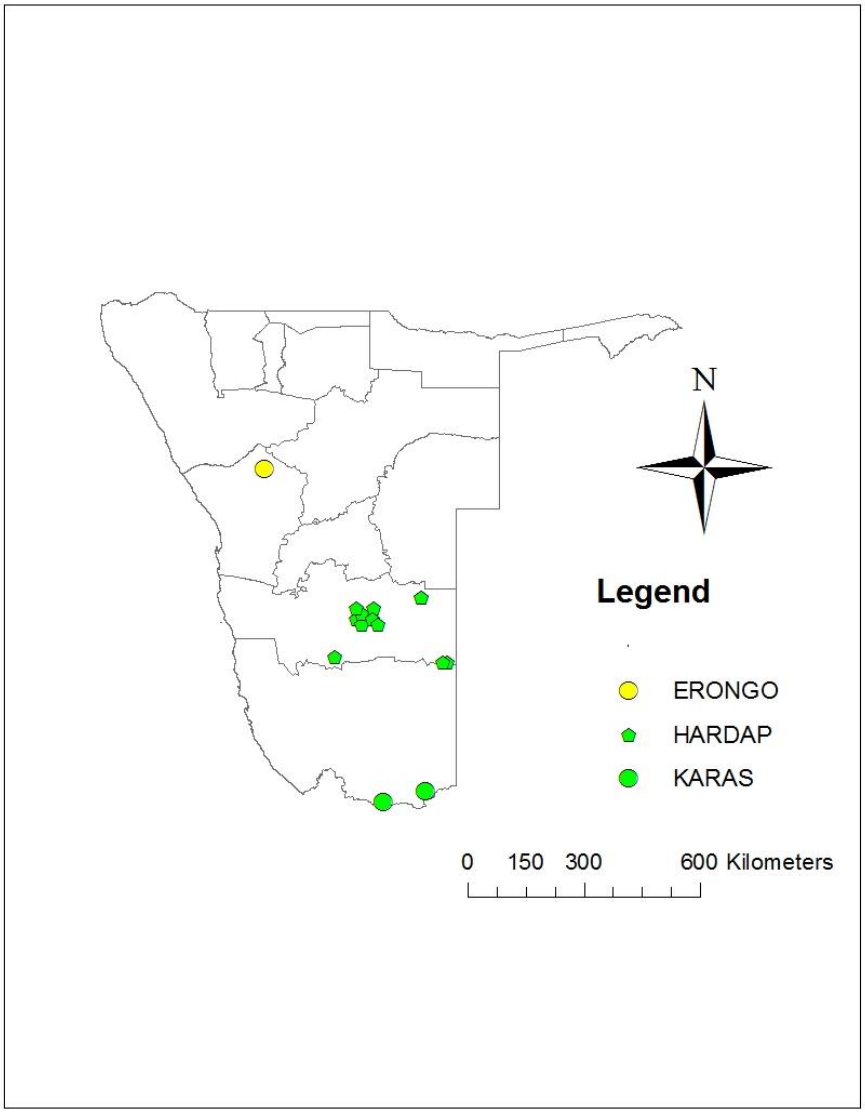

Figure 3.5 Rift Valley fever affected foci in 2010.

2011

The outbreak occurred in the northern part of Namibia, in Oshikoto region at 5 different foci, in Omuthiya constituency (4 foci) and Omuntele (1 focus) and in Otjozondjupa region at farm Chipururu. In Oshikoto region only goats were affected while in Otjozondjupa cattle were affected. The outbreak started in April and ended in June 2011. The virus isolated from this outbreak was also lineage H, similar to the one isolated in 2010. Figure 3.6 shows the areas affected in 2011.

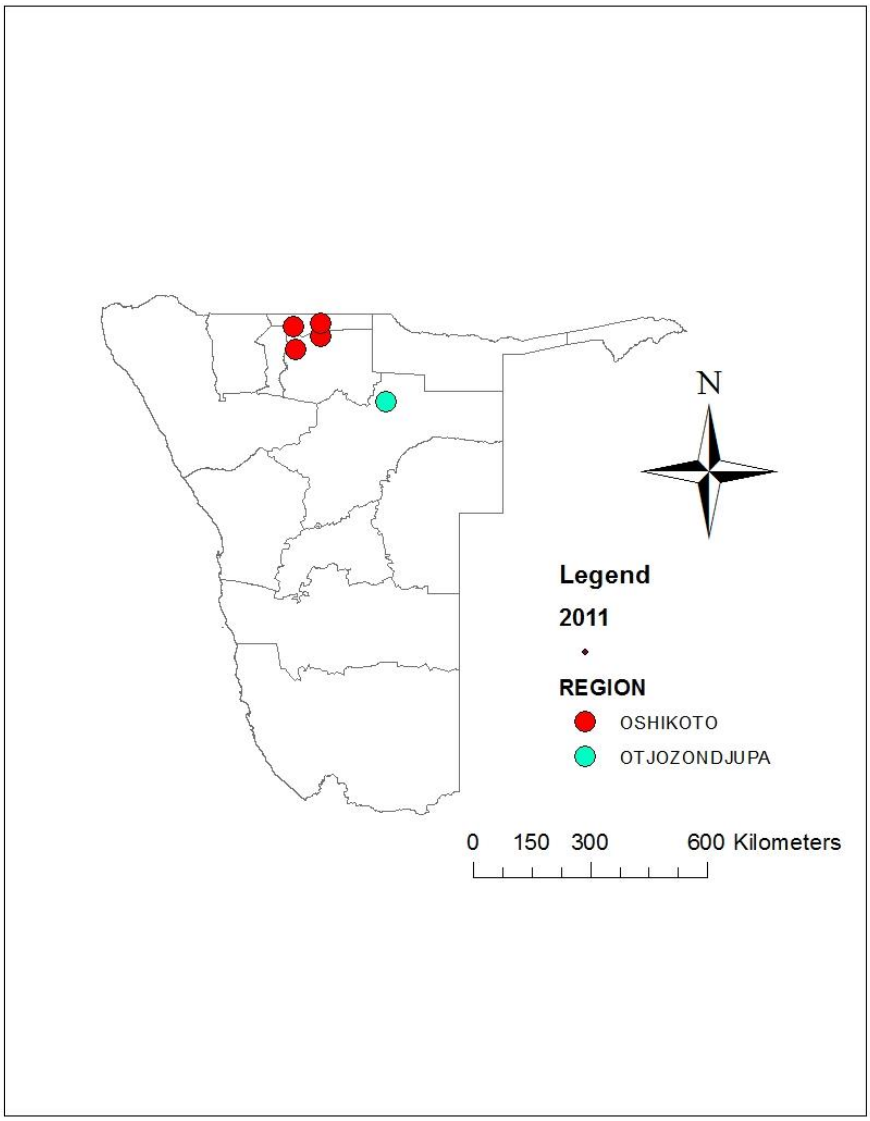

Figure 3.6 Rift Valley fever outbreak foci in 2011.

3.2.2 Suspected outbreaks

1986

This was a suspected outbreak since there were no samples send to the laboratory for confirmation. The outbreak was in Oshikoto region at farm Massaus where 5 goats out of 145 aborted. The abortions could have been due to other causes as well but the tentative diagnosis was RVF.

1989

Rift Valley fever was suspected at farm Grasheuwel in Karas region, Keetmanshoop district. On this farm 12 sheep died and RVF was suspected but not tested on samples that were sent to the laboratory, hence there was no confirmation.

2001

Rift Valley fever was suspected in Kavango region at Usivi and Rundu with 2 and 4 cattle having abortions at these locations respectively. The sera collected on the 2 foci were negative for RVF but this could have been affected by sample storage, shipping and testing.

2006

The outbreak was again suspected in Hardap and Otjozondjupa regions at farm Ober-Packriem and Otavi Township respectively. The suspected outbreak in Hardap region occurred in March while the one in Otjozondjupa occurred in April of 2006. In Hardap 27 sheep out 1200 died while in Otavi 8 out of 300 died, however on both farms no samples were taken for laboratory confirmation so the suspicion was based only on the clinical picture which was the mortality among sheep.

2009

The last suspected outbreak was in Caprivi region at Katima Mulilo, where 4 cattle were affected and 2 died. All the 4 cattle had late term abortions. Samples were collected and sent to the laboratory but RVF was not tested for. Instead, histopathology was done for bacterial causes of abortion, with negative results.

All the suspected cases were based on the clinical presentation as there was no laboratory confirmation. This was because in some cases samples were not sent to the laboratory or they were sent but RVF not tested for. This shows how the disease can be underreported and can be overlooked due to its long inter-epidemic periods as farmers and veterinary officials forgets about the disease. The foci for these suspected cases are shown in Figure 3.7.

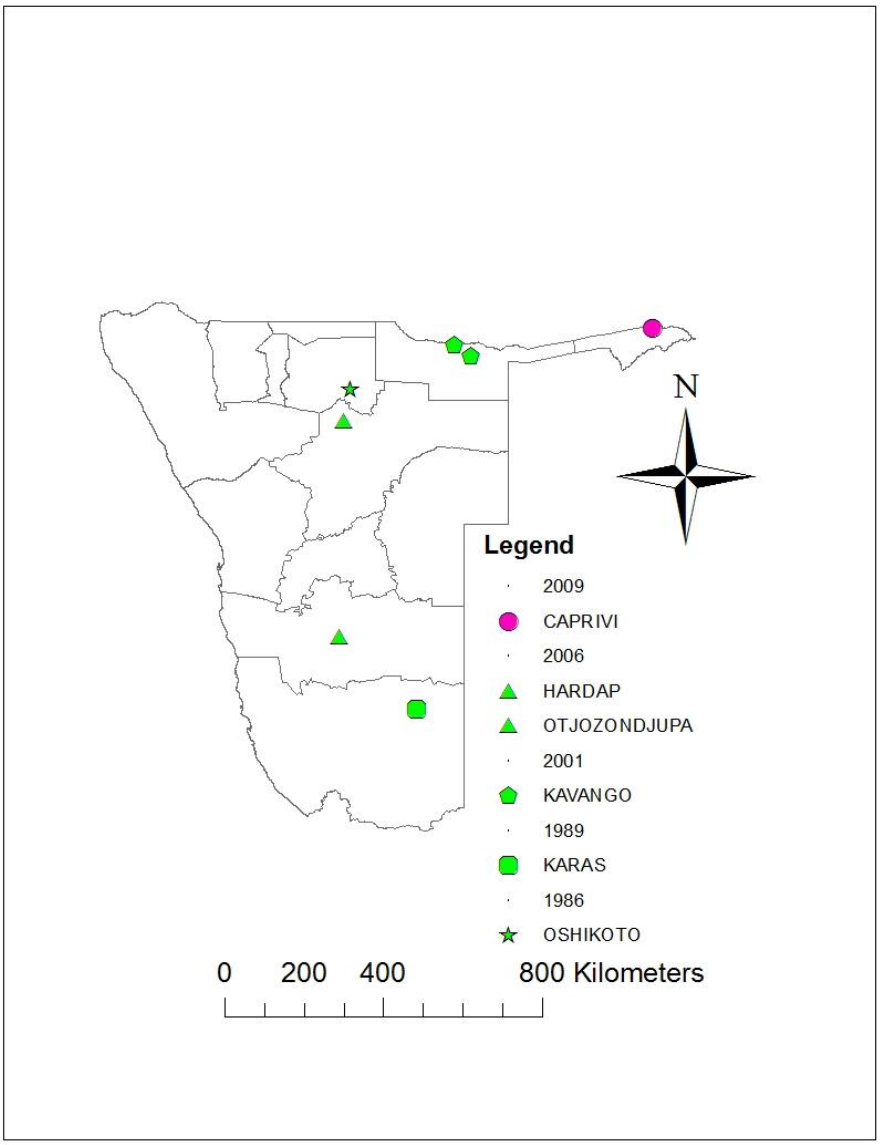

Figure 3.7 Suspected foci for RVF outbreaks in Namibia.

3.3 Risk mapping

3.3.1 Cumulative outbreak count

This was done to show the areas of Namibia which are at high risk of having outbreaks, based on the assumption that the higher the number of historical outbreaks in an area, the higher the risk of future outbreaks. The southern part of the country (Hardap and Karas) followed by the central (Khomas and Otjozondjupa) had more outbreaks in history than the NCA.

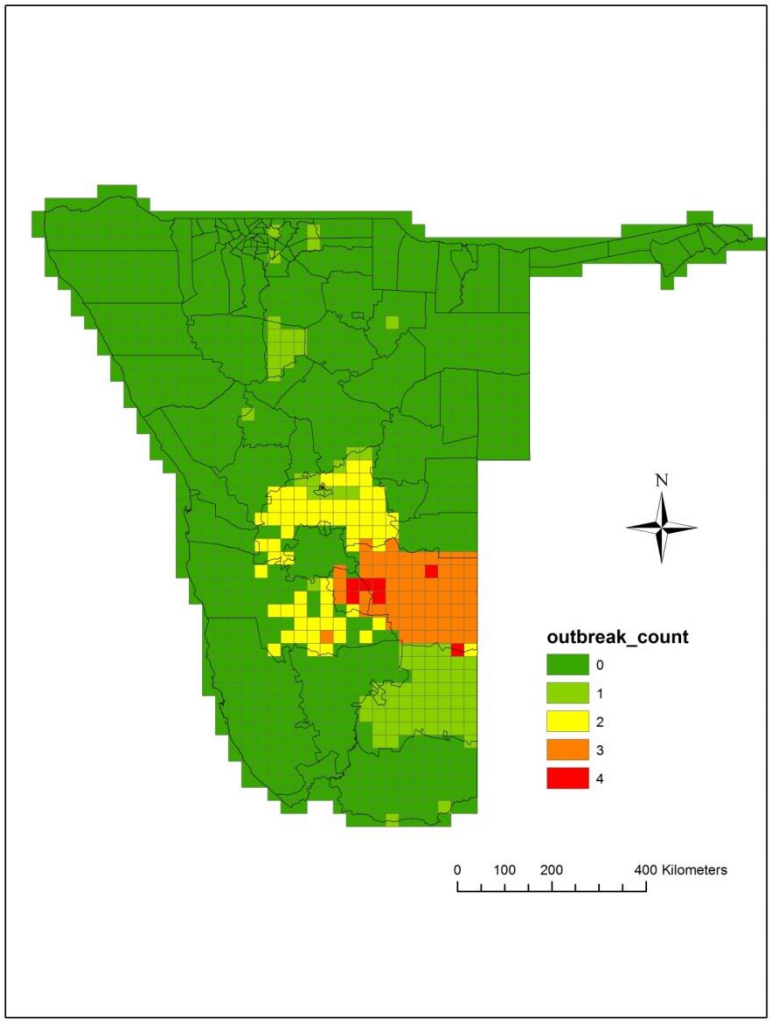

Figure 3.8 The cumulative number of confirmed RVF outbreaks from 1957 to 2011.

3.3.2 Sheep density and cumulative outbreak count

The data set was small for multivariable analysis to identify risk factors; therefore the maps below give a visual comparison between the sheep density and the cumulative of number of RVF outbreaks. The comparison suggests a positive correlation between sheep density and RVF outbreaks.

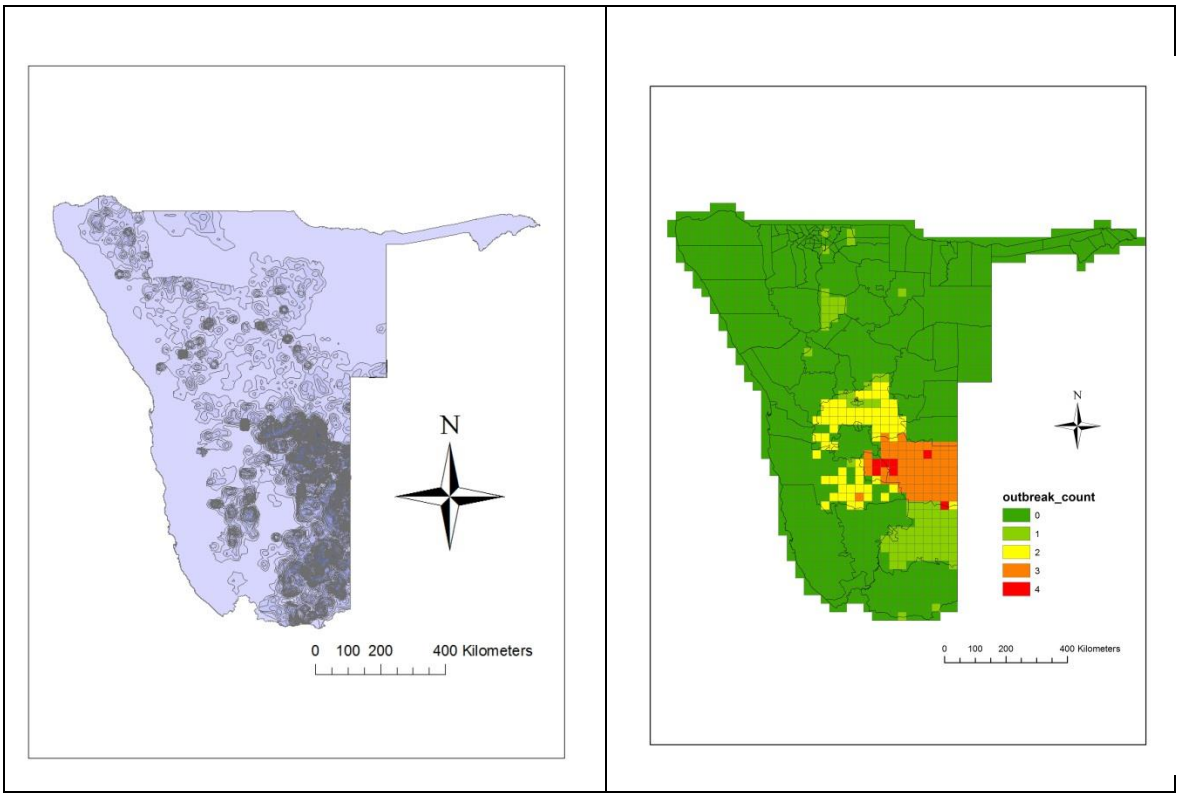

Figure 3.9 Comparison between sheep density and the cumulative number of RVF outbreaks in Namibia from 1957 to 2011.

3.3.3 Cattle density and cumulative outbreak count

A comparison was also done to determine if there was any correlation between RVF outbreaks and cattle density. Figure 3.10 shows no apparent correlation as only a few outbreaks occurred in the cattle dense areas. In addition, some of the outbreaks in the cattle dense areas occurred in goats. There were a few confirmed cases of RVF in cattle but not as many as those in sheep.

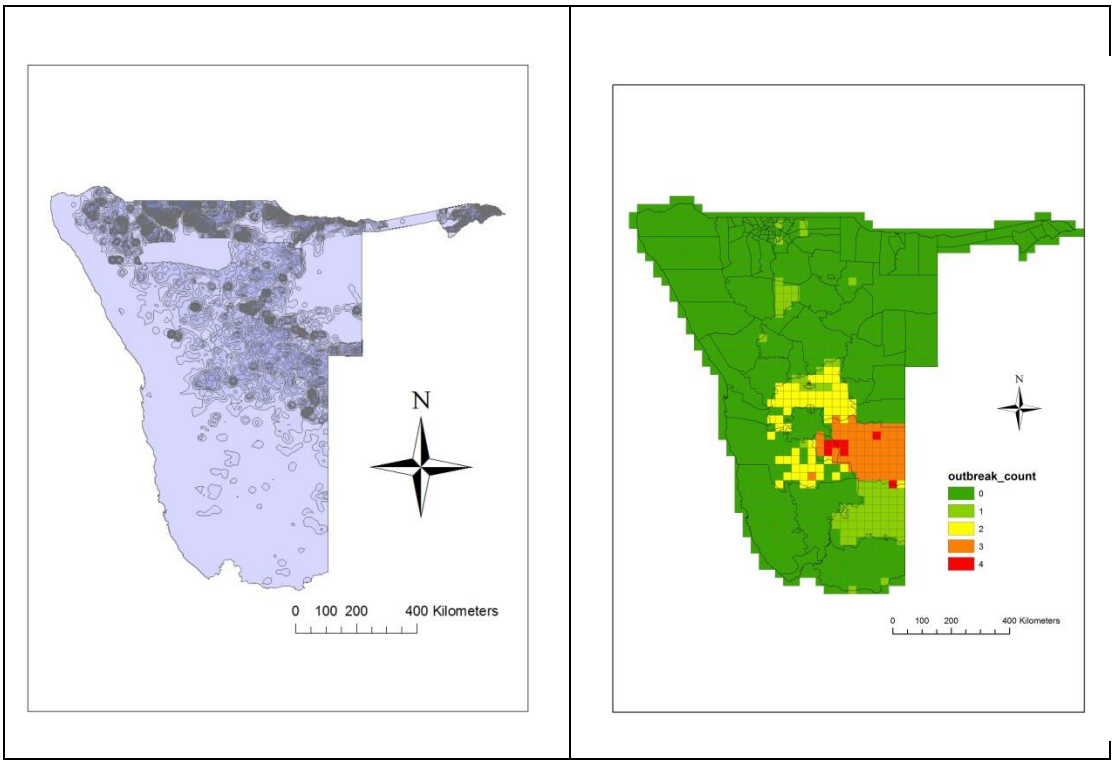

Figure 3.10 Comparison between the cattle density and the cumulative number of RVF outbreaks in Namibia from 1957 to 2011.

3.3.4 Average annual rainfall and cumulative outbreak count

Rift Valley fever is associated with abnormally high rainfall events as there will be enough breeding sites for the mosquito vector. Figure 3.11 shows that areas with low average annual rainfall had more outbreaks than those with high average annual rainfall. The northern areas receive more rainfall than the south but more outbreaks are in the south than in the north. This could be because of the drier conditions the vectors and hence the virus does not continuously circulate and when high rainfall events occur there is sudden increase in vector population. Epidemics will occur because the animal population with naïve as there is no continuous low level circulation. Rainfall data could not be obtained for the years which had outbreaks but according to Schneider, 1994 most of the outbreaks occurred after above average rainfall events.

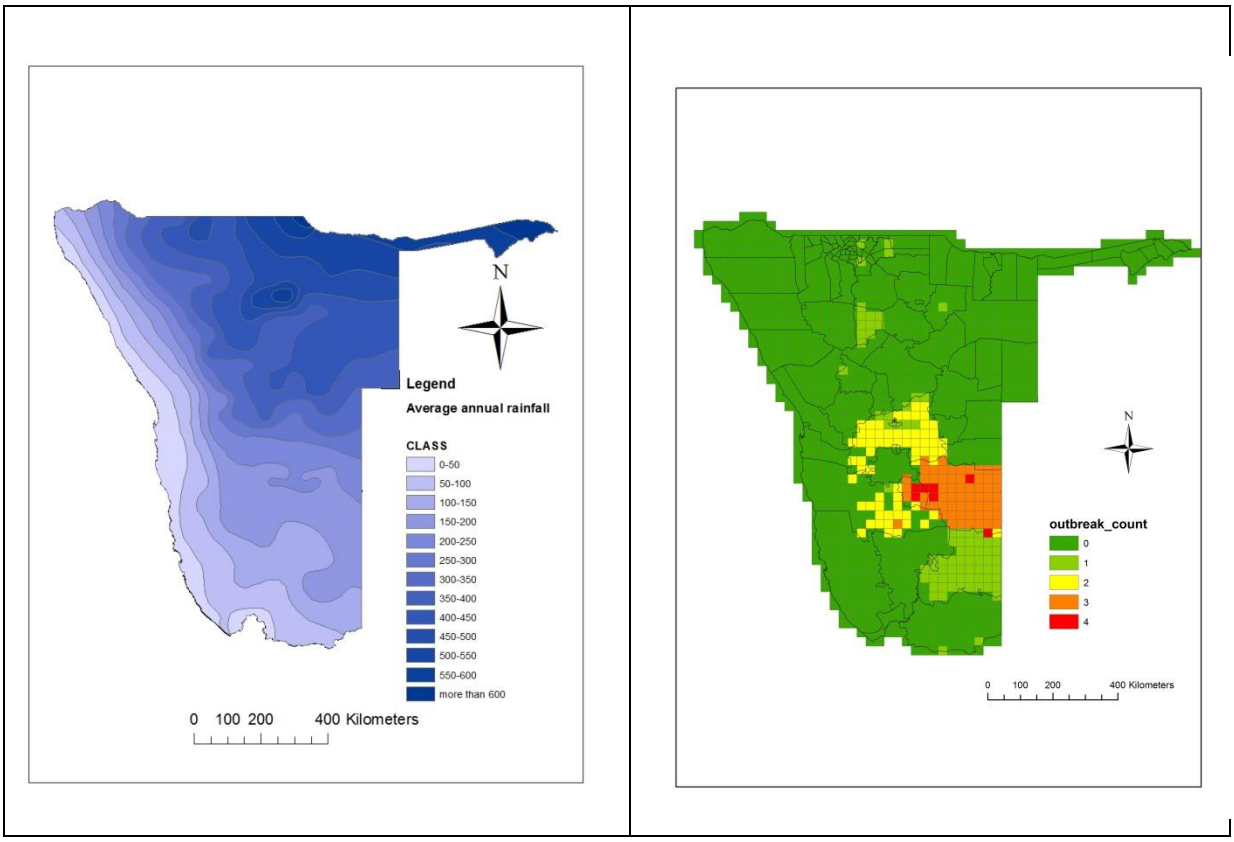

Figure 3.11 Comparison between the average annual rainfall and the cumulative RVF outbreak count in Namibia from 1957 to 2011.

3.4 Cluster analysis

The 2010 and 2011 outbreaks were analysed using SaTScan to determine the spatio-temporal clustering. A retrospective space-time analysis scanning for clusters with high rates using the space-time permutation model was done. The study period was from 01/01/2010 to 31/12/2011 since it was the only period with laboratory confirmed cases which had GPS coordinates. The number of locations over the study period was 19 and a total of 21 cases were observed.

The time frame for these cases was from 12/04/11 to 04/06/11, the number of cases of this cluster period was 5, the expected cases 1.19, the observed/expected cases 4.20, and the test statistic was 3.758237 (P = 0.002). The time frame for the second cluster was from 05/05/10 to 12/06/10 with the number of cases being 9, expected cases 4.71, observed/expected cases 1.91, test statistic 2.155065 (P = 0.896). The two

clusters described above are shown in Figure 3.12. Although the second cluster was not statistically significant, it made intuitive sense epidemiologically and is therefore included on the map.

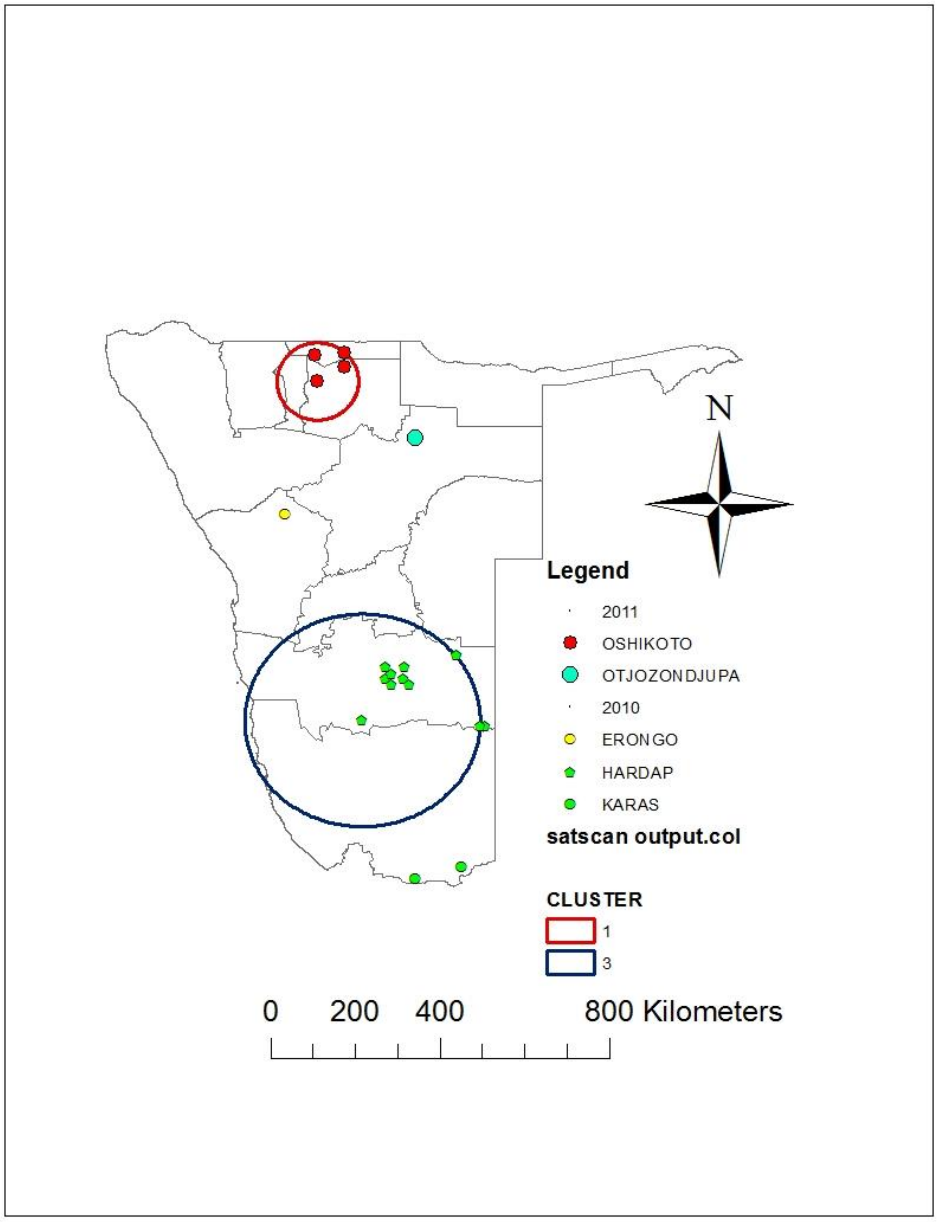

Figure 3.12 SaTScan clusters for the 2010 and 2011 RVF outbreaks.

3.5 Rift Valley fever serological surveys

3.5.1 Etosha National Park serological survey

The sero-survey was done in 2011 on springbok (*Antidorcas marsupialis*) and gemsbok (*Oryx gazella*) in the Etosha National Park to demonstrate the presence or absence of antibodies to RVF (the results were obtained for the CVL). The samples were tested using IgG and IgM ELISA and RT-PCR, 90 springbok were tested and all the animals had at least one positive result. 70/90 springbok (78%) were positive for IgG, 30 (33%) were positive for IgM and 18 (20%) were positive for RVFV using RT-PCR. The number of gemsbok tested was 12 and all were positive for IgG ELISA but were negative for both IgM and RT-PCR. Figure 3.13 shows the location where the sampling was done. These results indicated that wildlife is also susceptible to RVF and though there were no recorded outbreaks in the Etosha National Park there vectors and the virus is present.

3.5.2 Human sero-survey for RVF

3.5.2.1 Rundu

A survey was done for a number of arboviruses including RVF in Kavango region, Rundu district in May 1983 (Joubert *et al*, 1985). The sample population was volunteers from the national army, health workers and civilians in both urban and rural communities. A total of 189 people were tested of which 2% tested positive for RVF antibodies. The other arboviruses tested for in this sample population and their results were Sandbis 2%, Germiston 5%, Chikungunya 1% and Flaviviruses (Wesselsbron, West Nile, Banzi and Spondweni) 31%. The test used for all the viruses was the heamagglutination inhibition test (Joubert *et al*, 1985). Figure 3.13 shows the location where the sampling for the survey was done.

3.5.2.2 Katima Mulilo

The survey was done in Caprivi in 1984 following the survey in Rundu for the same diseases including RVF, 621 people were tested and 25 (4%) were positive to RVF (Joubert *et al*, 1991). There was a statistically significant difference in RVF seroprevalence between soldiers (10%) and civilians (3%). The other viruses tested were West Nile, Wesselsbron, Sandbis and Chikungunya. The cumulative occurrence of these viruses in soldiers was 68% and in civilians 29.2% meaning soldiers are at higher risk of getting

infected. The test used for all the viruses was the haemagglutination inhibition test (Joubert *et al*, 1991). Figure 3.13 shows the location where the sampling was done.

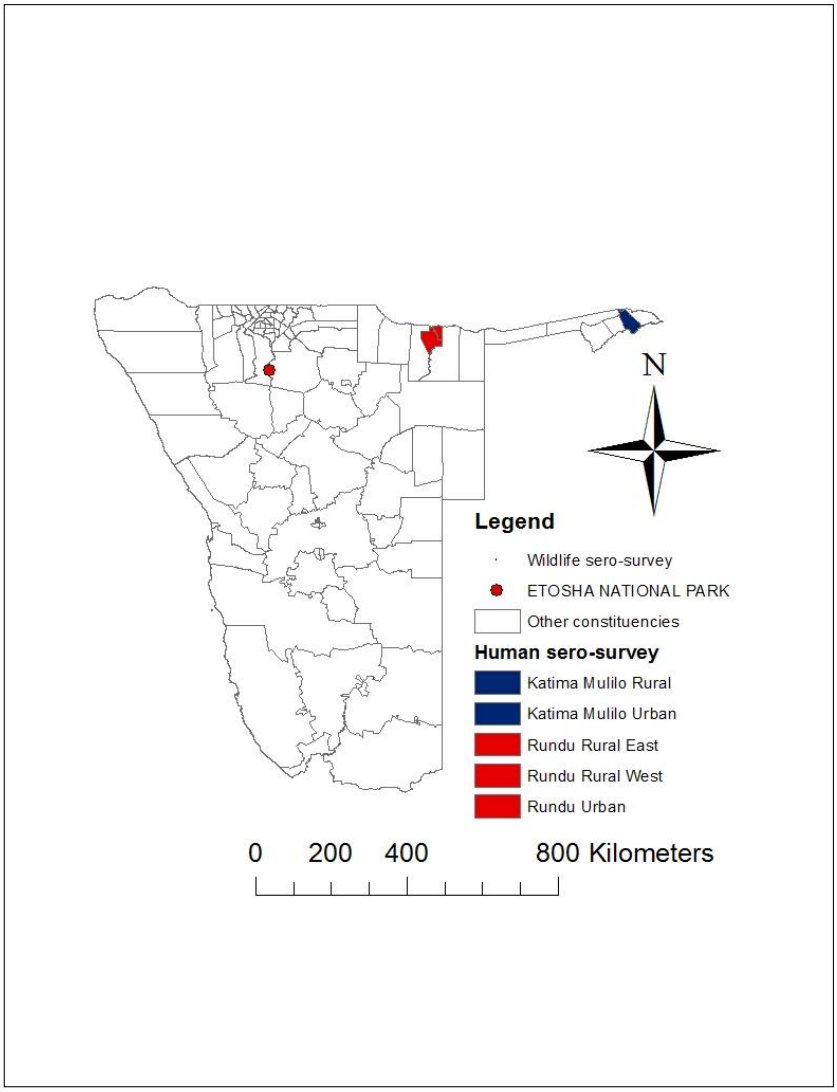

Figure 3.13 The location for human and wildlife sero-survey in Namibia.

Chapter 4: Discussion

The number of countries in Africa which have reported severe epidemics of RVF is increasing; the disease is endemic in at least 12 countries and has been serologically documented in 16 more countries (Gerdes, 2004). In 2000, a severe epidemic involving humans and livestock occurred in the Middle East, resulting in the virus becoming endemic in that region. The epidemics in Africa and the Middle East have resulted in death of millions of livestock, and over 2000 human deaths. Experts predict that the risk of even more severe epidemics in these regions and other parts of the world is increasing, in part due to changing global weather patterns (Anyamba et al, 2010).

The information obtained during the search for all the recorded outbreaks in Namibia did not yield the expected results, in that detailed records of outbreaks before 1986 could not be located. The information on these outbreaks was obtained only from scientific literature and not disease report forms or annual reports from veterinary services. The hard copies of these records were originally kept at the head office of veterinary services in Windhoek; however when there was the merging of the different directorates (agriculture, veterinary services, rural water supply and forestry) into the Ministry of Agriculture, Water and Forestry most of the information was apparently misplaced or lost. A lot of information on the exact location, animal species, number affected and time of the year when these outbreaks occurred was missing. This highlights the importance of the maintenance and preservation of detailed records of animal health information. Nevertheless, this study for the first time outlines the location and time of all the recorded outbreaks of RVF in Namibia. This study is a foundation for further research into the epidemiology of the disease and hopefully will result in better preparedness and better response to outbreaks.

Namibia has had severe and mild outbreaks from the first recorded outbreak in 1957 to the latest outbreak in 2011. The disease was confirmed in a total of six years during this period, in seven regions of Namibia namely Hardap, Karas, Khomas, Erongo, Otjozondjupa, Omaheke and Oshikoto, and was suspected in another two regions, namely Kavango and Caprivi. In Caprivi a human case was confirmed in 2004 and lineage H of the virus was isolated but no animal cases were ever confirmed (Grobbelaar *et al*, 2011). This is clear evidence that RVF can be transmitted to humans through mosquito bites as there was no prior contact with infected material of animal origin. The disease mainly affected sheep but goats and cattle were also affected with occasional human cases. This is consistent with reports from other countries in which outbreaks were experienced, such as neighbouring South Africa (Pienaar and Thompson, 2013).

Cumulatively, Hardap region had four confirmed outbreaks followed by Karas, Khomas and Otjozondjupa regions with two confirmed outbreaks each and Omaheke, Oshikoto and Erongo regions with one confirmed outbreak each. The southern part of the country (south of the veterinary cordon fence) had more foci affected by the disease than the Northern communal areas (North of the veterinary cordon fence). This difference could be due to the differences in the amount of rainfall received between these two areas and the differences in farming practices.

Hardap region is the most predisposed region to have RVF outbreaks as it had five confirmed outbreaks and one suspected outbreak from the time RVF was first recorded Namibia in 1957. The outbreaks occurred following above average rainfall events (Schneider, 1994); generally the region is dry with rains on average starting from February. The outbreaks occurred from March to June, i.e. during the latter half of the rainy season; during years of above average rainfall this would be the time when numerous habitats would potentially occur for vector population growth. The outbreaks ended around June showing that the onset of winter (low temperatures) had an overall reduction effect of the vector numbers either by affecting their life cycle, distribution or survival in the environment.

Most of the outbreaks were confined to the Hardap region except for the 1974 outbreak which went on to affect Karas, Khomas and Otjozondjupa regions. The other outbreak which spread was the 2010 outbreak which also affected Karas and Erongo regions. The control measures which included quarantining the affected areas and ring vaccinations may have been responsible for the relatively confined outbreaks. Quarantining the affected area meant that no viraemic animals were leaving the affected areas amplifying transmission and no new animals were introduced into the affected areas. This could have also reduced the entry of susceptible animals and effectively reduced the extent of the outbreak. Ring vaccinations around the affected areas increased the herd immunity of the animals and hence reduced the transmission rates of infection. The mechanism of virus spread to the other regions is not yet established with suspicions being vector and or viraemic animal movements.

Karas region borders Hardap region and it has a higher goat population compared to that of sheep Karas receives less annual rainfall than Hardap and thus likely has fewer water bodies for mosquito proliferation. Goats are more resistant to RVFV infection than sheep as was shown in the Egyptian outbreak in 1977-78 (Swanepoel and Coetzer, 2004) and it could be another reason why there are fewer outbreaks than Hardap despite the fact that there is a large amount of animal movement between the two regions.

Khomas and Otjozondjupa regions each had two confirmed outbreaks followed by Oshikoto and Erongo regions with one confirmed outbreak. The Oshikoto outbreak affected only goats, while during the

outbreak in Otjozondjupa cattle at one focus were the only species affected. The reason for different species being affected in different locations may be related to local differences in vector diversity and their host preference, which are poorly understood. Several outbreaks were suspected but samples were either not collected or samples were sent to the laboratory but RVF was not tested for even though it was suspected based on the clinical picture. On a number of occasions bacterial causes of abortions were tested for on the samples sent to the laboratory and results were negative, making it possible that it could have been RVF. The reason why RVF was not tested for could have been that the laboratory lacked the expertise or reagents to test for RVF or that the samples sent were not suitable. Both the suspected and confirmed cases were compiled in this study to have a complete picture of what was or what could have been cases of RVF in the history of Namibia. Since RVF has long inter-epidemic periods, small outbreaks could have gone unreported and could have been misdiagnosed as long periods of absence makes both farmers and veterinary officials overlook the disease.

The 1974 and 2010 outbreaks showed that it is possible for the disease to spread over long distances from one area to the other. This could be due to endemic vectors triggering the outbreak and then epidemic vectors amplifying and spreading the disease, or due to animal and human movement. The virus responsible for the outbreak in 2010 and 2011 was lineage H, which was first reported in Namibia in 2004 from a human case in Caprivi region (Grobbelaar *et al*, 2011) and was also responsible for the earlier outbreak in South Africa in 2010. The first two foci affected in the Hardap region during the 2010 outbreak were close to South African border which had an outbreak earlier in the year, making it the likely source of the virus (Monaco *et al*, 2010). Climatic conditions in Namibia and South Africa differ, with South Africa receiving more average annual rainfall, yet both countries experience the same general fluctuations in rainfall. Rift Valley fever outbreaks occurred during similar years, hence there is a high possibility that similar viruses crossed the borders but the mechanism of transmission is yet to be established. The strain of RVFV (lineage H) that circulated from 2004 to 2010 between Namibia and South Africa show a high degree of sequence identity suggesting that these strains could have originated from a virus population that circulated between these two countries (Monaco *et al*, 2010). It also indicates that relatively long-distance movement of virus has occurred between Caprivi, central South Africa and southern Namibia. This is consistent with long-distance movements suspected in the case of other RVFV lineages, particularly lineage C on the eastern side of the continent.

The southern parts of Namibia are drier than the northern areas which are prone to flooding and high rainfall events. However, outbreaks occur more frequently in the southern parts which could partly be due to the high sheep density in the south compared to the north where cattle and goats dominate. It is also likely that, since the northern areas are wetter and less subject to temperature extremes, there is a

continuous low level circulation of the virus between vectors and the susceptible population, thus increasing herd immunity. This is supported by the very high seroprevalence observed at Etosha in springbok and gemsbok and also the positive serological results in humans in Rundu and Katima Mulilo. Since the southern areas are generally hot and dry, and very cold at night during the winter, the virus may not survive in those harsh conditions therefore no continuous circulation and hence low herd immunity. When favorable climatic conditions coincide with introduction of the virus, the sudden increase in vector population may lead to a severe epidemic since the whole population will be susceptible. This can be further evaluated by carrying out serological tests in the southern areas during inter-epidemic years to determine if there is low level circulation of the virus. These serological tests will also help to determine whether the virus survives the inter-epidemic periods or it is re-introduced from other areas during outbreak years.

The virus lineages which were responsible for the 1957 to 1984 outbreaks were not documented. The positive serological results in the northern areas of Namibia show that the virus can survive long inter-epidemic periods by low level circulation. The situation is different from the southern parts of the country where conditions are harsh for virus survival and reintroduction is the most likely source of infection. South Africa had three major epidemics of RVF, in 1950-1951, 1974-1976 and 2010-2011 (Pienaar & Thompson, 2013), with small outbreaks and isolated cases in between. The outbreaks occurred around similar years but only the 2010 and 2011 outbreaks in Namibia were known to be caused by the lineage H which was also responsible for the outbreak in South Africa in 2010 (Monaco *et al*, 2010). This lineage was first isolated in Namibia in 2004 from the Caprivi in an infected human (Grobbelaar *et al*, 2011). The lineage for the South African 1951 was N, 1974-5 was L and 1999, 2008-9 was C (Grobbelaar *et al*, 2011). The lineages responsible for the Namibia 1957 and 1974 epidemics are not known but could be similar to the South African lineages as shown by the 2010 outbreak. Animal movement is common between the two countries, with Namibia exporting cattle, sheep and goats to feedlots and abattoirs while South Africa exports breeding stock to Namibia. It is also likely that there is significant illegal movement, particularly of small ruminants, in both directions across the borders in the southern part of Namibia.

The risk map showing the spatial distribution of RVF outbreak counts in Namibia shows that outbreaks occur more frequently in the south eastern and central parts of the country than in the north. This map is an overestimation of the extent of these outbreaks since the outbreaks before 1986 had no exact spatial location recorded. Nevertheless, it may serve as a useful indication of the relative predisposition of different areas of the country to future outbreaks of RVF.

Due to the low number of confirmed outbreaks for which precise spatial information could be obtained, it was not possible to determine the risk factors for RVF occurrence. The confirmed outbreaks which occurred before 1986 only had districts affected and not the exact foci hence it was impossible to pinpoint the factors which lead to the occurrence of the outbreaks. The visual comparison between the sheep density and the cumulative outbreak count suggested a positive correlation between the sheep density and the outbreaks. The cattle density map showed little correlation and, though not indicated, the goat density may have been an important factor in the cattle dense areas. Very few foci had only cattle affected as more goat foci were recorded than cattle foci.

High average annual rainfall was not correlated to the RVF outbreaks. As discussed above, this could be due to high herd immunity resulting from a continuous vector presence and continuous exposure to the virus in the higher rainfall northern areas. The sero-positive results in humans and animals proves that even if there were no outbreaks in livestock there is evidence of virus presence as has been found in northern Botswana and coastal Mozambique (Fafetine *et al*, 2013). The central and southern parts with low average rainfall are more prone due to low herd immunity and introduction of the virus when suitable conditions prevail for vector population growth. This is supported by the finding that outbreaks occurred in years of above average rainfall.

It is therefore clear that not one factor alone precipitates RVF outbreaks. Suitable climatic conditions, presence of vector population, introduction of the virus and presence of a naïve host population are some of the important factors.

The confirmed outbreaks in 2010 and 2011 showed evidence of clustering as two clusters were identified during SaTScan analysis. The outbreaks in Hardap and Oshikoto regions as indicated in Figure 3.12 suggests that there were suitable climatic conditions and presence of naïve population as these outbreaks were not randomly distributed over space and time. Spatio-temporal clustering is typical of infectious diseases. The spatio-temporal scan statistic is, however, a crude method of assessing clustering, in that it uses case-only data, without taking into account the population at risk, i.e. it assumes an evenly distributed susceptible host population, which is unlikely to be the reality. More accurate methods for assessing clustering would require a larger amount of spatially referenced data, as well as more detailed information on the distribution of the population at risk.

Serological surveys were conducted in wild animals (springbok and gemsbok) and also in humans to demonstrate the presence of antibodies to RVF in these populations. The presence of serologically positive wild animals and humans in Namibia indicates the presence of vectors and the virus especially in regions where RVF was never confirmed in domestic animals, i.e. the Kavango and Caprivi regions. This

is also consistent with other southern African countries such as Mozambique, Angola and Botswana where no outbreaks were recorded but sero-positivity is well documented. This can suggest that since there is this continuous circulation of the virus, the animals are always exposed and hence are immune even if there is an explosion in vector population. The suspected outbreaks in these two regions also suggest the virus presence but due to the existence of varying degrees of herd immunity the outbreaks are expected to be small and self-limiting, and are likely to be overlooked and misdiagnosed.

4.1 Limitations

4.1.1 Level of reporting and resolution of data

There was a marked variation in the level of reporting from the first recorded to the last recorded outbreak. The information obtained from years before 1986 only mentioned the districts affected but not the exact location and time when the outbreaks occurred. The annual reports and disease report forms were missing and hence no full detail of these outbreaks was obtained. There could be missed diagnosis of small outbreaks and cases during inter-epidemic years due to either lack of veterinary personnel during those years or small outbreaks could have been perceived as other causes of abortion or death as they can be self-limiting. This made it impossible to determine the factors that lead to these outbreaks and to determine the potential risk factors for RVF occurrence in Namibia. This also caused the overestimation of outbreaks which occurred before 1986 on the risk map.

4.1.2 Availability of vector data

There is no published literature on the available RVF vectors and their distribution in Namibia. The entomological studies that were conducted in Hardap and Etosha National Park following the 2010 outbreak were not published. The presence or absence of vectors is important in the occurrence of the disease hence it is difficult to have a complete understanding of the epidemiology of the disease without vector data.

4.1.3 Lack of molecular data

The only sequence data for RVFV available from Namibia are from the human case in the Caprivi in 2004 (Grobbelaar *et al*, 2011), the 2010 (Monaco *et al*, 2010) and the 2011 (laboratory results from CVL) outbreaks. There was also lack of molecular information on viruses responsible for the outbreaks and the virus lineages that caused the outbreaks before 1986. Molecular data can help to determine movements of the virus between localities and therefore to possibly identify factors responsible for those movements.

4.2 Further research

This study is a comprehensive compilation of all the recorded outbreaks and occurrences of RFV and RVFV in Namibia. There is therefore a serious need for further research into the geographical distribution of RVF vectors, their ecology and movement to understand why there are outbreaks over large distances caused by similar lineages of the virus. The specific conditions required to trigger outbreaks should be further explored. Molecular sequence data should be collected from as many RVFV isolates as possible in order to allow phylogeographic studies.

The presence or absence of RVFV in vectors and non-domestic hosts during inter-epidemic periods and the possibility of subclinical low level virus circulation in domestic animals in endemic areas needs to be further investigated. This can be done through serological and entomological tests during inter-epidemic years in suspected endemic areas, such as northern Namibia. Further research can also be done into understanding the mechanisms of spread of RVF during large outbreaks, investigating factors like animal movement or vector spread.

Chapter 5: Conclusions and recommendations

5.1 Conclusions

This study showed the complete spatial and temporal distribution of RVF in Namibia using the information from the first to the latest outbreak. It showed that ongoing low-level RVFV circulation is likely to occur in northern Namibia. It also highlighted areas (central and southern Namibia) which are more prone to outbreaks and which are therefore likely to experience future outbreaks. It is therefore critical to keep high herd immunity in these areas through vaccination to prevent future disease incursions.

The 2010 and 2011 outbreaks in Namibia reminded both farmers and veterinary services that given suitable conditions outbreaks will occur hence the need for early warning systems in the prediction of impending outbreaks.

5.2 Recommendations

If an area has had an outbreak of RVF there are higher chances for future outbreaks; therefore, these areas must have adequate preventive and control measures in place. Farmers are therefore encouraged to vaccinate all their stock to keep herd immunity high and veterinarians should be alert and include RVF as a differential diagnosis on all abortion cases. All replacement stock should be vaccinated even during inter-epidemic periods to reduce the impact of outbreaks when they eventually occur.

Prediction of high rainfall events and early warning and early detection systems for possible RVF occurrence should be in place. Further research should be done to understand the vector dynamics, the spread of disease during large epidemics, presence of viruses during inter-epidemic periods and possibly low level circulation of virus in domestic animals and wild animals in endemic areas.

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