

# A RETROSPECTIVE ANALYSIS OF THE EPIDEMIOLOGY OF RIFT VALLEY FEVER IN SOUTH AFRICA

by

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## **B. Summary**

# A retrospective analysis of the epidemiology of Rift Valley fever in South Africa

By

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**DEPARTMENT:** Production Animal Studies  
**DEGREE:** MSc (Veterinary Science)

The aim of this study was to investigate the epidemiology of Rift Valley fever (RVF) in South Africa. The first part of the study consisted of the compilation of a full history of RVF in South Africa. This was done by compiling all references to outbreaks of the disease in South Africa from all available literature, annual reports, disease reports and animal disease databases. The geographic location and temporal occurrence of each outbreak was recorded as accurately as allowed by the available records. The result was a better and more complete picture than has hitherto been available of the spatial and temporal distribution of RVF for the period 1950, when the disease was first recognised in South Africa, to 2010. Several smaller outbreaks not mentioned in the literature were found. It emerged that large outbreaks occur in the Free State Province, Eastern Cape Province and Northern Cape Province with long periods of absence and smaller outbreaks occur in KwaZulu-Natal, Mpumalanga and Gauteng at more frequent intervals.

The second part of the study used the data collected during the first part of the study to determine which climatic and other environmental factors could have played a role in the occurrence of RVF in South Africa. Multiple logistic regression analysis was used to estimate associations between the various potential risk factors and the occurrence of Rift Valley fever.

The study found that the El Niño/Southern Oscillation influence on rainfall in South Africa has an effect on the occurrence of RVF in South Africa which is opposite to the effect that

has been described for Kenya. A positive Southern Oscillation Index (La Niña) increases the likelihood of a RVF outbreak in South Africa.

The study also found that very high rainfall during the summer months (December to February) is an important risk factor for the occurrence of RVF and it confirmed the increased risk of an outbreak where pans and wetlands are present as reported in several articles and disease reports on past outbreaks. Several other factors, such as minimum and maximum temperature were also found to have a statistically significant effect on the occurrence of Rift Valley fever.

**KEYWORDS:** Rift Valley fever, epidemiology, South Africa, risk factors, multiple logistic regression, Southern Oscillation Index, El Niño, La Niña

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## **F. Abbreviations**

ARC-ISCW	- Agricultural Research Council – Institute for Soil, Climate and Water
ELISA	- Enzyme Linked Immunosorbent Assay
ENSO	- El Niño/Southern Oscillation
GIS	- Geographic Information System
NICD	- National Institute for Communicable Diseases
OIE	- World Organisation for Animal Health
ONI	- The Oceanic Niño Index
RVF	- Rift Valley fever
RVFV	- Rift Valley fever virus
SARCCUS	- Southern African Regional Commission for the Conservation and Utilisation of the Soil
SA	- South Africa
SOI	- Southern Oscillation Index
USA	- United States of America

# Chapter 1 : Literature review

## 1.1 Introduction

Rift Valley fever (RVF) is a zoonotic viral disease of ruminants. It is transmitted by mosquitoes of various genera. In animals the most noted effect is abortions, but it also causes fever and it can cause mortalities in young animals, especially lambs. Occasional mortalities in adult animals can occur. The symptoms in humans are mostly a febrile, influenza-like illness, but in severe cases it can lead to haemorrhagic fever, encephalitis, retinal haemorrhage and even death (Swanepoel & Coetzer 2004).

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

## 1.2 History

Rift Valley fever occurs widely in many sub-Saharan African countries. It was first diagnosed in the Rift Valley of Kenya in 1931 and has since been diagnosed in, amongst other countries, South Africa, Zimbabwe, Zambia, Mozambique, Somalia, Namibia, Madagascar, Sudan, Egypt and Senegal. There have also been outbreaks in the Middle East in Saudi-Arabia and Yemen (Swanepoel & Coetzer 2004). If a country has had an outbreak in the past, there is a very high likelihood of future outbreaks (Gerdes 2004). Murithi, Munyua, Ithondeka, Macharia, Hightower, Luman, Breiman and Njenga (2010) published a detailed description of the history of RVF in Kenya. They used the animal disease reports from the Kenya Department of Veterinary Services for the period 1910 to 2007. They found that if the disease had occurred in a district it had a fivefold higher probability of occurring in the same district again.

In South Africa the occurrence of RVF was first recorded in late 1950 when large numbers of livestock mortalities were seen in the northern Cape, western Orange Free State and Transvaal (now North West, Gauteng and Limpopo provinces) (Swanepoel & Coetzer 2004). But it was only recognised for the first time as RVF when it was diagnosed in Johannesburg in people who assisted in a necropsy of a bull (Alexander 1951). During this outbreak sheep mortalities were estimated to number 100 000 with an estimated 500 000 abortions (Gerdes 2004). The next major outbreak in South Africa occurred in 1955-56 in the Orange Free State in several districts (Alexander 1956). After this outbreak the disease was not reported for almost 15 years. The next reported outbreak was seen during 1969-70; this outbreak occurred over widespread areas of South Africa, including the Orange Free State, Natal and the north eastern Cape (now North West Province) (Division of Veterinary Services 1970). The most severe outbreak in South African history was recorded in 1974 to 1976, coinciding with heavy rainfall. This outbreak was seen in all parts of South Africa except in the Western Cape, Eastern Transvaal and Northern Transvaal (Division of Veterinary Services 1974, 1975 & 1976). A mortality rate of up to 95% was reported amongst young lambs, with widespread abortions and deaths in adult animals (Division of Veterinary Services 1974).

Other, smaller outbreaks of RVF in South Africa were also reported (Table 1.1).

Table 1.1 Some reported outbreaks of Rift Valley fever in South Africa

Year	Area
1952 - 53	Orange Free State (Van der Linde 1953)
1976 - 77	Natal, Cape
1977 - 78	Free State, Eastern Cape and Karoo
1979 - 80	Natal
1980 - 81	Highveld
1981 - 82	Natal, Eastern Cape and Karoo, Highveld
1982 - 83	Natal, Highveld
1983 - 84	Natal, Western Cape
1984 - 85	Transvaal, Highveld, Natal
1985 - 86	Natal, Eastern Cape and Karoo, Northern and Eastern Transvaal
1999	Kruger National Park (State Veterinarian Skukuza 1999)
2008	Mpumalanga, Limpopo, Gauteng, North West Province
2009	KwaZulu-Natal, Eastern Cape Province
2010	Large number of outbreaks in Free State Province, Northern Cape Province and Eastern Cape Province with smaller numbers in Western Cape Province, North West Province, Gauteng, Limpopo and Mpumalanga.

(Directorate of Veterinary Services 1977, 1978, 1983, 1984, 1985 & 1986 and Directorate of Animal Health 1980, 1981, 1982, 1999, 2008, 2009, 2010)

### **1.3 Aetiology**

The RVF virus (RVFV) belongs to the *Phlebovirus* genus in the *Bunyaviridae* family. It is an enveloped spherical RNA virus up to 120nm in diameter (Gerdes 2004). The envelope is host derived and has glycoprotein spikes projecting through it. The single stranded RNA is divided up into three segments and is negative sense, with the smallest segment being ambisense RNA, i.e. it can be coded in both directions (Swanepoel & Coetzer 2004).

### **1.4 Zoonosis**

In humans RVF is usually an occupational disease, with farmers, farm workers and veterinary personnel who have direct contact with animal tissues being most at risk. The disease causes mild influenza-like illness with fever, joint and muscle pains and headache. A small percentage of patients can develop severe complications such as retinitis, meningo-encephalitis and even death (McIntosh, Russell, Dos Santos & Gear 1980).

Risk factors for a seropositive RVF outcome in humans in Senegal were found to be treating sick animals, nursing sick people and assisting animals during parturition/abortions (Wilson, Chapman, Hall, Dykstra, Ba, Zeller, Traore-Lamizana, Hervey, Linthicum & Peters 1994)

### **1.5 Epidemiology**

Outbreaks of RVF in sub-Saharan Africa have always been associated with above average rainfall, with long inter-epidemic periods during which no disease is reported. Although a correlation between high rainfall and RVF outbreaks exists, not all wet periods are associated with RVF outbreaks (Swanepoel & Coetzer 2004).

The reservoir of the RVF virus during periods of absence has been a topic of much discussion and research. At first it was thought that the virus circulates in forest areas and that heavy rainfall causes an explosion in numbers of mosquito vectors and this results in spread to domestic animals, causing an outbreak. It has since been shown that there are three other possibilities regarding the epidemiology of RVF (Swanepoel & Coetzer 2004). The first is that transovarial transmission takes place in certain *Aedes* sp. mosquitoes, associated with shallow grassland depressions or dambos (Linthicum, Davies, Kairo & Bailey 1985). These mosquitoes lay their eggs on the grass at the edges of water bodies and the eggs must dry out before they are able to hatch. Flooding of the pan/dambo causes an explosion in these mosquito numbers. These mosquitoes then infect domestic animals. Other mosquito species 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 the virus numbers (Gerdes 2004). One report from 1957 in South Africa reported infected mosquitoes hatching from eggs (Linthicum et al. 1985). Several other studies could not repeat this finding in South Africa, and failed to isolate virus from vectors during inter-epidemic periods (McIntosh, Jupp, Dos Santos & Barnard 1983). This could be due to a very low proportion of mosquitoes that remain infected, since these studies sampled low numbers of mosquitoes (Swanepoel & Coetzer 2004).

Another possibility is that there could be low level circulation of virus between animals and the vector, without resulting in clinical signs or severe outbreaks. Bengis (personal communication 2010) has found serological evidence of low level circulation of RVF virus in buffalo in the Kruger National Park. Davies, Kilelu, Linthicum and Pegram (1992) also showed low level circulation in cattle in Zambia.

The third possibility is the spread of virus over long distances, but this possibility and the mechanism for this have not been investigated. The most likely method is the movement of infected animals (Balkhy & Memish 2003; Chevalier 2010) through trade and illegal trans-boundary animal movements.

Swanepoel (2009) separates the vectors of RVF into two groups, namely the enzootic (endemic) vectors and the epizootic (epidemic) vectors. The enzootic vectors are the floodwater breeding *Aedes* sp. mosquitoes, in which transovarial transmission takes place and the epizootic vectors are the Culicine mosquitoes and biting flies, which propagate an outbreak.

In South Africa *Aedes mcintoshi* has been shown to be the enzootic vector (Swanepoel & Coetzer 2004) and *Culex theileri*, *Culex zombaensis*, *Aedes juppi* and *Aedes caballus* to be epizootic vectors (Jupp 2004), but virus has also been isolated from other *Aedes*, *Culex*, *Anopheles* and *Eretmapodites* mosquito species in southern Africa. Mechanical transmission by mosquitoes, phlebotomid flies, midges, stomoxids, simuliids, other biting flies and ticks has also been proven (Swanepoel & Coetzer 2004). Rift Valley fever virus has been isolated from *C. zombaensis* and *Aedes circumluteolus* in KwaZulu-Natal and from *C.theileri*, *A. juppi*, *A. caballus* and *A. mcintoshi* in the inland plateau of South Africa (Jupp 2004). McIntosh (1972) reported isolating RVF virus from *C. theileri* during March 1970 from the farm 'Berlin' in the Kroonstad district and also from *C. theileri* at the Johannesburg sewage farm during February 1970. After a suspected human infection in Port Shepstone an isolation of the virus was made from *Eretmapodites quinquevittatus* during February 1971.

Outbreaks in Kenya have been shown to be positively correlated with abnormally high rainfall associated with the warm phase of El Niño/Southern Oscillation Index (SOI). El Niño is the warming of the central and eastern Pacific Ocean and the Southern Oscillation is the atmospheric changes that El Niño causes. This climatic phenomenon has effects on weather on a global scale. The Southern Oscillation Index (SOI) is a measure of this change. The satellite normalised difference vegetation index (NDVI), which is a measure of vegetation growth using satellite images, has been used to predict RVF outbreaks (Anyamba, Linthicum & Tucker 2001). It has also been reported that all outbreaks of RVF in East Africa followed after periods of abnormally high rainfall due to a period of strong negative deviation of the SOI, i.e. El Niño conditions. The best predictor for a RVF outbreak was found to be equatorial Pacific and Indian Ocean sea surface temperature and this was used together with NDVI in an autoregressive integrated moving average (ARIMA) model (Linthicum, Anyamba, Tucker, Kelley & Peters 1999).

A study of the history of RVF outbreaks in Kenya indicated that outbreaks occurred during 1951, 1956, 1961-1965, 1967-1972, 1977-78, 1981, 1983, 1989-1991, 1993, 1997-1998 and 2006-2007 and identified certain districts that are more prone to RVF outbreaks (Murithi *et al.* 2010). Anyamba *et al.* (2001) reported outbreaks in Kenya during 1951-53, 1957, 1961-63, 1968-69, 1977-79, 1982, 1989, 1997-98. The differences in these reports could be due to the reporting period. The one researcher might have compiled report from annual reports and the other from laboratory reports. Another possibility is that one researcher reported the start of outbreaks and the other when the epidemic peak was reached.

In South Africa the SOI El Niño/La Niña Cycle has the opposite effect on rainfall compared to Kenya. A positive SOI (La Niña) usually causes normal or higher rainfall in South Africa and a negative SOI (El Niño) is associated with below normal rainfall or drought (South African Weather Service 2003). Mabaso, Kleinschmidt, Sharp and Smith (2006) showed that the incidence of malaria, which is also transmitted by mosquitoes, in South Africa was above normal during a positive SOI (La Niña) and below normal during a negative SOI (El Niño).

However, the epidemiology of RVF in West Africa appears to differ from the situation in southern Africa. Rift Valley fever outbreaks occurred during periods of average rainfall and even below average rainfall. In Senegal, Mauritania, Gambia and Mali RVF outbreaks are reportedly not associated with climatic factors, but rather with the cyclical patterns of herd immunity (Chevalier, Delarocque, Baldet, Vail & Roger 2004)

Clements, Pfeiffer, Martin and Otte (2007) used a literature review of serological studies and a spatially explicit Bayesian logistic regression model to identify areas in Africa as significant high and low prevalence areas for RVF. The Northern Cape Province, Free State Province and KwaZulu-Natal were identified as a significant high prevalence cluster. This was due to several published reports on RVF outbreaks in these areas.

## **1.6 Pathogenesis**

The RVF virus replicates at the site of infection and then spreads to other organs such as the liver, spleen and brain. The virus attaches to receptors on susceptible cells, is taken up into the cell by endocytosis and viral replication occurs in the cytoplasm of the cell (Swanepoel & Coetzer 2004). The virus is detectable in lambs 16 hours after infection and death occurs within 36 to 42 hours. In adult sheep, goats and cattle the viraemia is detectable one to two days after infection and reaches its peak after two to five days and lasts up to seven days. The virus can persist in the spleen and other visceral organs of sheep for up to 21 days. The virus causes hepatic necrosis, nephrosis, vasculitis, lymphoid necrosis and haemorrhagic disease. Abortion usually occurs in pregnant cattle, sheep and goats due to febrile illness and foetal death (Swanepoel & Coetzer 2004).

Blood investigation reveals a severe leucopenia, elevated blood enzyme levels associated with liver damage and a thrombocytopenia (Gerdes 2004).

## **1.7 Clinical signs, pathology and diagnosis**

The clinical signs of RVF in domestic ruminants can be very non-specific. A very high fever, anorexia, abdominal pain, weakness, a bloody diarrhoea and hyperpnoea are common signs of acute RVF. Abortion may take place during all stages of pregnancy and in adult animals, infection may be inapparent. The mortality rates and abortion rates vary between outbreaks. In South Africa the mortality rates ranged between 5% and 30% and abortion rates varied between 40% and 100% (Swanepoel & Coetzer 2004).

A post mortem investigation typically reveals hepatic lesions (necrosis), widespread haemorrhages (petechiae and ecchymoses) of various organs, especially in the gut, and kidney damage. Histopathological examination of the liver indicates severe hepatic necrosis. Other organs that are affected are the lungs (congestion and oedema), lymphoid tissue, the eyes (humans) and the brain (foetuses) (Odendaal & Prozesky 2010).

Samples that need to be taken if RVF is suspected are blood and serum from live animals and liver, spleen, kidney, lymph nodes and heart blood from mortalities. Diagnosis of RVF is made by demonstrating viral antigen with complement fixation, immunofluorescence, immunodiffusion, ELISA, VNT and viral culture. Antibodies to RVFV can also be demonstrated with complement fixation, indirect-immunofluorescence, immunodiffusion, ELISA and others. After heavy rains in areas that are known to have had RVF in the past, RVF should always be suspected (Swanepoel & Coetzer 2004).

## **1.8 Control**

The most effective mode of control of RVF is vaccination. There are two vaccines that are generally used, the modified live Smithburn vaccine and a formalin inactivated cell culture vaccine. The Smithburn vaccine sometimes causes teratology and abortion in pregnant animals, but it gives long lasting immunity within a week. The inactivated vaccine is safe to use in pregnant animals, but its effect is short lived. The Smithburn vaccine gives a poor antibody response in cattle, but is reported to be protective (Swanepoel & Coetzer 2004). There are several vaccines under development using various vaccine development methods (Wallace 2009). The most promising vaccine is the Clone 13 vaccine, derived from a mild field strain (Dungu, Louw, Lubisi, Hunter, Von Teichman & Bouloy 2010).

Other methods for the control of RVF include the burning of grass around pans and vleis to reduce the number of mosquito eggs, the application of larvicides to mosquito breeding areas to control mosquito numbers and preventing mosquitoes from feeding on livestock using repellents (Swanepoel & Coetzer 2004).

## **1.9 Climate change**

Gould and Higgs (2009) speculate that climate change could theoretically expand the range of RVF or could cause an increase in frequency of outbreaks. The specific example used by them is the emergence of RVF outbreaks in the Arabian Peninsula. The recent sudden re-emergence of RVF in South Africa could also be a sign of climate change.

Gage, Burkot, Eisen and Hayes (2008) mentioned RVF as one of the vector borne diseases that will be influenced by a change in climatic factors. Khasnis and Nettleman (2005) warned that global climate change could increase the incidence of vector borne diseases such as malaria and RVF in Africa due to more frequent and more intense El Niño cycles and their effects in parts of Africa. This would cause higher rainfall and increases in vector populations. Martin, Chevalier, Ceccato, Anyamba, De Simone, Lubroth, De La Rocque and

Domenech (2008) indicated that climate change may affect three components of the RVF cycle, namely vectors, hosts and virus, of which vectors are the most significant. Climate change can affect rainfall patterns, which in turn affects the hatching of the *Aedes* vectors. It will be difficult to predict the effect of climate change on RVF in South Africa, because the effect of climate change may differ in South Africa from the rest of Africa. More intense and more frequent El Niño events may, for example, cause droughts in South Africa, even leading to a reduction in the incidence of vector-borne diseases. It is clear that general predictions regarding RVF in Africa cannot simply be applied in South Africa and that study of local risk factors is necessary.

## **Chapter 2 : Research design and methodology**

### **2.1 Research questions**

Although the epidemiology of RVF has been extensively researched, mostly in other countries, there are several factors that are not fully explained. It is well documented that RVF outbreaks in South Africa are preceded by abnormally high rainfall events, but not all high rainfall events trigger outbreaks. It is also not known whether the virus survives the inter-epidemic period by transovarial transmission in the mosquitoes or whether it is re-introduced before each epidemic. Several of the literature sources mention that outbreaks occur around pans, but the disease also occurs in areas where there are no pans. It is therefore clear that there are other factors also involved in triggering outbreaks. However, these risk factors have never been formally assessed in a systematic fashion in South Africa.

There is also no comprehensive, easily accessible compilation of all recorded RVF outbreaks in livestock in South Africa. In order to carry out a systematic analysis of risk factors for RVF outbreaks, it is necessary first to assemble as complete as possible a record of when and where the disease has occurred in South Africa.

### **2.2 Objectives of the study**

The first objective of this study was to compile a complete history of the temporal and spatial occurrences of RVF outbreaks in South Africa since the disease was first recognised in 1950.

The second objective was to estimate the effect of several potential risk factors that might have played a role in the occurrence of RVF in South Africa. Climatic factors such as rainfall and spatial factors such as the presence or absence of pans, which may have been associated with the occurrence of RVF outbreaks in South Africa, were investigated using multivariable statistical methods.

## **2.3 Materials and methods**

### **2.3.1 Study design**

#### ***2.3.1.1 History of RVF in South Africa***

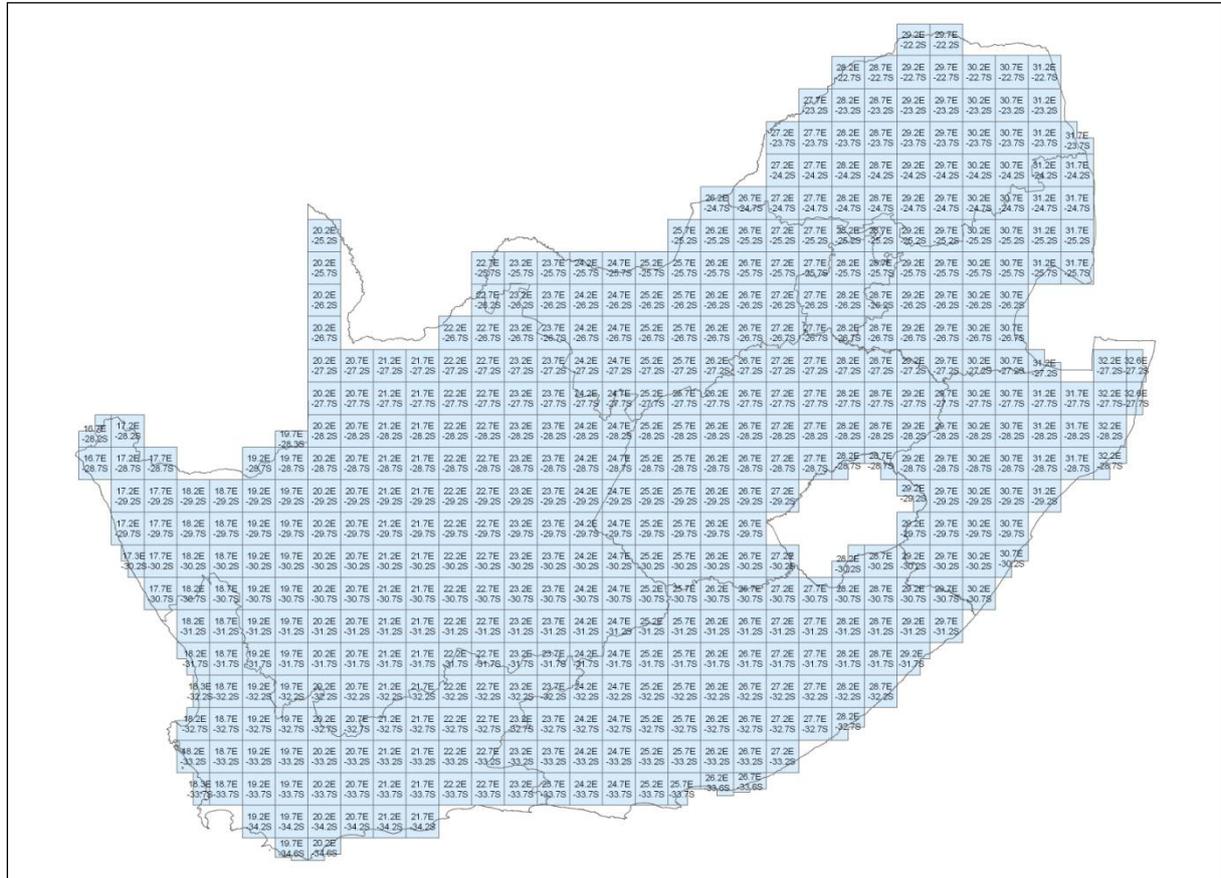
All available sources describing RVF outbreaks in South Africa were consulted and the temporal and spatial details of each outbreak were recorded. Sources consulted were the scientific literature available on electronic journal databases via the University of Pretoria's Library Services such as CABDirect and Science Direct, annual reports from 1951 to 2000 of the South African Veterinary Services, disease reports from Veterinary regions and state veterinary areas to the central office available in the registry and archives of the Directorate of Animal Health, disease reports to international organisations such as the World Organisation for Animal Health (OIE) and Southern African Regional Commission for the Conservation and Utilisation of the Soil (SARCCUS) and the Animal Disease Database held and maintained at the Directorate of Animal Health of the Department of Agriculture, Forestry and Fisheries, covering all animal disease reports to the National Directorate from 1993 to 2010. Where several of these sources reported the same outbreak or the same season's outbreaks, all available accounts were compared with each other and used to determine a greater level of detail. For example, some sources only reported the month of the outbreak, whereas others only reported the spatial location, therefore these reports were combined.

No records on laboratory confirmation of animal outbreaks before 1999 could be found. The reason for this is that prior to 1994 veterinary laboratories were part of the South African Veterinary Services and did not compile separate reports. The reports from state veterinary areas included information from the local veterinary laboratory. We therefore accepted that most of the reports of RVF outbreaks were laboratory confirmed. In several reports it was stated that suspected cases of RVF could not be confirmed. These reports were not considered as outbreaks in this study.

#### ***2.3.1.2 Risk factor study***

The land surface area of South Africa was divided into 462 half degree square blocks (Fig. 2.1) using ArcGIS 9.3.1 (ESRI Corporation 2010). Portions of blocks falling on the coastline or border of South Africa that was smaller than half a full block were excluded from the study. The half degree by half degree resolution for the study was determined as a reasonable compromise based on the resolution of the available RVF outbreak data. This enabled the analysis of the outcome and the predictor variables on the same resolution. Variables available in a higher resolution were averaged inside a block and for variables with a lower resolution all blocks falling more than 50% inside the area with the same value were

given that value. Data were collected for each of the 60 seasons (July to June) from 1950/51 to 2009/10. The unit of interest for this study was the individual block-season combination, giving a total sample size of  $462 \times 60 = 27\,720$  observations.



**Figure 2.1 South Africa divided into half degree blocks**

Potential risk factors investigated included several factors concerning rainfall, temperature, Southern Oscillation Index, animal numbers and the occurrence of RVF outbreaks elsewhere in South Africa or in neighbouring countries, and spatial factors included were climate zone, vegetation type and the presence of different types of water bodies.

### **2.3.2 Data collection**

A summary of the data that were compiled to be used in this study, and their sources, is shown in Table 2.1. Details of all the individual predictor variables that were screened for possible inclusion in the multivariable model are given later.

**Table 2.1** Sources consulted for data on potential risk factors for RVF outbreaks in South Africa, 1950 – 2010

Variable/factor	Source
Occurrence of Rift Valley fever	Department of Agriculture, Veterinary Services Annual Reports and literature (1950-2010).
Monthly rainfall	South African Weather Service and ARC-ISCW (2010)
Monthly minimum and maximum temperature	South African Weather Service and ARC-ISCW (2010)
Previous known occurrence of RVF	Department of Agriculture, Veterinary Services Annual Reports and literature
El Niño / La Niña event / Southern Oscillation Index	USA National Oceanic and Atmospheric Administration's Climate Prediction Centre (2010)
Presence of vlei / pan /standing water	Vegmap2006 (Mucina and Rutherford 2006) Landcover 2000 (Majeke, Poti, Ramoelo, Thompson, Flemming, McFerren & Van Aardt 2000)
Presence of vector	Literature
Outbreaks in neighbouring countries	Literature
Climate regions	Kruger (2004) and Steynor (2006)
South African vegetation	Mucina and Rutherford (2006)
South African landcover	National Land Cover Database (2000)
Animal numbers	Directorate of Animal Health Livestock Census (2004)
Grazing capacity	Smith, Pretorius, Newby and Morgenthal (2006)

### **2.3.3 Data analysis**

#### ***2.3.3.1 Compilation of dataset***

##### **Rift Valley fever outbreak [rvf\_outbreak]**

The main outcome variable was a binary (0/1) variable indicating whether or not an outbreak was reported for a particular block during a particular season. Using ArcMap 9.3.1 (ESRI Corporation 2010) each outbreak map (see Chapter 3) was displayed with the half degree grid projected over it. Blocks falling inside or containing an outbreak were selected and the value of [rvf\_outbreak] for that block-season combination was set to 1. Where the outbreak area was large, the value for a block on the edge was set to 1 if more than 50% of the block fell within the outbreak area. For all blocks in which no outbreak was recorded the value of [rvf\_outbreak] was set to 0.

##### **Variables constant over time**

Some factors, such as vegetation and the presence of water bodies, were assumed to vary very little or not at all from year to year, yet differ between blocks within season. Compilation of the dataset started with the creation of a dataset, with one record for each half-degree block, containing all such temporally constant data.

##### **Half-degree block name**

The naming convention applied was the longitude of the centroid of the block, rounded to one decimal with the letter “E” for East, followed by to the latitude of the centroid, also rounded to one decimal with the letter “S” for South. For example the block in which the city of Johannesburg is located has a centroid coordinate of 28.25 decimal degrees East and - 25.75 decimal degrees South; the name of this block was therefore “28.2E-25.7S”. This ensured that each block had a unique name.

##### **Climatic region or zone**

Data were generated for two different climatic region classifications. The climate zones of South Africa (Juta General Atlas as referenced by Steynor 2006) are shown in Fig. 2.2. The 11 possible climate zones for this field [Climate\_zo] are: Bushveld, Desert and Semi-Desert, Drakensberg, Highveld, Karoo, Lowveld, Mediterranean, South Coast, South East Coast, Steppe, and Sub-Tropical East Coast (Fig. 2.2). The climatic regions according to Kruger (2004) are shown in Fig. 2.3. For each of these two classifications, each block was assigned the value for its climate region using the Spatial Join tool in ArcMap 9.3.1 (ESRI Corporation 2010).

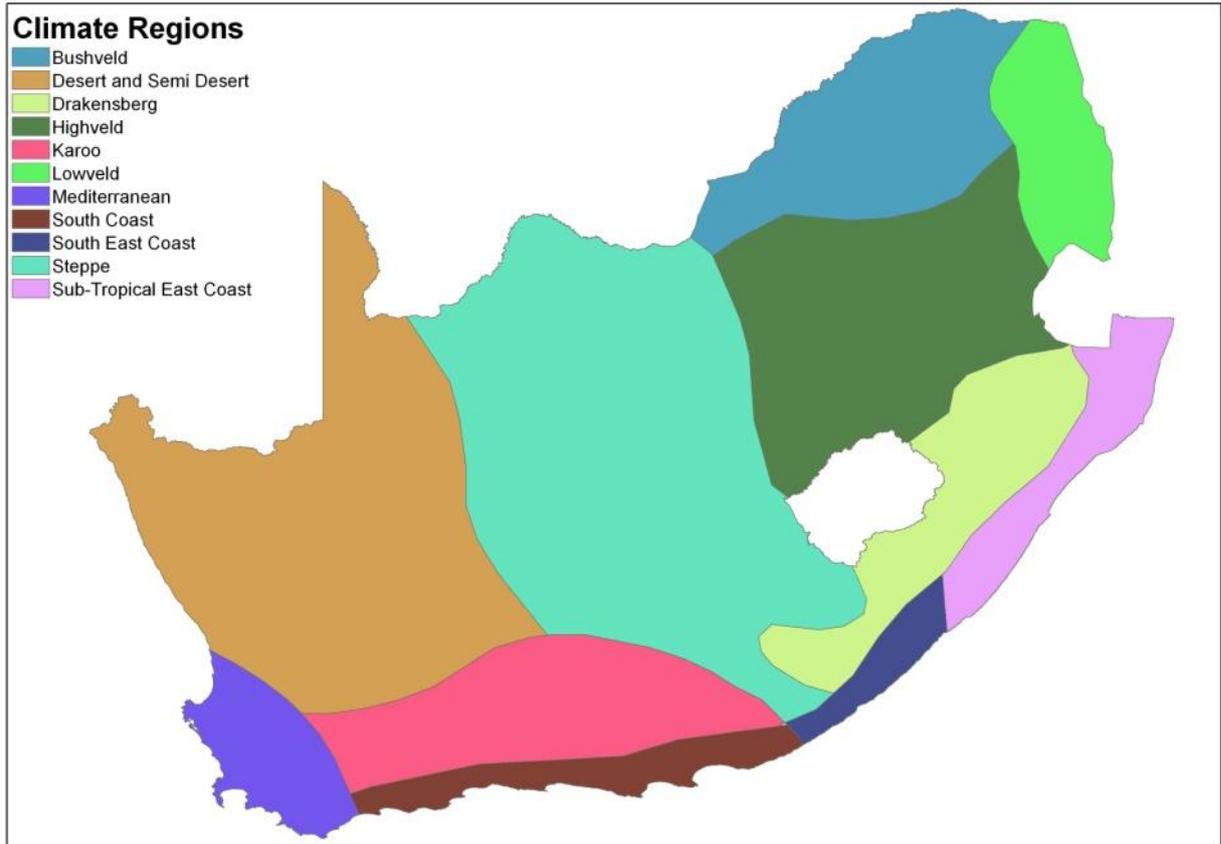


Figure 2.2 Climate regions of South Africa (Adapted from Steynor 2006, originally from Juta General Atlas)

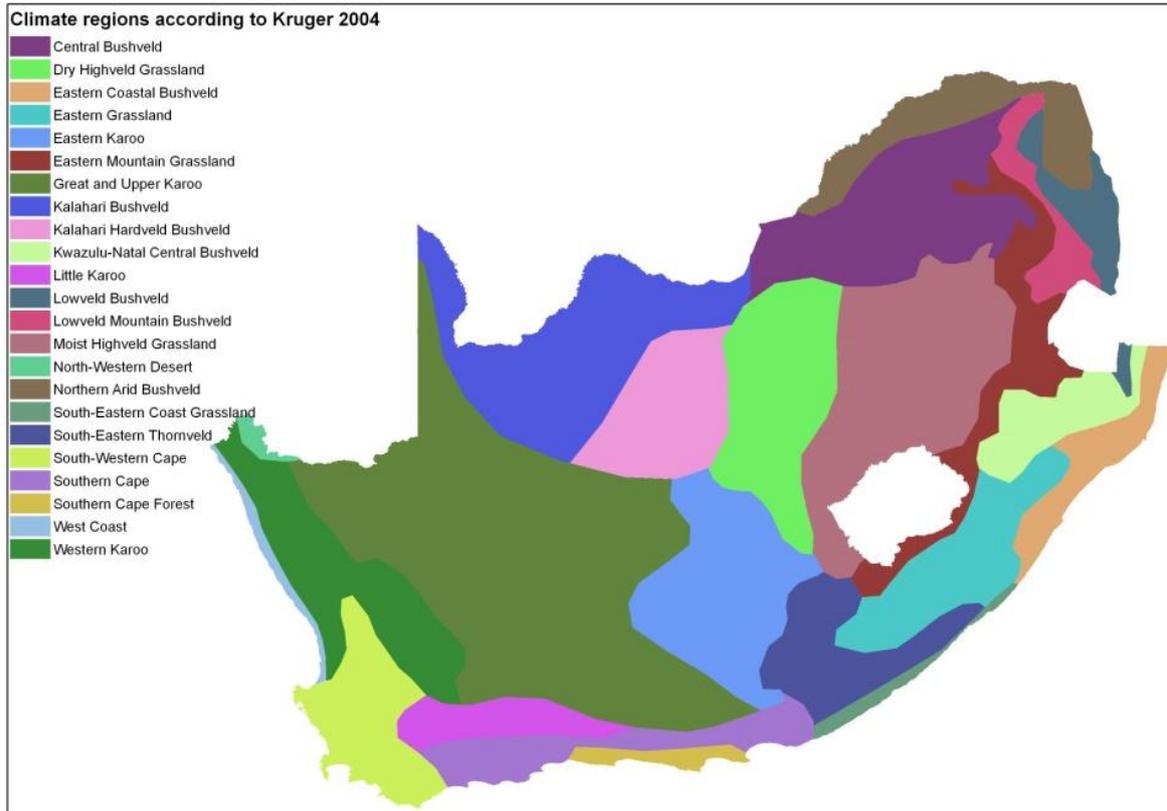


Figure 2.3 Climate regions according to Kruger (2004)

### Average rainfall

Using Microsoft Office Access 2007 the data from all the weather stations in each block (South African Weather Service 2010 and ARC-ISCW 2010) were averaged, resulting in the following fields for each station:

- Average rainfall for each month
- Average yearly rainfall
- Average total rainfall
- Altitude

A spatial join in ArcMap (ESRI Corporation 2010) assigned to each block the average of the above fields for all the weather stations in each block to account for the fact that several weather stations can fall in the same block. A field indicating the number of weather stations ([count\_]) in each block was also created.

The average monthly rainfall (for each month), average annual rainfall and total annual rainfall over the study period were assigned to each block (South African Weather Service

2010; ARC-ICSW 2010). These were calculated by averaging the data from all the weather stations in each block. The following fields resulted

- [avg\_alt] - Average altitude of all the weather stations in each block
- [avg\_year\_avg] - Average yearly rainfall of all the weather stations in each block over the 60 year period
- [avg\_year\_tot] - Average total yearly rainfall of all the weather stations in each block over the 60 year period

The average monthly rainfall for each block:

- [avg\_jul\_avg], [avg\_aug\_avg], [avg\_sep\_avg], [avg\_oct\_avg], [avg\_nov\_avg], [avg\_dec\_avg], [avg\_jan\_avg], [avg\_feb\_avg], [avg\_mar\_avg], [avg\_apr\_avg] [avg\_may\_avg], [avg\_jun\_avg]

A field indicating whether the square was in the winter rainfall area was created and set to 1 if the sum of the average rainfall for July, August, September, April, May and June was higher than the sum of the average rainfall for October, November, December, January, February and March over the entire 60 year period.

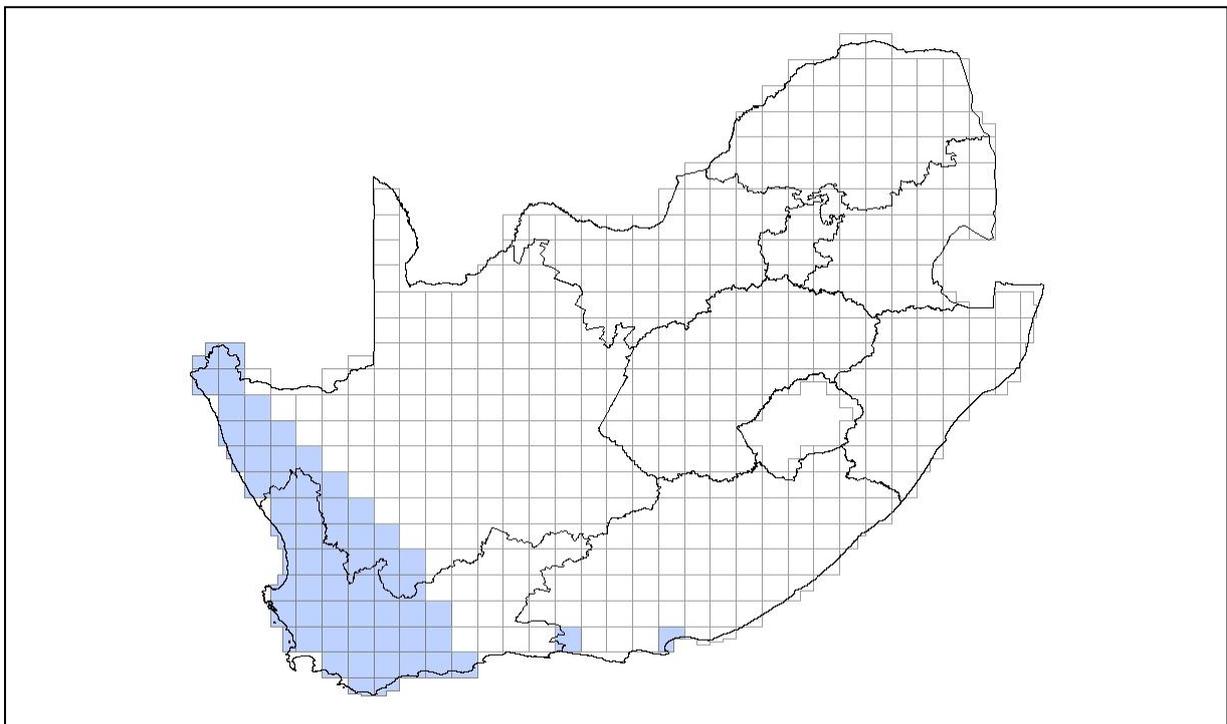


Figure 2.4 Map showing blocks (in blue) that qualified as winter rainfall area

### Vegetation type

Mucina and Rutherford (2006) define vegetation types as groups of plant communities ecologically and historically occupying the same habitats. Biomes are defined as major life zones defined by vegetation type, climate and large scale disturbance factors such as fire.

Bioregions are defined as subdivisions of the biomes based on factors such as rainfall or vegetation type.

The vegetation type, biome and bioregion were extracted from Vegmap2006 (Mucina & Rutherford 2006) and were used to populate the following variables:

- [vegname], [vegtypeid]
- [bioregion], [brgncode]
- [biome], [biomecode], [biomeid]

The assignment was made by selecting the category with the highest surface area in each block, using Africa Albers Equal Area projected coordinate system (ESRI Corporation 2010).

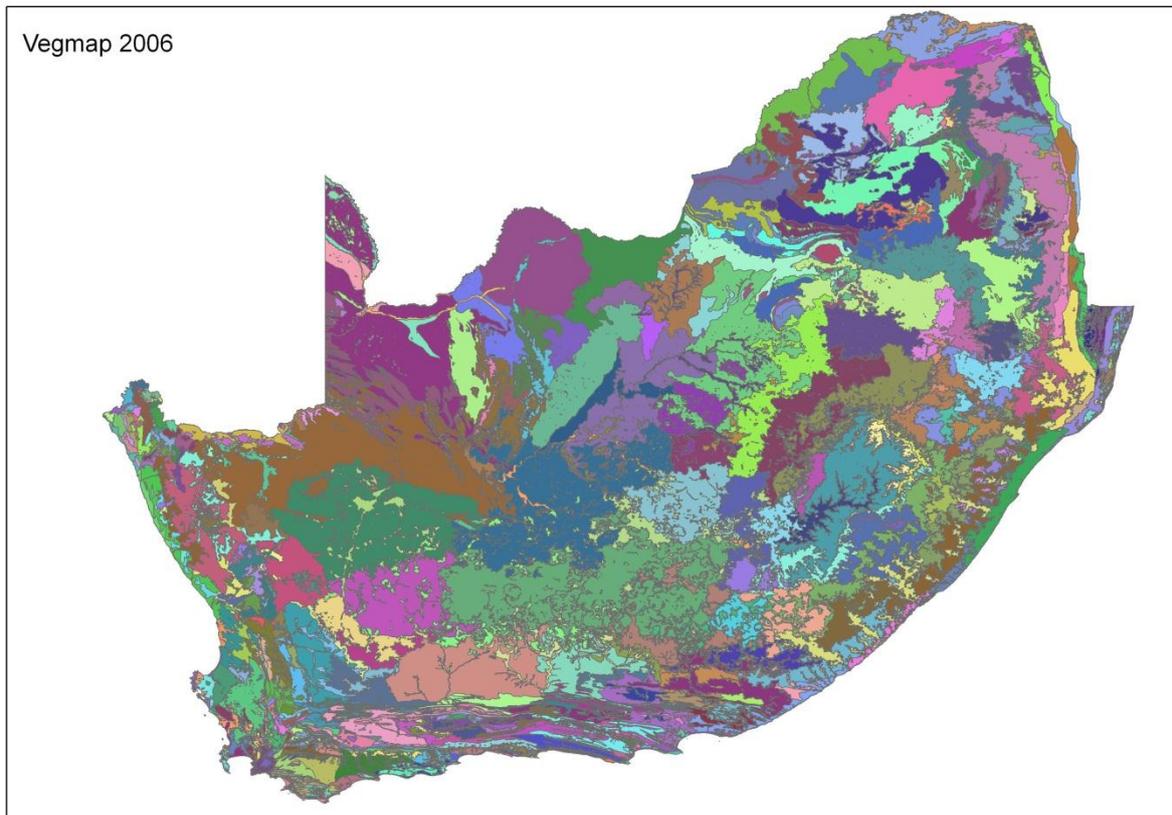


Figure 2.5 Vegetation types in South Africa (Mucina & Rutherford 2006)

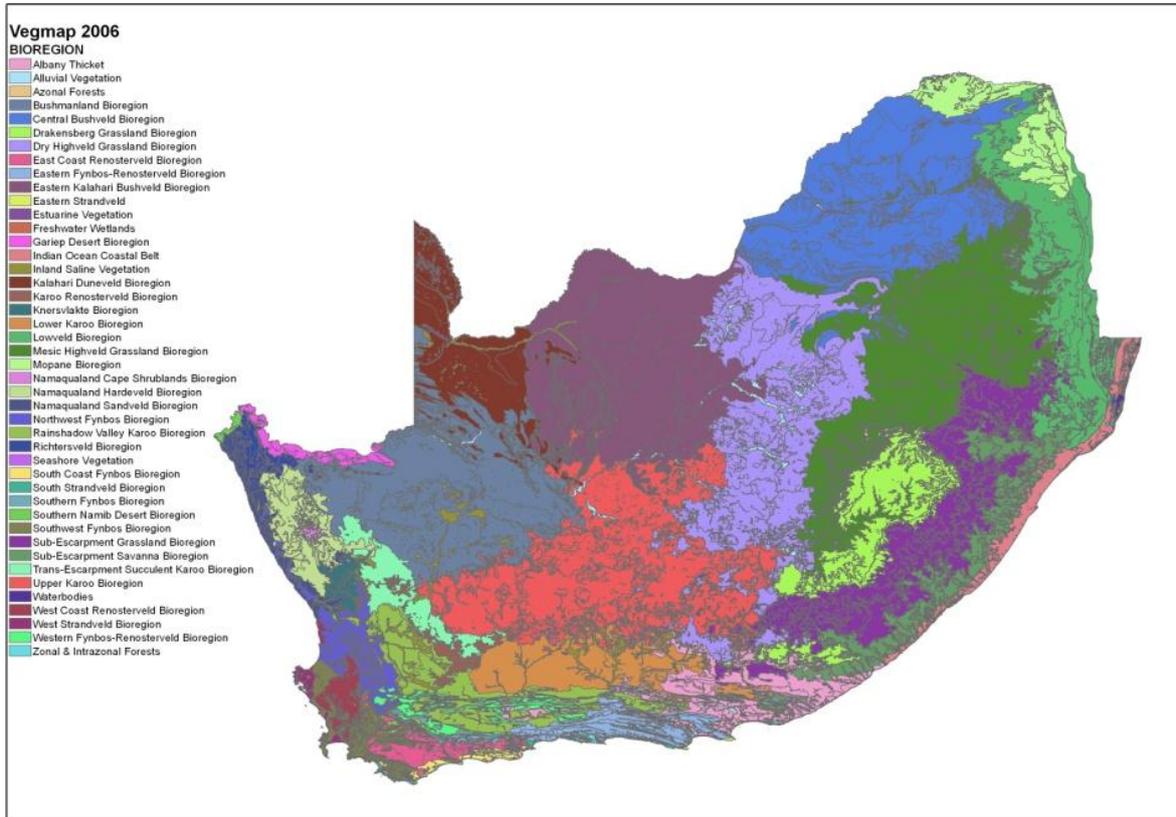


Figure 2.6 Vegetation bioregions in South Africa (Mucina & Rutherford 2006)

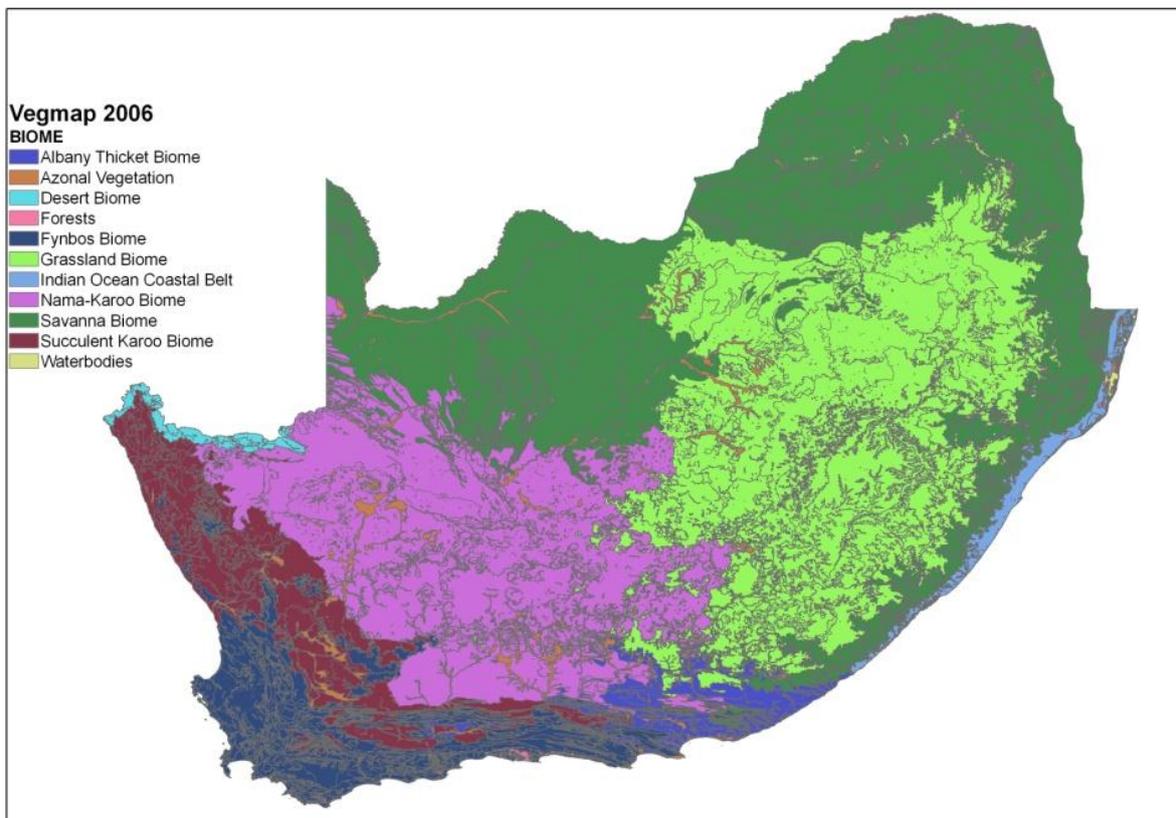


Figure 2.7 Vegetation biomes in South Africa (Mucina & Rutherford 2006)

### Water sources

There are several different measures for water sources. Water bodies are all sources of standing water, including man-made dams, lakes and pans. The different water sources were extracted from various datasets and encoded for inclusion in the study.

Wetlands are areas overgrown with reeds where water accumulates during rainy seasons and water bodies are all sources of standing water, like lakes, farm dams and dams. Using the National Land-cover 2000 dataset (Majeke, Poti, Ramoelo, Thompson, Flemming, Mcferren, & Van Aardt 2000), the wetland and water body portions were extracted. These were then used to populate the following fields:

- [Wetlands\_Count] – The number of wetlands in each block
- [Wetlands\_Length] – The total circumference of all the wetlands in each block (in metres)
- [Sum\_Wetlands\_Area] – The total surface area of wetlands in each block (in square metres)
- [Waterbody\_Count] – The number of water bodies in each block
- [Waterbody\_Length] – The total circumference of all the water bodies in each block (in metres)
- [Sum\_Waterbody\_Area] – The total surface area of water bodies in each block (in square metres)

The Africa Albers Equal Area projected coordinate system (ESRI Corporation 2010) was used to calculate accurate areas for the above surface area fields.

A pan is a shallow water-filled depression with no outflow. It is filled by rain and rises with the water table. The pan vegetation type was extracted from Vegmap2006 (Mucina & Rutherford 2006) and used as an indication of pans. There are three different types of pan vegetation types in this dataset, namely Bushmanland vloere, Highveld salt pans and Kalahari salt pans (Fig. 2.8). For each block, fields for the area, circumference and number of each type of pan, as well as for all the types of pans added together, were added to the dataset. This resulted in the following fields:

- [count\_bushmanland\_vloere], [sum\_bushmanland\_vloere\_area],  
[sum\_bushmanland\_vloere\_length]
- [count\_highveldsalt], [sum\_highveld\_saltpans\_area],  
[sum\_highveld\_saltpans\_length]

- [count\_kalahari\_salt], [sum\_kalahari\_salt\_pans\_area],  
[sum\_kalahari\_salt\_pans\_length]
- [count\_all\_pans], [sum\_pans\_length], [sum\_pans\_area]

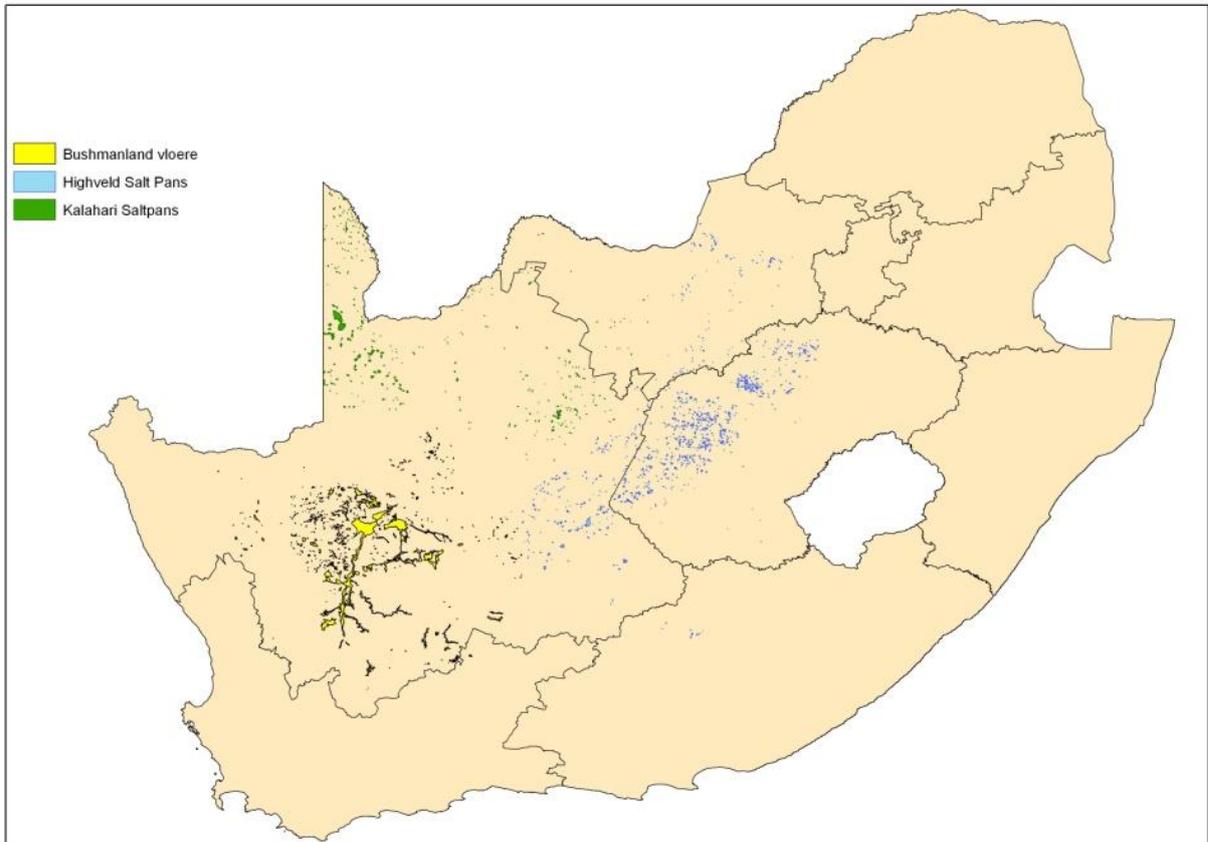


Figure 2.8 Pans according to vegetation type in South Africa (Mucina & Rutherford 2000)

The rivers (Department of Land Affairs 1998) and dams (Department of Land Affairs 1998) were coded for in the following fields:

- [count\_dams] – number of dams in the block
- [sum\_total\_dam\_area] – surface area of dams in square kilometres
- [sum\_dams\_length]– circumference of dams, i.e. length of dam edge
- [river\_size] – largest river size present in the block
- [river\_large\_perennial] – binary variable indicating the presence of a large perennial river
- [river\_group] – a categorical variable indicating the most predominant river system catchment area (for example rivers draining into the Limpopo River) present in the block

### Animal numbers

The Directorate of Veterinary Services (2004) census data were used to assign an animal number field to each block. The animal numbers are given as number of animals per district. These were converted to number of animals per square kilometre and the average of the all the districts within each block was assigned to the block. Animal numbers were assumed to remain constant over time. The following fields were created:

- [avg\_cattlesqkm] - Average number of cattle per square kilometre
- [avg\_sheepsqkm] - Average number of sheep per square kilometre
- [avg\_goatssqkm] - Average number of goats per square kilometre

### Grazing capacity

Grazing capacity was calculated from spatial data published by Smith, Pretorius, Newby and Morgenthal (2006). The grazing capacity is given in number of hectares per livestock unit. The average of the areas within each block was assigned to each block in the [avg\_grazcap] field.

### Average minimum and maximum temperatures

The average monthly maximum temperature (South African Weather Service 2010) over the 60 year period for each block:

- [avgmaxjul], [mintempaug], [avgmaxsep], [avgmaxoct], [avgmaxnov], [avgmaxdec], [avgmaxjan], [avgmaxfeb], [avgmaxmar], [avgmaxapr], [avgmaxmay], [avgmaxjun]

The average monthly minimum temperature (South African Weather Service 2010) over the 60 year period for each block:

- [avgminjul], [avgminaug], [avgminsep], [avgminoct], [avgminnov], [avgmindec], [avgminjan], [avgminfeb], [avgminmar], [avgminapr], [avgminmay], [avgminjun]

### **Data constant within season**

#### Season

Indicating one of the 60 seasons (July to June) represented by the record.

#### Southern Oscillation Index

The Southern Oscillation Index (SOI) is a measure of the atmospheric changes caused by the warming and cooling of the southern and eastern Pacific Ocean (U. S. A. National Oceanic and Atmospheric Administration's Climate Prediction Centre 2010). The following data were obtained or calculated:

- Monthly SOI
- Three month running average – calculated as the average SOI of the previous three months.
- Five month running average – calculated as the average SOI of the previous five months.
- The Oceanic Niño Index (ONI) is based on the sea surface temperature departures from the average in a specific region of the Pacific Ocean (called Niño 3.4) and is used to predict the El Niño Southern Oscillation (ENSO) (U. S. A. National Oceanic and Atmospheric Administration’s Climate Prediction Centre 2010)
- El Niño / La Niña – Two reported sources of El Niño / La Niña were coded for in these fields. The one [elnino\_lanina] (Cold, Neutral or Warm) was obtained from Meyers and O’Brien (1995) and the other [eln\_lan] from the Centre for Ocean-Atmospheric Prediction Studies (2010)

#### Rift Valley fever occurs in South Africa

If RVF occurred elsewhere in South Africa during the same season it was indicated using the [rvf\_sa] variable. This was then used to calculate the binary variable indicating whether RVF had occurred in South Africa at any time during the previous three years

- [rvf\_sa], [rvf\_sa3y]

#### Rift Valley fever occurs in neighbouring countries

Where the literature reviewed indicated that an outbreak occurred in a neighbouring country during that season, it was recorded, as well as a binary variable indicating whether an outbreak had occurred in a neighbouring country during the previous three years.

- [rvf\_neighb], [rvf\_neighb3y]

#### Rift Valley fever occurrence in Kenya

Murithi et al. (2010) and Anyamba et al. (2001) recorded somewhat different histories for the occurrence of RVF in Kenya. Each was summarised according to the season during which it was reported to occur. The differences in these reports could be due to the reporting period. The one researcher might have compiled report from annual reports and the other from laboratory reports. Another possibility is that one researcher reported the start of outbreaks and the other when the epidemic peak was reached.

These were used to create the following fields:

- [rvf\_kenya\_anj] a binary field indicating whether an outbreak occurred as reported by Anyamba et al. (2001)

- [rvf\_kenya\_2] a binary field indicating whether an outbreak occurred as reported by Murithi et al. (2010)
- [rvf\_kenya\_3y] a binary field indicating whether an outbreak had occurred during the previous three years as reported by Murithi et al. (2010)

### **Data varying between both blocks and seasons**

#### Cumulative number of previous RVF outbreaks for each block

The variable [rvf\_cumulative] indicated the number of previous seasons in which this block experienced a RVF outbreak, excluding the current season.

#### Monthly rainfall

The average rainfall for all the weather stations within a block for each season (South African Weather Service 2010; ARC-ICSW 2010) was captured in the following fields:

- [count\_] – number of weather stations used for the calculation
- [avg\_jul] [avg\_aug] [avg\_sep] [avg\_oct] [avg\_nov] [avg\_dece] [avg\_jan] [avg\_feb] [avg\_mar] [avg\_apr] [avg\_may] [avg\_jun] – rainfall during the specified month
- [avg\_season\_rain\_avg] [avg\_season\_rain\_total] – total and average monthly rainfall for the season for the specified block.

#### Monthly minimum and maximum temperatures

The minimum and maximum temperatures for each block for each season (South African Weather Service 2010; ARC-ICSW 2010) were captured in the following fields:

- [maxtempjul] [maxtempaug] [maxtempsep] [maxtempoct] [maxtempnov] [maxtempdec] [maxtempjan] [maxtempfeb] [maxtempmar] [maxtempapr] [maxtempmay] [maxtempjun]
- [mintempjul] [mintempaug] [mintempsep] [mintempoct] [mintempnov] [mintempdec] [mintempjan] [mintempfeb] [mintempmar] [mintempapr] [mintempmay] [mintempjun]

Because temperature data were available from far fewer weather stations (compared with rainfall data), each block was given the values from the nearest weather station and not an average of the stations in the block.

### Previous season's rainfall

This was taken from the previous season's average and total rainfall for that block (South African Weather Service 2010; ARC-ICSW 2010).

- [prev\_season\_rain\_avg] – Average rainfall during the previous season in the specified block.
- [prev\_season\_rain\_total] – Total rainfall during the previous season in the specified block.

### Merging and cleaning of final dataset

The yearly sets of blocks were merged into one dataset using ArcGIS 9.3.1 (ESRI Corporation 2010). The spatially constant data were then joined to this using the [Name] field and the temporally constant data were also joined to this using the [Season] field in Microsoft Office Access 2007. All obviously incorrect data, for example a negative maximum temperature, were replaced with missing values (i.e. a value indicating no data).

#### **2.3.3.2 Reduction in number of variables**

Due to the large number of independent variables, summary variables were created to summarise some factors and to create variables that were more meaningful. From the large pool of variables, a subset was then selected for inclusion in the analysis, in order to prevent the inclusion of several highly correlated predictor variables in the multivariable model which would result in multicollinearity. All the created variables were selected, as well as any variables suspected to have an influence on the occurrence of RVF outbreaks. Selection was done based on biological plausibility and sometimes using pseudo  $R^2$  (see below). Logistic regression does not have a value for  $R^2$  as found in ordinary least squares regression. Several equivalents for  $R^2$  have been proposed and STATA gives McFadden's pseudo  $R^2$  (Statacorp 2007) and can be used (with caution) as an indication of goodness-of-fit of one model compared to a similar model.

### Rainfall

The following variables represented rainfall:

- Average rainfall for each month for each season
- Average yearly rainfall for each season
- Average total rainfall for each season
- [avg\_year\_avg] - Average yearly rainfall of all the weather stations in each block
- [avg\_year\_tot] - Average total yearly rainfall of all the weather stations in each block

- Monthly rainfall for each block (average of all the weather stations falling inside the block)
- Winter rainfall area
- [prev\_season\_rain\_avg] – Average rainfall during the previous season in the specified block
- [prev\_season\_rain\_total] – Total rainfall during the previous season in the specified block

The following rainfall variables were created from the above:

- [months\_above\_rain] - Number of months in which the rainfall in the block was above the average rainfall for the block
- [threemonthhighrain] - A binary variable indicating whether there were three consecutive months of above average rainfall
- [HighRainStart] - A binary variable indicating whether the first six months of the season experienced above average rainfall
- [HighRainSummer] - A binary variable indicating whether the months December, January and February all experienced more than double the average rainfall for those months (i.e. rainfall for December was more than two times the average rainfall for December for that block AND rainfall for January was more than two times the average rainfall for January for that block AND rainfall for February was more than two times the average rainfall for February for that block)
- [difprev] - The average rainfall for the indicated season minus the average rainfall for the previous season.

From the above the following variables were selected to represent rainfall:

- [winter\_rainfall] – prior to 2010 no RVF outbreaks occurred in the region
- [Months\_above\_rain] – to indicate high rainfall seasons
- [threemonthhighrain] – to indicate high rainfall events
- [HighRainStart] – to indicate high rainfall during the beginning of the season
- [HighRainSummer] – to indicate high rainfall during the months known to have more RVF outbreaks (from history of RVF investigation, see Chapter 3)
- [prev\_season\_rain\_avg] – to indicate rainfall of the previous season

### Temperature

The following variables represented temperature:

- Average monthly maximum temperature

- Average monthly minimum temperature

The following summary variables for temperature were created:

- [coldwinter] - The minimums for the winter at the start of the season were below normal.
- [avgmaxdif] - The average season maximum minus the average maximum for that block.
- [coolermaxYN] - A binary variable indicating that the average season maximum was cooler than normal.
- [avgmindif] - The average season minimum minus the average minimum for that block.
- [coolerminYN] - A binary variable indicating that the average season minimum was cooler than normal.
- [cooleryearYN] - A binary variable indicating that both the average season minimum and the average season maximum were cooler than normal.

From the above the following variables were selected to indicate temperature:

- [Avgmaxdif]
- [coolermaxYN]
- [Avgmindif]
- [coolerminYN]

### Southern Oscillation Index

The following variables represented the SOI

- Monthly SOI
- Three month running average – calculated as the average SOI of the previous three months.
- Five month running average – calculated as the average SOI of the previous five months.
- The Oceanic Niño Index (ONI) is based on the sea surface temperature departures from the average in a specific region of the Pacific Ocean (called Niño 3.4) and is used to predict the El Niño Southern Oscillation (ENSO) (U. S. A. National Oceanic and Atmospheric Administration's Climate Prediction Centre 2010)
- El Niño / La Niña – Two reported sources of El Niño / La Niña where coded for in these fields. The one [elnino\_lanina] (cold, neutral or warm) was obtained from Meyers and O'Brien (1995) and the other [eln\_lan] from the Centre for Ocean-Atmospheric Prediction Studies (2010)

From the above the Five month running average was selected [soi5avg]

### Water sources

The following variables indicated water sources:

- [Wetlands\_Count] – The number of wetlands in each block
- [Wetlands\_Length] – The total circumference of all the wetlands in each block (in metres)
- [Sum\_Wetlands\_Area] – The total surface area of wetlands in each block (in square metres)
- [Waterbody\_Count] – The number of water bodies in each block
- [Waterbody\_Length] – The total circumference of all the water bodies in each block (in metres)
- [Sum\_Waterbody\_Area] – The total surface area of water bodies in each block (in square metres)
- [count\_bushmanland\_vloere], [sum\_bushmanland\_vloere\_area], [sum\_bushmanland\_vloere\_length]
- [count\_highveldsalt], [sum\_highveld\_saltpans\_area], [sum\_highveld\_saltpans\_length]
- [count\_kalahari\_salt], [sum\_kalahari\_salt\_pans\_area], [sum\_kalahari\_salt\_pans\_length]
- [count\_all\_pans], [sum\_pans\_length], [sum\_pans\_area]
- [count\_dams] – number of dams in the block
- [sum\_total\_dam\_area] – surface area of dams in square kilometres
- [sum\_dams\_length] – circumference of dams, i.e. length of dam edge
- [river\_size] – largest river size present in the block
- [river\_large\_perennial] – binary variable indicating the presence of a large perennial river
- [river\_group] – a categorical variable indicating the most predominant river system (for example rivers draining into the Limpopo river) present in the block

The following summary variables indicating water sources were created

- [wetlandsNOTpans] - The area of wetland minus the area of pans. This variable was created because the wetland polygon includes pans.
- [wetlandsYN] - A binary variable indicating that wetlands are present in a block.
- [pansYN] - A binary variable indicating that pans are present in a block.

- [waterbodyYN] - A binary variable indicating that waterbodies are present in a block, excluding pans and wetlands.

From the above the following variables were selected to represent water sources:

- [sum\_waterbodies] / [waterbodyYN]
- [sum\_wetlandsNOTpans] / [wetlandsYN]
- [sum\_pans\_area] / [pansYN]
- [river\_large\_perennial]

### Vegetation

The following variables represented vegetation type

- [vegname], [vegtypeid]
- [bioregion], [brgncode]
- [biome], [biomecode], [biomeid]

From the above only biome was selected, since the numbers of categories in the other two variables were too large to be easily applied as a fixed effect in a statistical model. The Desert biome was recoded to be included in the adjacent Nama Karoo biome due to the fact that it is very small and never experienced any RVF outbreaks.

### Animals

The following variables indicated the presence and estimated concentrations of animals:

- [avg\_cattlesqkm] - Average number of cattle per square kilometre
- [avg\_sheepsqkm] - Average number of sheep per square kilometre
- [avg\_goatssqkm] - Average number of goats per square kilometre
- [avg\_grazcap] - Average grazing capacity

From the above [avg\_cattlesqkm], [avg\_sheepsqkm] and [avg\_goatssqkm] were selected.

### RVF outbreaks in other areas

The following variables indicated RVF outbreaks elsewhere:

- [rvf\_sa], [rvf\_sa3y] – RVF occurred in South Africa during the same season and during the previous three seasons.
- [rvf\_neighb], [rvf\_neighb3y] RVF occurred in a neighbouring country (Namibia, Botswana, Zimbabwe, Mocambique, Swaziland or Lesotho during the same season and during the previous three seasons.

- [rvf\_kenya\_anj] – a binary field indicating whether an outbreak occurred as reported by Anyamba et al. (2001)
- [rvf\_kenya\_2] – a binary field indicating whether an outbreak occurred as reported by Murithi et al. (2010)
- [rvf\_kenya\_3y] – a binary field indicating whether an outbreak had occurred during the previous three years as reported by Murithi et al. (2010)

From the above the following variables were selected:

- [rvf\_sa3y]
- [rvf\_neighb3y]
- [rvf\_kenya\_3y]
- [rvf\_kenya\_2]

#### Cumulative number of previous RVF outbreaks

- [rvf\_cumulative]

#### **Selection between similar variables**

Where two variables indicated different aspects of the same factor, multiple logistic regression models with all the included variables were run separately with each of the two variables. The pseudo  $R^2$  was then used as an indication of which variable explained the most variation in the outcome.

#### Pans

When the variable indicating the area covered by pans was replaced with the binary variable indicating the presence of pans [pansYN], a more significant result and a higher pseudo  $R^2$  were obtained. The binary variable indicating the presence or absence of pans are therefore included in the model.

#### Waterbodies

Replacing the variable indicating the area covered by water bodies with a binary variable indicating the presence or absence of a waterbody [waterbodyYN] gave a less significant result but a model with a higher pseudo  $R^2$ . The binary variable indicating the presence or absence of waterbodies are therefore included in the model.

### Wetlands

The variable [wetlandsNOTpans] was selected, because [wetlandsYN] had a non-significant result during univariable logistic regression.

### Temperature

Replacing the maximum temperature difference and minimum temperature difference variables with binary variables indicating that the season was colder than average resulted in a model with a lower pseudo  $R^2$ . The unchanged minimum temperature and a binary variable for maximum temperature were selected.

### Rift Valley fever outbreaks in Kenya

The variable indicating that RVF occurred in Kenya during the previous 3 years, as reported by (Murithi et al. 2010) resulted in the highest pseudo  $R^2$ .

### **Variables selected**

In summary, the independent variables selected for inclusion in the analysis were the following:

- [rvf\_cumulative]
- [soi5avg]
- [rvf\_sa3y]
- [rvf\_neighb3y]
- [rvf\_kenya\_3y]
- [biome\_cat]
- [waterbodyYN]
- [sum\_wetlandsNOTpans]
- [pansYN]
- [winter\_rainfall]
- [avg\_cattlesqkm]
- [avg\_sheepsqkm]
- [avg\_goatssqkm]
- [Months\_above\_rain]
- [threemonthhighrain]
- [HighRainStart]
- [HighRainSummer]
- [coolermaxYN]
- [Avgmindif]
- [prev\_season\_rain\_avg]
- [river\_large\_perennial]

### **2.3.3.3 Univariable analysis**

The crude association of each selected independent variable with the outcome (occurrence of a RVF outbreak) was estimated using simple (univariable) logistic regression. All variables associated with the outcome at a very liberal level of  $P < 0.25$  were selected for possible inclusion in the maximum multivariable model, in order not to miss any variables whose association with the outcome was masked by confounding.

#### **Highly correlated predictors**

All pairwise correlations between the above variables were then tested using Pearson's correlation. Where two variables were highly correlated, with  $|r| > 0.7$ , one of the variables was dropped from the analysis.

### **2.3.3.4 Multivariable analysis**

#### **Linearity**

An assumption of the multiple logistic regression model is that all the continuous predictor variables in the model have a linear association with the log odds of the outcome. Therefore all the continuous variables must be tested for linearity. According to the method described by Hosmer and Lemeshow (2000), each selected continuous variable was split into quartiles and the midpoints of each quartile were displayed graphically against their estimated coefficients when used in the multivariable model. This was done using the **lincheck** function in STATA (Gamma 2005). The graphs were then visually inspected for approximate linearity, and all non-linear predictor variables were recoded into categorical variables using biologically meaningful and statistically appropriate cutpoints.

#### **Development of the multiple logistic regression model**

The maximum model was then developed by backward elimination. Variables that did not show a significant effect in the model were dropped one by one, starting with the variable with the highest  $P$ -value based on the Wald test, until all the variables remaining in the model were significant ( $P < 0.05$ ). Robust variance estimation was used to account for clustering of the outcome within the seasons (**vce(cluster season\_cat)** command in STATA).

#### **Interactions**

Possible interactions (effect modification) between variables remaining in the model that made biological sense were tested, and if found to be significant were retained in the model.

### **2.3.3.5 Model checking**

The following post-estimation commands were used to assess the goodness-of-fit of the model:

#### Hosmer-Lemeshow goodness-of-fit test

Hosmer and Lemeshow (2000) describe goodness-of-fit as how effectively the model describes the outcome variable. STATA's **estat gof** was used to calculate the Hosmer-Lemeshow goodness-of-fit statistic for the final multiple logistic regression model.

#### Area under the receiver operating characteristic curve

A receiver operating characteristic (ROC) curve is an overall assessment of the ability of the model to correctly classify the outcome and is calculated by plotting the sensitivity of the model against the false positive rate (1-specificity). The 45 degree line indicates a model that predicts the outcome no better than pure chance. The higher the curve and the further away it is from the diagonal line, the better the predictive ability of the model. The greater the area under the curve, the better the model is at predicting the outcome. A perfect model will have an area under the curve of one. Hosmer and Lemeshow (2000) indicate that an area under the curve of between 0.8 and 0.9 is considered as excellent discrimination. The **iroc** function in STATA was used to produce the ROC curve and to calculate its area under the curve.

### **2.3.3.6 Month by month analysis of the effect of the SOI on RVF outbreaks**

In a separate analysis, the association between RVF outbreaks and the monthly SOI (U. S. A. National Oceanic and Atmospheric Administration's Climate Prediction Centre 2010) and 5 month running average of the SOI was estimated using simple logistic regression. A separate dataset was compiled for this analysis using sources where the month of the RVF outbreaks were indicated. Only seasons where the month of the outbreak is reported or seasons without any outbreaks were included in this dataset. The dataset only consisted of the month, the 5 month running average of the SOI and a binary field indicating that a RVF outbreak occurred (1) or did not occur (0) anywhere in South Africa. This resulted in a dataset with 440 observations.

### **2.3.3.7 Software packages used for the study**

- ArcGIS ArcMap 9.3.1 (ESRI Corporation Redlands, CA, U.S.A)
- ArcGIS ArcCatalog 9.3.1(ESRI Corporation Corporation Redlands, CA, U.S.A
- STATA 10 IC (StataCorp, College Station, TX, U.S.A.) Statistical software
- Microsoft Office Access 2007 (Microsoft Corporation, Richmond, CA, U.S.A.)
- Microsoft Office Excel 2007 (Microsoft Corporation, Richmond, CA, U.S.A.)
- Microsoft Office Word 2007 (Microsoft Corporation, Richmond, CA, U.S.A.)
- JabRef version 2.6 2009 Open Source referencing software  
(<http://jabref.sourceforge.net/>)
- LINCHECK (Gamma 2005): STATA module to graphically assess the linearity of a continuous covariate in a regression model.

## Chapter 3 : Results: Temporal and spatial history of Rift Valley fever

### 3.1 Introduction

The first part of the study investigated the occurrence of RVF in South Africa on a temporal (when it occurred) and spatial (where it occurred) basis. Sources of information on the occurrence of RVF were:

- Annual reports of the National Department of Agriculture
- Annual reports of the Directorate of Veterinary Services / Animal Health
- Disease reports to international organisations such as the OIE and Southern African Regional Commission for the Conservation and Utilisation of the Soil (SARCCUS)
- Literature
- Disease reports from veterinary regions and provincial veterinary services

One source of outbreak information that could not be found was reports or annual reports from veterinary laboratories. One reason could be that most veterinary laboratories were part of the veterinary services in the past and did not produce separate annual reports. The researcher could not determine if laboratory test results for RVF tests before 1992 existed.

During the 60 year study period (1950-2010) a total of 26 seasons (July to June) were found to have a report of one or more RVF outbreaks. South Africa experienced three major epidemics that affected an extensive area of South Africa, during 1950-51, 1974-76 and 2010. The rest of the reports were of smaller outbreaks or isolated cases.

The geographic distribution of RVF outbreaks and the cumulative number of outbreaks in each half degree square are shown in Figure 3.1. The map should be interpreted bearing in mind that some reports gave very little detail with regard to the exact geographic location of the outbreak. Some reports only state the veterinary region that experienced an outbreak. This would then cause a large number of blocks to be filled, when in reality only a few blocks were involved.

The temporal distribution and indication of the extent of the RVF outbreaks are shown in Figure 3.2. Similarly, this figure should be interpreted with caution since the height of the bars indicates the number of blocks reported to have experienced RVF outbreaks. Prior to about 1990, bar heights are almost certainly overestimates of the number of blocks that

experienced outbreaks, since the recorded spatial information was far less precise than in more recent years.

In some reports the actual month of the RVF outbreak was mentioned. Table 3.1 gives a summary of which months experienced RVF outbreak during specific seasons.

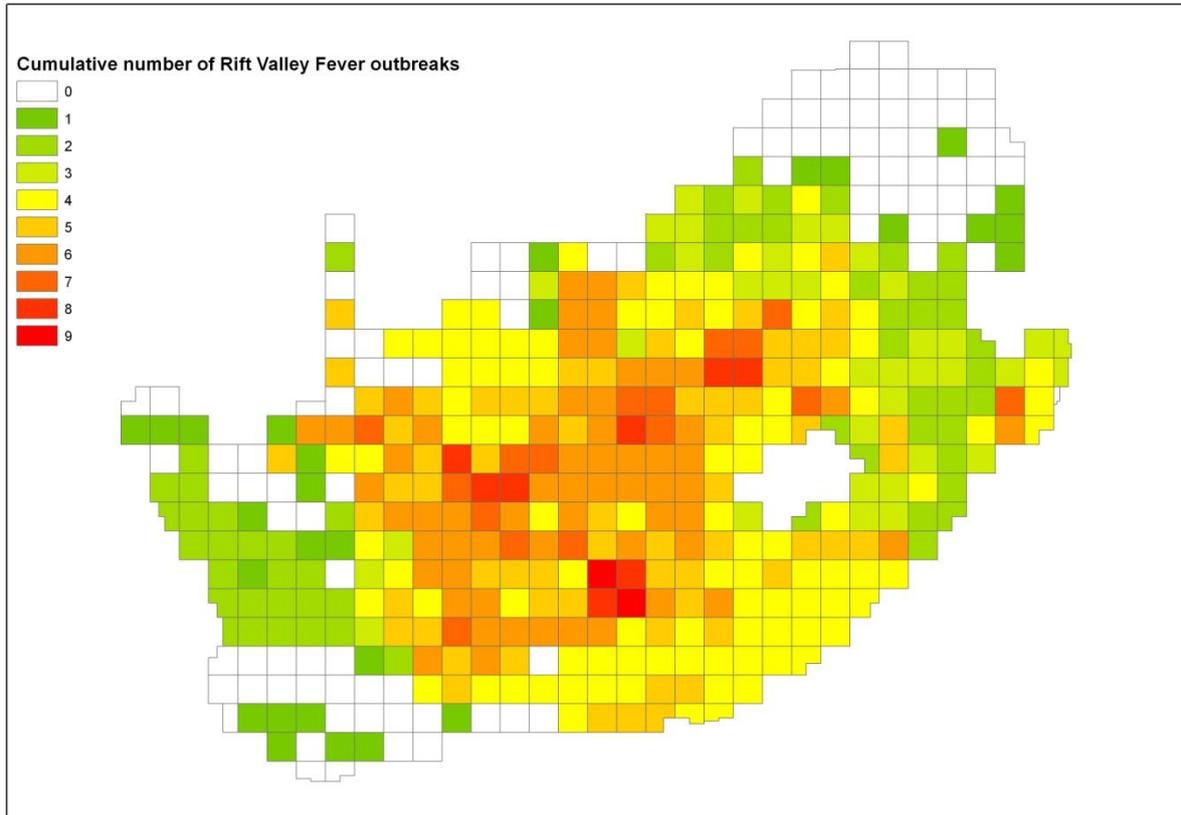


Figure 3.1 The cumulative number of RVF outbreaks in South Africa during the period 1950-2010

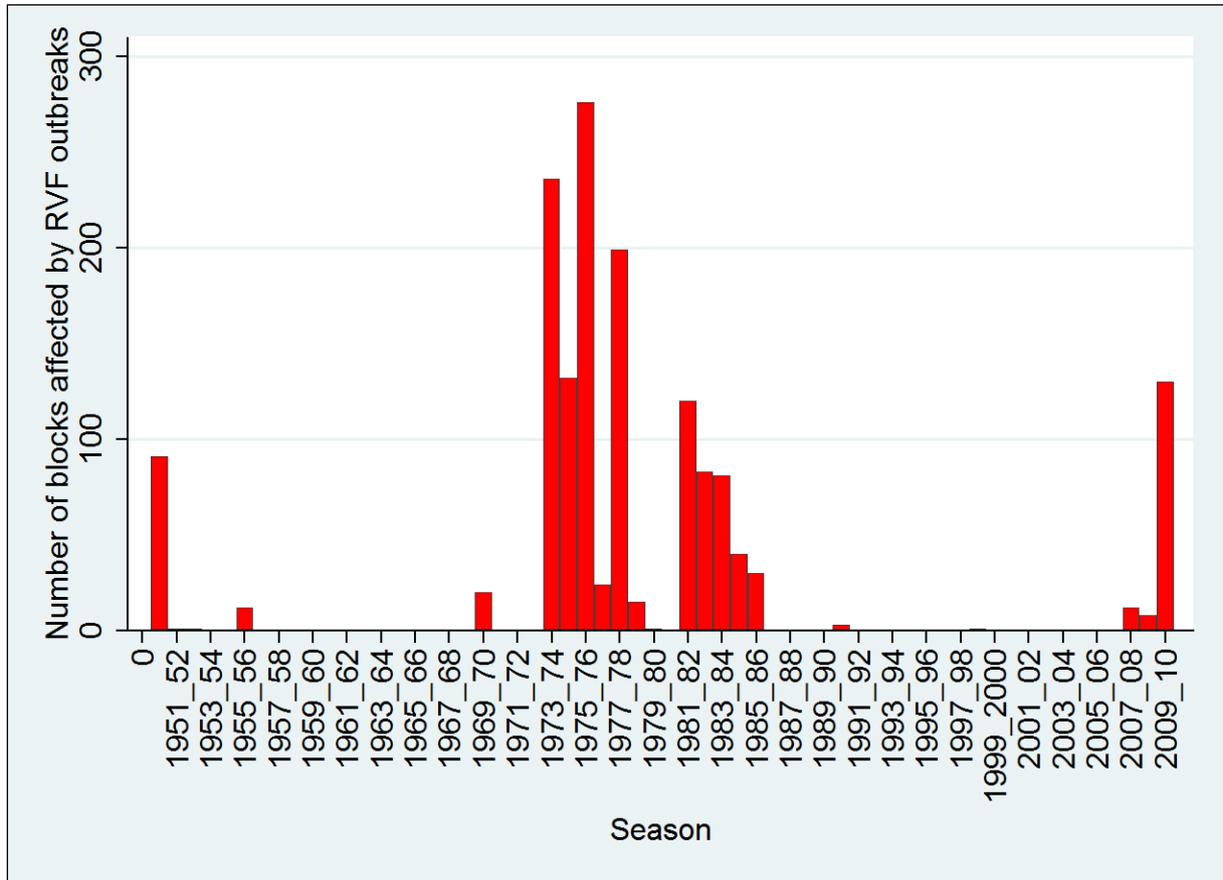


Figure 3.2 The temporal distribution of reported Rift Valley fever outbreaks in South Africa during the period 1950-2010

Table 3.1 The temporal distribution of RVF outbreaks in South Africa, 1950-2010, where the month of the outbreak is mentioned in the literature

Season	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
1950_51						X		X		X		
1951_52							X					
1952_53									X			
1955_56							X	X				
1969_70								X	X			
1973_74								X	X	X	X	X
1974_75		X	X				X	X	X			
1976_77		X	X	X	X		X	X	X		X	
1977_78					X		X	X			X	
1978_79					X	X		X		X		
1979_80	X											
1981_82										X		
1982_83									X	X		X
1983_84				X	X	X		X		X		
1985_86		X						X	X			
1988_89									X			
1989_90				X								
1998_99							X					
2007_08							X	X	X	X	X	X
2008_09								X	X	X	X	X
2009_10					X			X	X	X	X	X

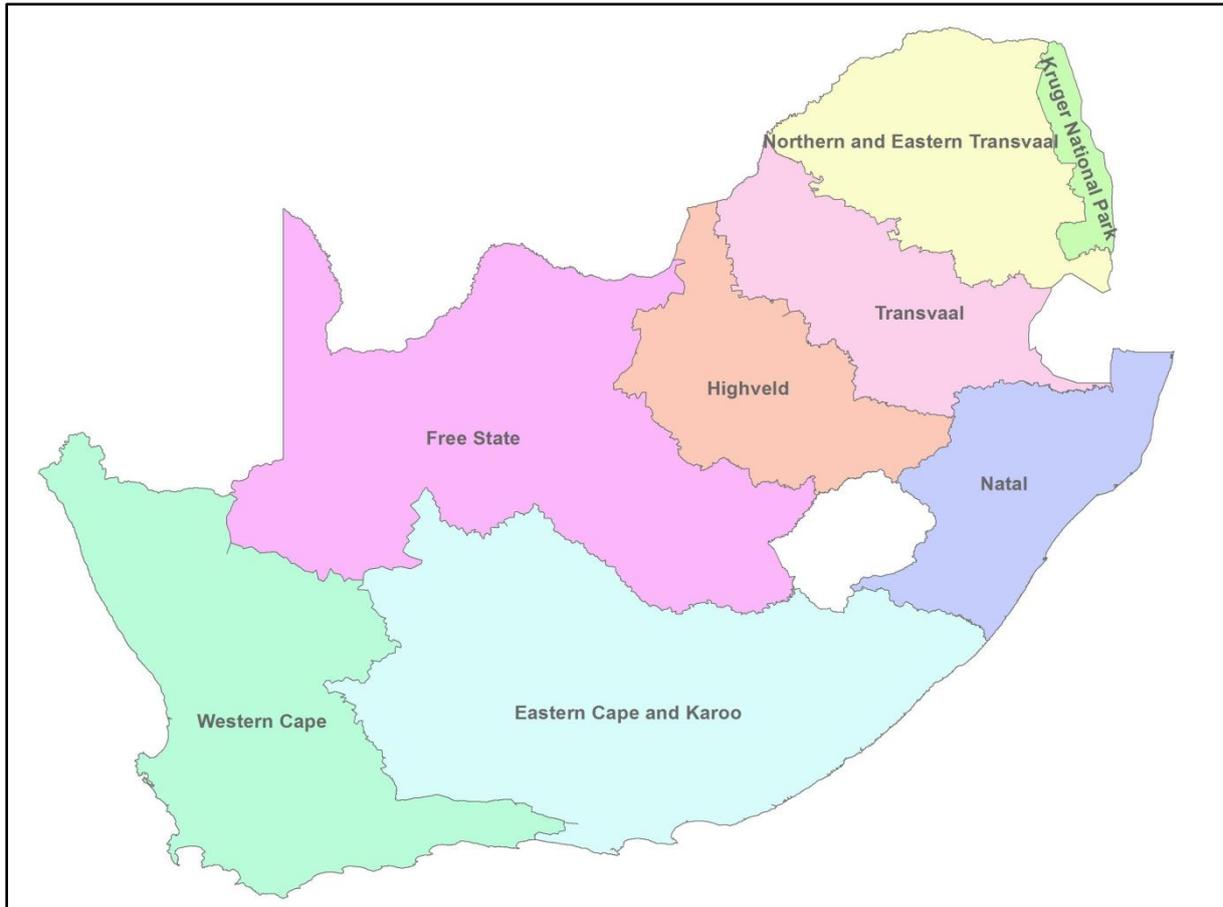


Figure 3.3 Veterinary regions in South Africa during the period 1950 to 1994

### **3.2 Individual seasons**

The reported outbreaks are detailed below by season, i.e. July to June the following year. Some references are made to veterinary regions (Figure 3.3), the names and boundaries of which differ in many cases from those of both previous and present provinces of South Africa.

#### **1950-51**

Rift Valley fever was recorded in South Africa in 1950-51 in the northern Cape Province, western Orange Free State and the southern Transvaal (Figure 3.4). This was the first time RVF was diagnosed in South Africa and no reports of a similar disease prior to this outbreak could be found. It started in the western Free State in December 1950 and it continued until April 1951. Specific areas mentioned are the Wolwespruit and Dealesville areas of the Boshof District, Vaalhartz, the Vaal River Barrage, Loskop dam, Koffiefontein and Standerton (Alexander 1951). The disease was at first not recognised, but after a veterinarian performing a post mortem inspection on a farm south of Johannesburg became sick, it was recognised as RVF (Mundel & Gear 1951). During this outbreak it was recognised that the outbreak was associated with the panveld area (Alexander 1951).

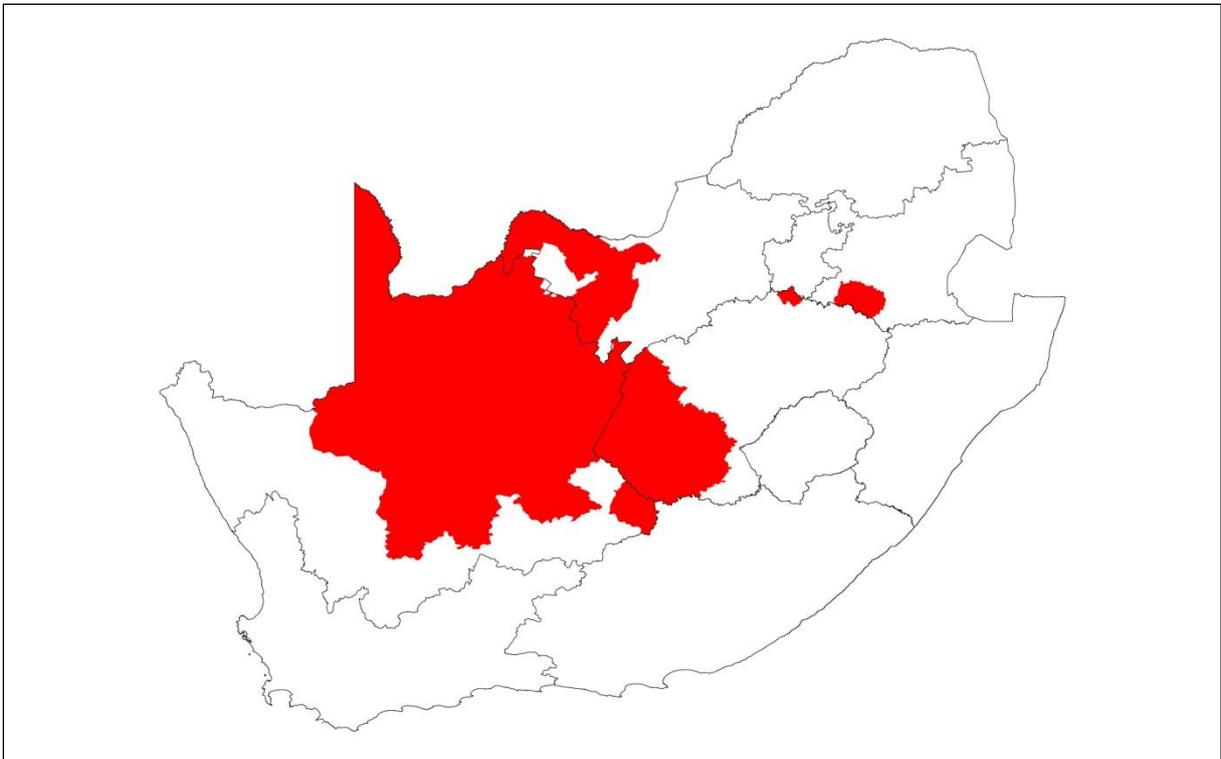


Figure 3.4 Districts and veterinary regions affected by Rift Valley fever in South Africa 1950-

1951-52

On 30 January 1952 RVF was diagnosed (laboratory confirmed) only on one farm: Weltevreden in the Wolvenspruit area of the Boshof District (Figure 3.5) (Van der Linde 1953).



Figure 3.5 One Rift Valley fever outbreak in South Africa during January 1952 on the farm Weltevreden

1952-53

During April 1953 an outbreak was confirmed in the Gannapan and Legpan areas of the Fauresmith (Luckhoff) District, northwest of Luckhoff in the Orange Free State (Figure 3.6). These pans have a geographical reference of 24°40' East and 29°40' South. Farms affected where Eldorado, Legpan, Bossiespan A & B, Wolvenkraal, Nelsdam, Overskot, Koppiesdam, De Rif, Alpha and Wolvenplaat. During this outbreak it was also noted that the outbreak was associated with the flooding of the nearby pans (Van der Linde 1953). A team from the South African Institute for Medical Research was also sent to investigate this outbreak. They mentioned that several people fell ill due to the disease after handling meat and also suggested the involvement of pans in the epidemiology of the disease (Gear, De Meillon, Le Roux, Kofsky, Rose Innes, Steyn, Oliff & Schulz 1955).

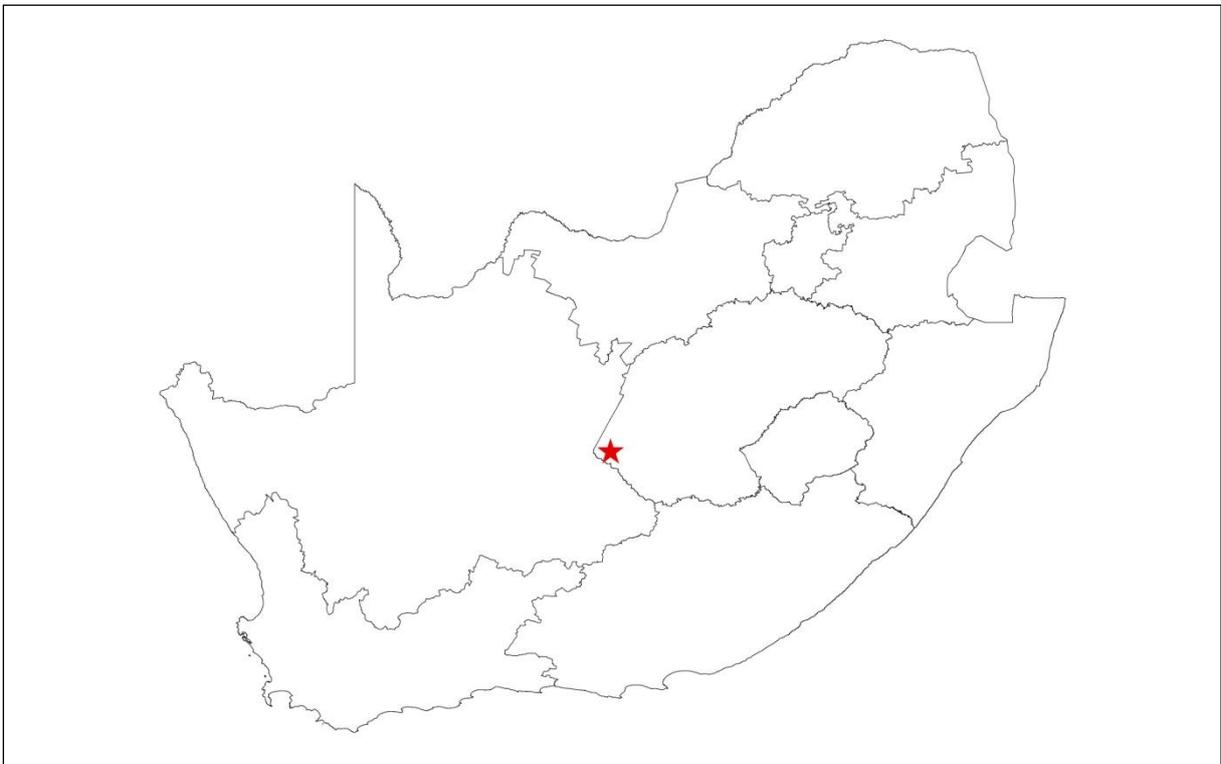


Figure 3.6 Rift Valley fever in the Luckhoff District in South Africa 1952-53

1953-54

No outbreaks of RVF were found even though several suspected outbreaks were investigated (Alexander 1955a). No further details on the suspected outbreaks could be found.

1954-55

A large number of samples for suspected RVF outbreaks were tested, but no outbreaks were found (Alexander 1955b). No further details on the suspected outbreaks were given.

1955-56

Twenty-eight outbreaks were reported from the Free State Province in the Wesselsbron, Odendaalsrus, Soutpan, Dealesville, Boshof, Hoopstad, Ventersburg and Bothaville Districts (Figure 3.7) (Alexander 1956).

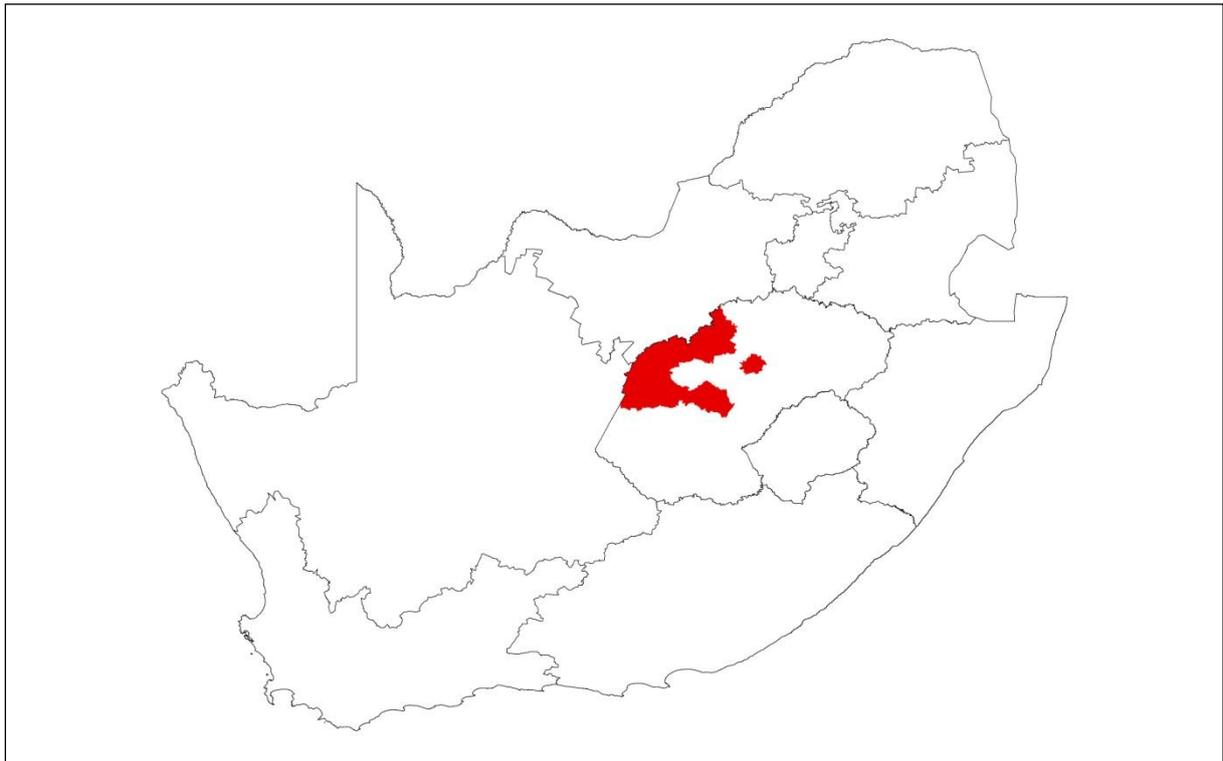


Figure 3.7 Districts affected by Rift Valley fever in South Africa during 1955-56

1956-57

The annual report for 1956-57 reports two outbreaks in the western Free State without giving more detail regarding the exact place and month (Division of Veterinary Services 1957).

1957-65

No outbreaks of RVF were reported (Division of Veterinary Services 1958; 1959; 1960; 1961; 1962; 1963; 1964; 1965).

1965-66

Two suspected outbreaks in the Free State Province could not be confirmed by the laboratory (Division of Veterinary Services 1966).

1965-66

Several suspected outbreaks were reported, but none could be confirmed (Division of Veterinary Services 1967).

1967-69

No outbreaks were reported (Division of Veterinary Services 1968; 1969).

1969-70

Severe losses occurred due to outbreaks reported from the Standerton, Frankfort, Kroonstad, Koppies, Odendaalsrus, Vryburg and the Lower Umfolozi Districts (Figure 3.8) (Division of Veterinary Services 1970).

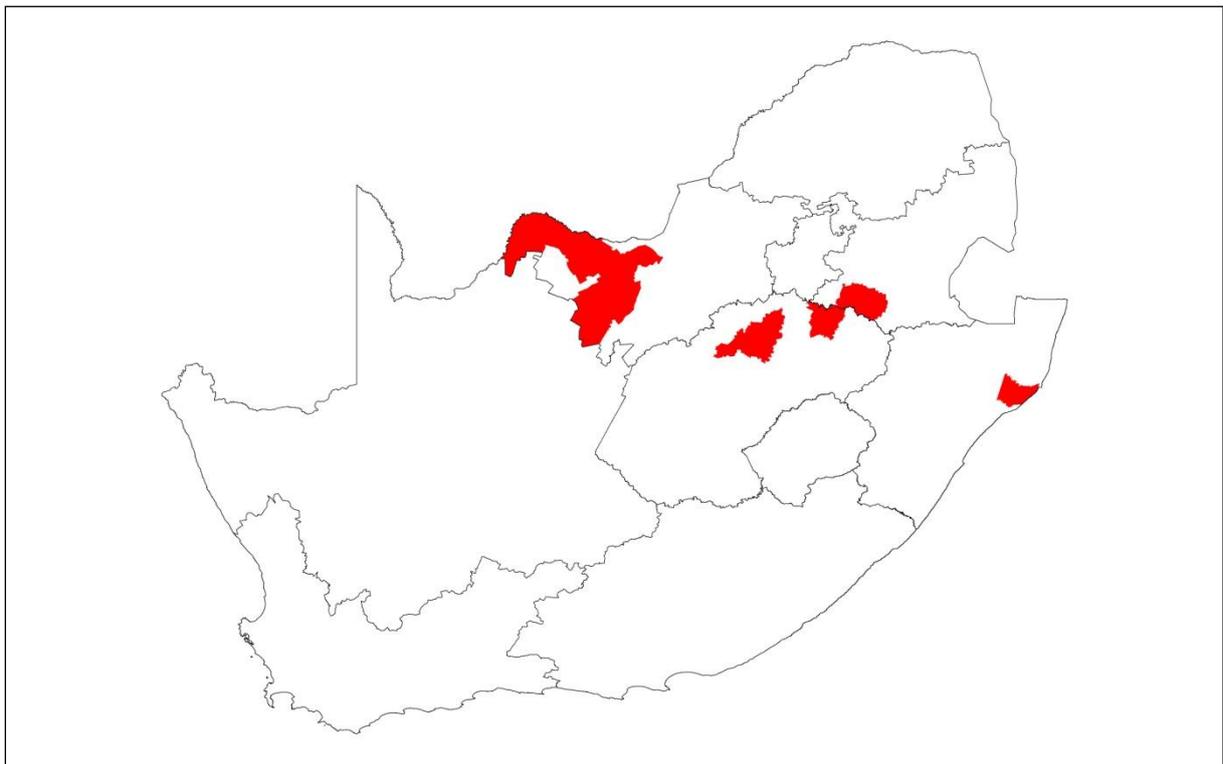


Figure 3.8 Districts affected by Rift Valley fever in South Africa during 1969-70

1970-73

No outbreaks were reported (Division of Veterinary Services 1971; 1972; 1973)

1973-74

During this period South Africa's largest RVF outbreak began. It had the largest extent, affected the most number of animals (no estimates available) and lasted three years. All areas except the winter rainfall area, Eastern Transvaal and Transvaal reported widespread occurrence of the disease (Figure 3.9). In Natal the disease only occurred in the Eshowe State Veterinary Area. The Kimberley, Bloemfontein and Fauresmith areas and the Eastern Cape and Karoo suffered severe losses due to the disease. Heavy rains and large tracts of standing water created ideal conditions for the Rift Valley fever vectors. The outbreak continued through the winter (which was warmer than average), spilling over into the next season (Division of Veterinary Services 1974).

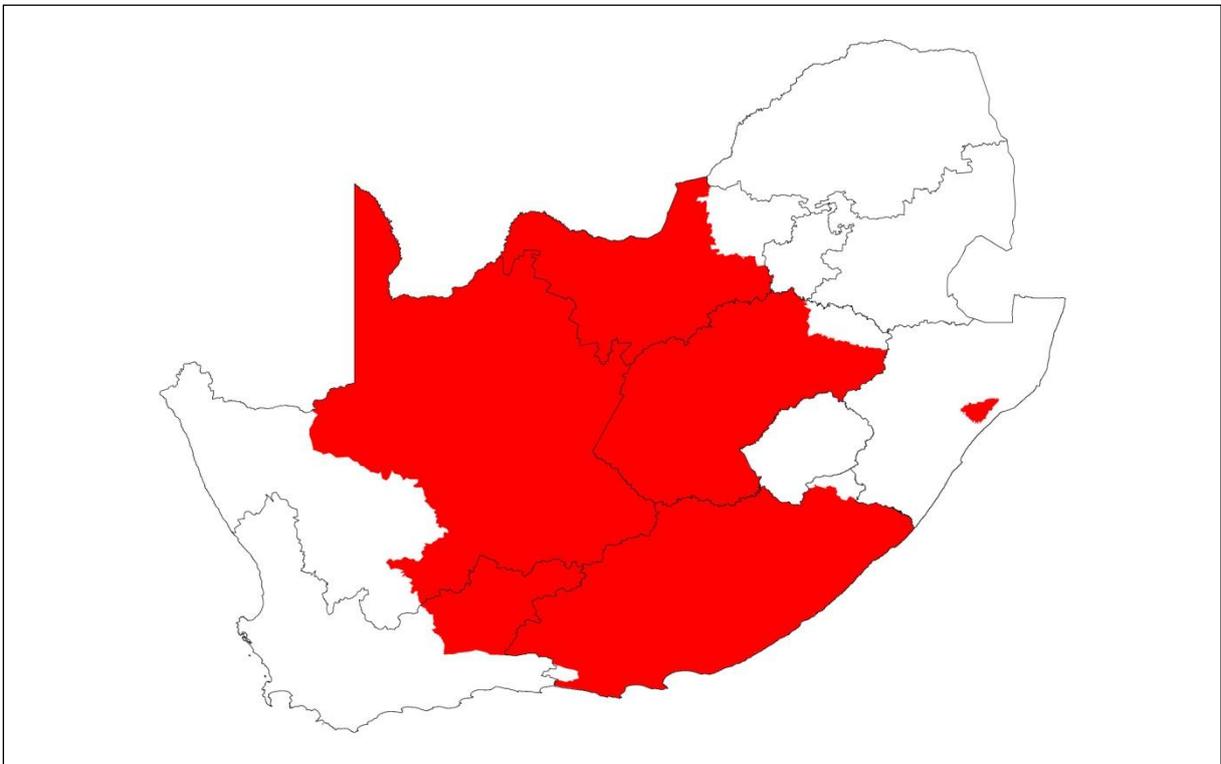


Figure 3.9 Veterinary regions and one district in Natal affected by the 1973-74 Rift Valley fever outbreak in South Africa

1974-75

The major outbreak of 1973-74 continued during this season, being most severe in the northern Western Cape, southern Orange Free State and the western parts of Transvaal. Other areas specifically mentioned were the Calvinia (September 1974) area, areas along the Orange River, the Nylrivier Valley near Potgietersrus, East Griqualand. A few cases were reported from Natal (Division of Veterinary Services 1975). Areas specifically mentioned as being affected by this outbreak in an unpublished report of the Western Cape Veterinary region (Anonymous 1976) were Steinkopf, Springbok, Brandvlei, Sutherland, Williston, Nieuwoudtville, Vredendal, Lutzville, Calvinia (February 1975), Clanwilliam, Van Rhynsdorp (October 1974), Kenhardt (September 1974), Pella (August 1974), Graafwater (May 1975) Lamberts Bay and Boesmanland (May 1975).

During this outbreak the human cases appeared to be more severe, with more complications and deaths than had previously been noted (McIntosh, Russell, Dos Santos & Gear 1980).

Barnard and Botha (1977) published a map with dots indicating reported RVF outbreaks. These can be seen as the dots on the map in Figure 3.10.

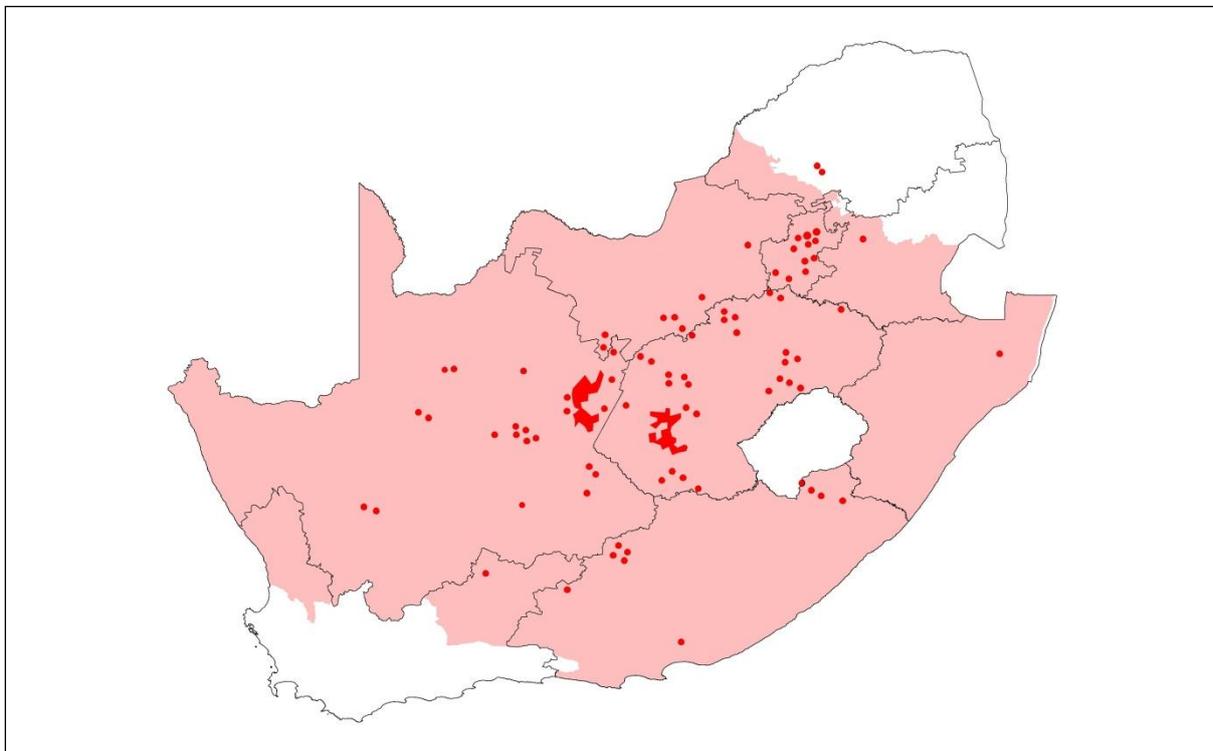


Figure 3.10 Veterinary regions (pink areas) affected by Rift Valley fever outbreak during 1974 to 1975 in South Africa (Red dots adapted from a map published by Barnard & Botha 1977).

1975-76

The outbreak continued, but with fewer losses than during the previous seasons. The Kenhardt district reported a serious outbreak towards the end of the season and a few cases were reported from the Pietermaritzburg district (Figure 3.11) No cases were reported from the Northern and Eastern Transvaal region (Division of Veterinary Services 1976a). An unpublished report of the Western Cape Veterinary region (Anonymous 1976) mentions outbreaks in the Brandvlei area.

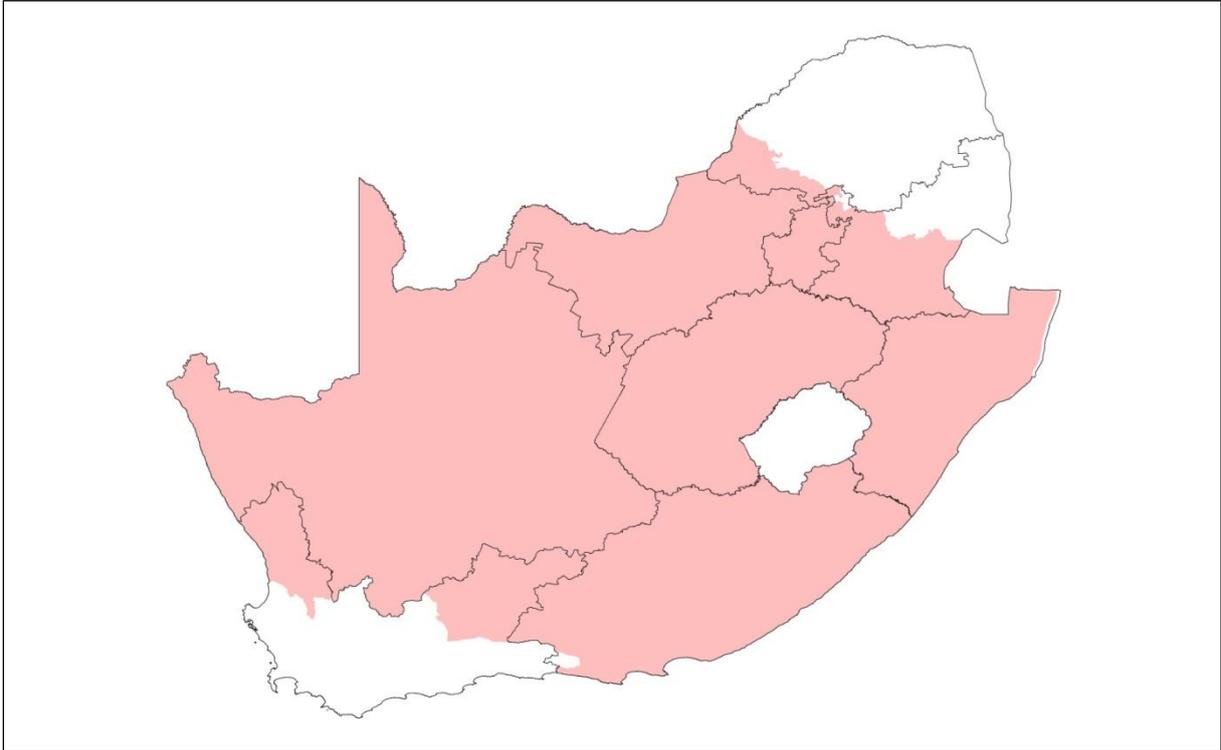


Figure 3.11 Veterinary regions affected by Rift Valley fever outbreaks during 1975 to 1976 in South Africa

1976-77

A few outbreaks were reported from the Mtunzini and Lower Umfolozi districts of Natal and the Queenstown and Middelburg areas of the Eastern Cape (Figure 3.12) (Division of Veterinary Services 1977a). The monthly disease reports (Division of Veterinary Services 1976b & 1977b) from the regional veterinary services reported the following outbreaks:

- August 1976           Gordonia in the Free State Region
- September 1976       The Vryburg district of the Free State Region
- October 1976         The Middelburg and Welkom Districts of the Free State Region
- November 1976       The Viljoenskroon district of the Highveld Region and Vryburg district of the Free State Region
- January 1977         The Queenstown district of the Eastern Cape and Karoo Region
- February 1977        The Queenstown and Middelburg districts of the Eastern Cape and Karoo Region
- March 1977            A few cases from the Eastern Cape and Karoo Region and a few suspected cases from the Free State Region

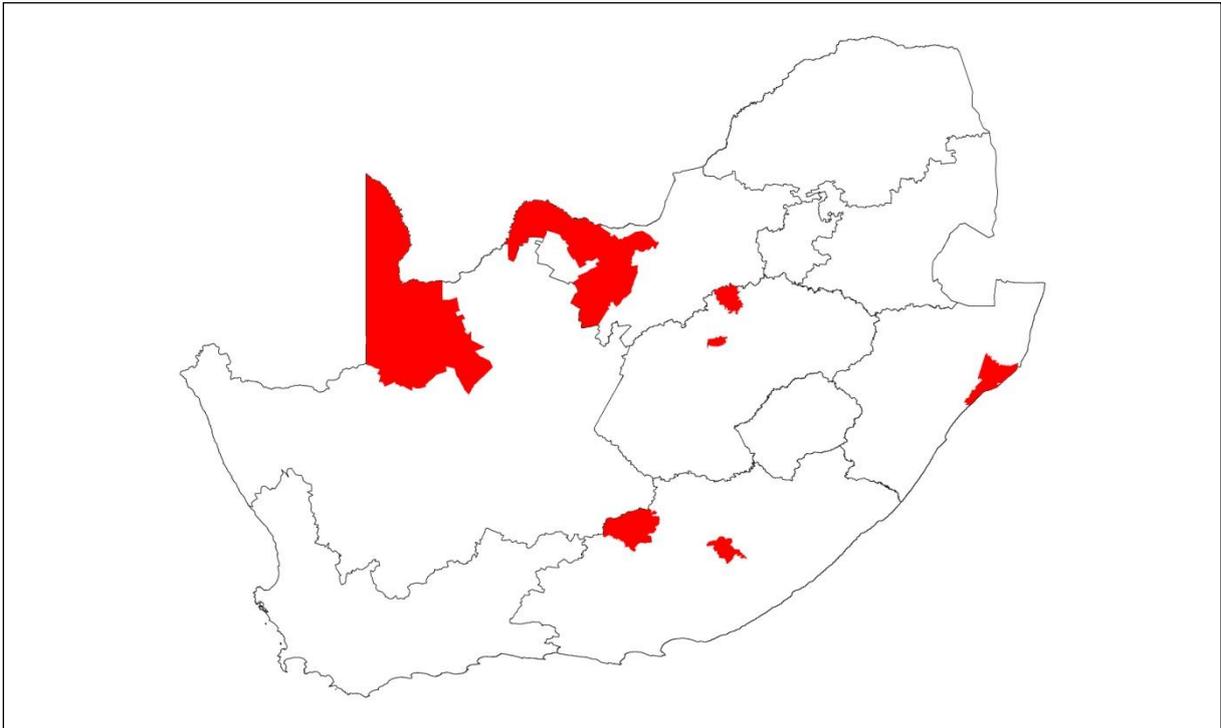


Figure 3.12 District affected by Rift Valley fever outbreaks in South Africa during 1976-77

1977-78

A few cases were reported from the Free State and the Eastern Cape and Karoo regions (Figure 3.13) (Division of Veterinary Services 1978a). The monthly disease reports from the various veterinary regions (1977b & 1978b) reported the following:

- November 1977      The Koppies district of the Free State Veterinary Region (the owner of the animals also contracted RVF)
- January 1978      Middelburg Veterinary Laboratory confirmed one case in the Eastern Cape and Karoo region
- February 1978      A private veterinarian reported a case from the Welkom district of the Free State region
- May 1978            A suspected case from Upington was reported

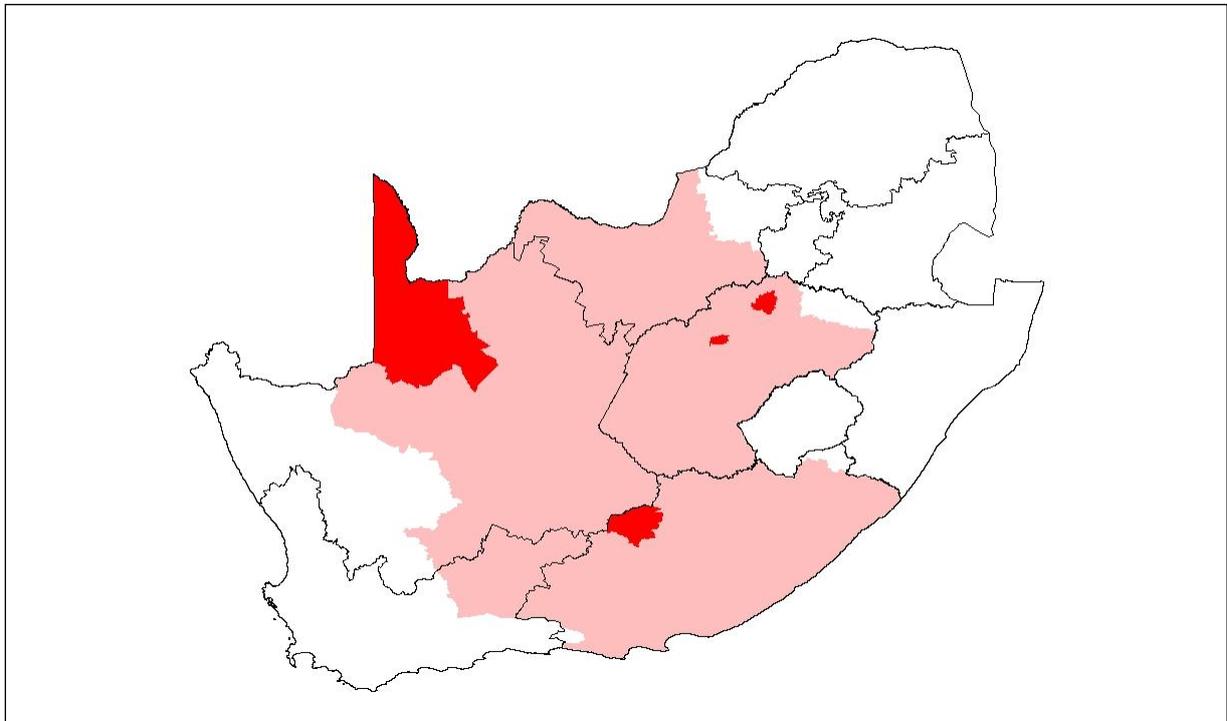


Figure 3.13 Veterinary regions (pink) and districts (red) affected by Rift Valley fever outbreaks in South Africa during 1977-78

1978-79

The monthly disease reports of the veterinary regions reported the following outbreaks (Division of Veterinary Services 1978b; 1979) (Figure 3.14):

- November 1978 Middelburg and Prieska districts of the Eastern Cape and Karoo region
- December 1978 The Pietermaritzburg and Mtonjaneni districts of the Natal region
- February 1979 The Estcourt district of the Natal region
- April 1979 The Bethlehem district of the Free State region

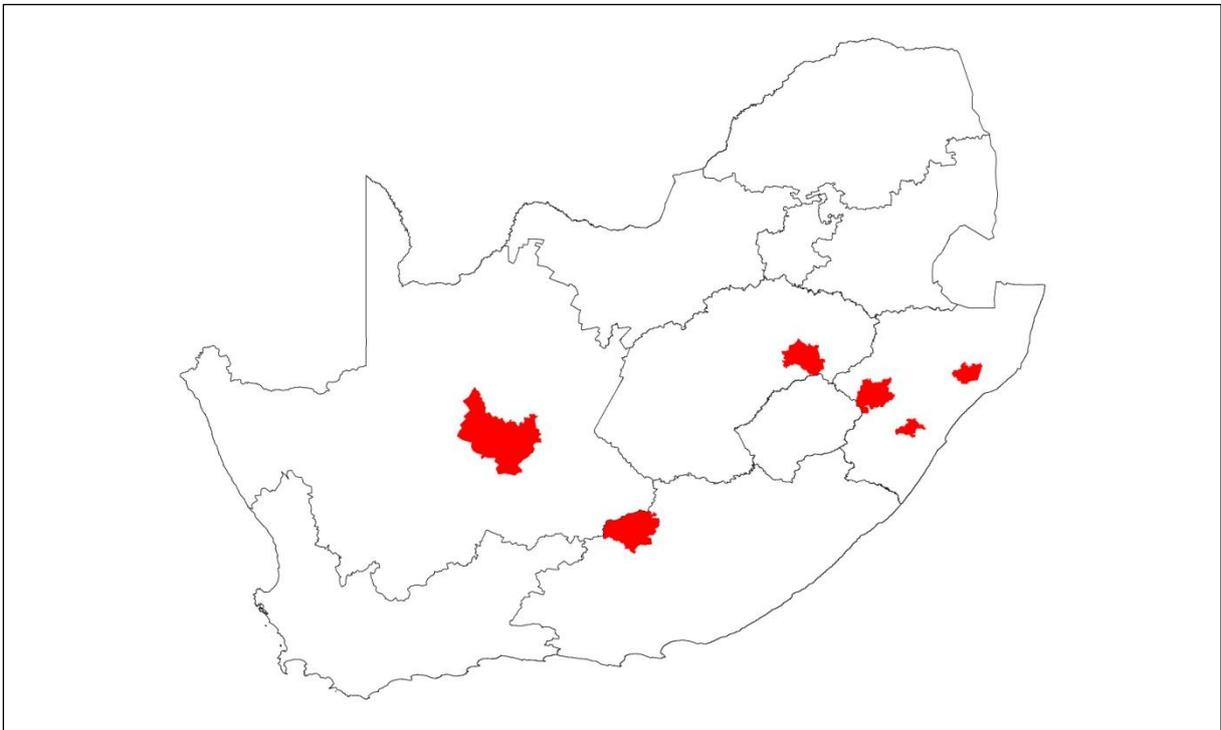


Figure 3.14 Districts affected by Rift Valley fever outbreaks in South Africa during 1978-79

1979-80

A single outbreak was reported in the Mtunzini District of Natal region (Figure 3.15) (Directorate of Animal Health 1980).

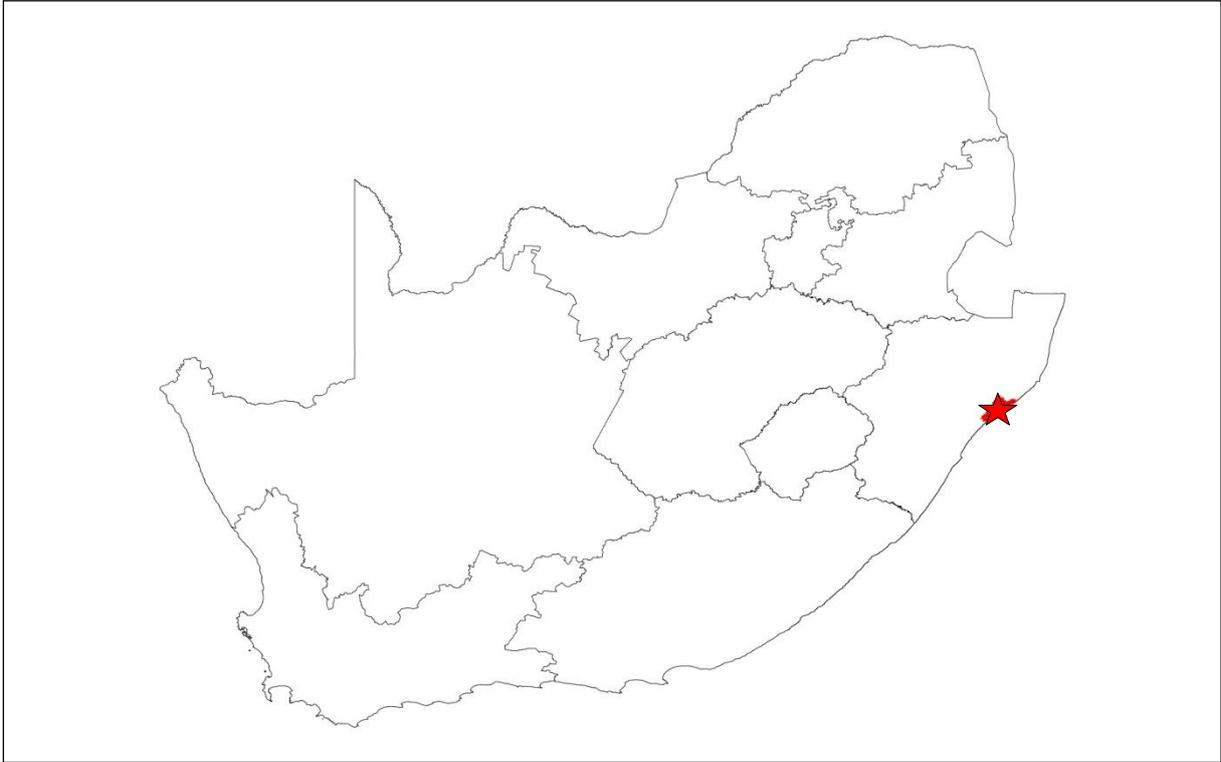


Figure 3.15 One Rift Valley fever outbreak in the Mtunzini District of South Africa during 1979-80

1980-81

Several outbreaks of RVF were reported by private veterinarians from the Highveld region, but none were laboratory confirmed (Directorate of Animal Health 1981).

1981-82

Three outbreaks were reported from the Hlabisa district in Natal, one outbreak was reported from the Eastern Cape and Karoo district and the disease also occurred in the Bethlehem and Kroonstad areas (Figure 3.16) (Directorate of Animal Health 1982). A 1982 disease report by the Directorate of Animal Health to Southern African Regional Commission for the Conservation and Utilisation of the Soil (SARCCUS) (Division of Veterinary Services 1983a) reported only one RVF outbreak, with no geographical reference, during April 1982, so it is very likely that most of the above mentioned outbreaks occurred in 1981, during the period July to December.

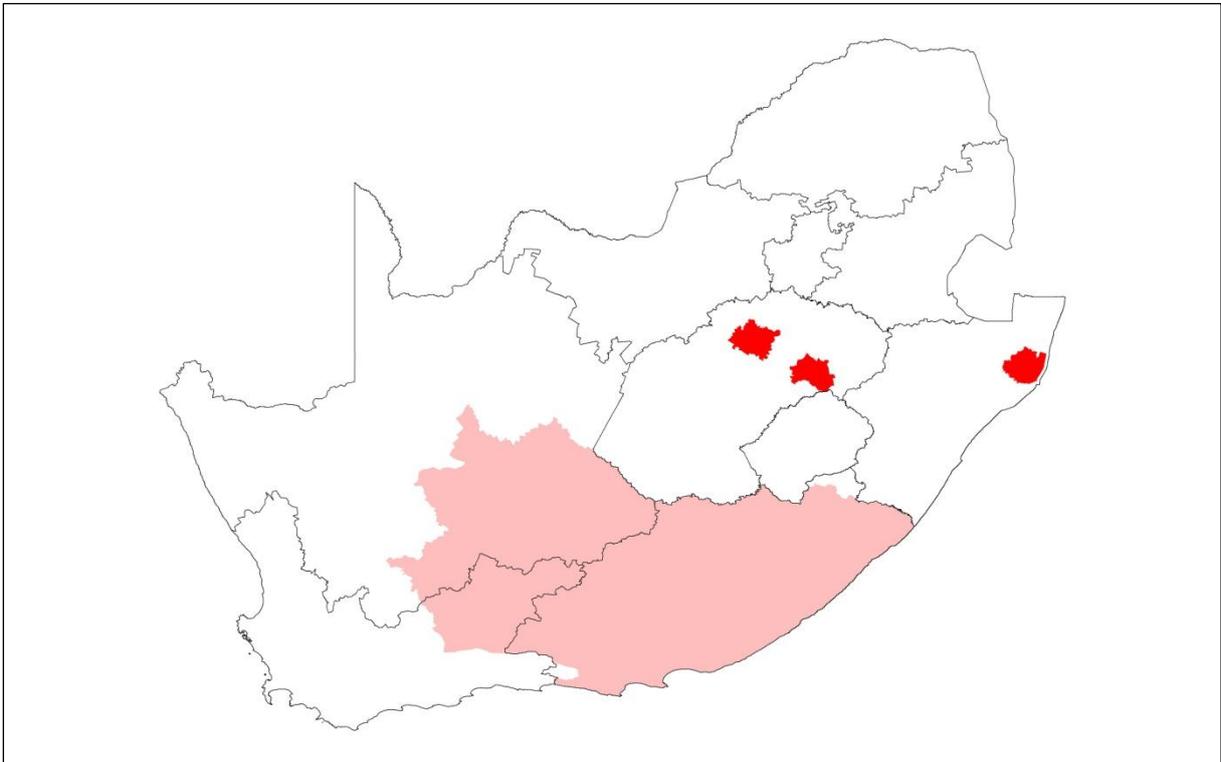


Figure 3.16 Veterinary region (pink) and districts (red) affected by Rift Valley fever outbreaks in South Africa during 1981-82

1982-83

Small outbreaks of RVF were reported from the Natal region and the Highveld region (Figure 3.17) (Division of Veterinary Services 1983b). A disease report by the Division of Veterinary Services to SARCCUS (Division of Veterinary Services 1984a) reported RVF outbreaks during March, April and June 1983.

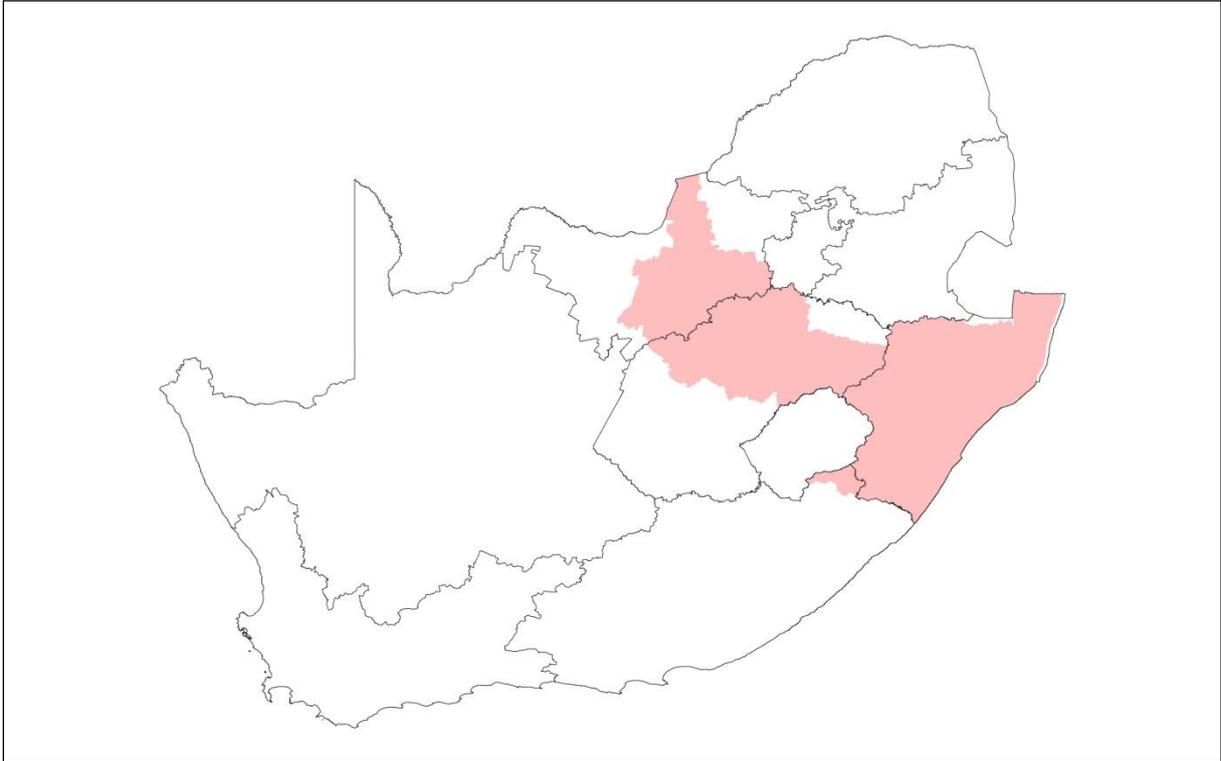


Figure 3.17 Veterinary regions affected by Rift Valley fever outbreaks in South Africa during 1982-83

1983-84

Small outbreaks of RVF were reported from the Natal region and the Western Cape region (Figure 3.18) (Division of Veterinary Services 1984b). A disease report by the Division of Veterinary Services to SARCCUS (Division of Veterinary Services 1984a) reported RVF outbreaks during October, November and December 1983, with 18 outbreaks during November 1983. The report by the Division of Veterinary Services to SARCCUS for the following year (Directorate of Veterinary Services 1985c) reported one RVF outbreak during February 1984 and one during April 1984.

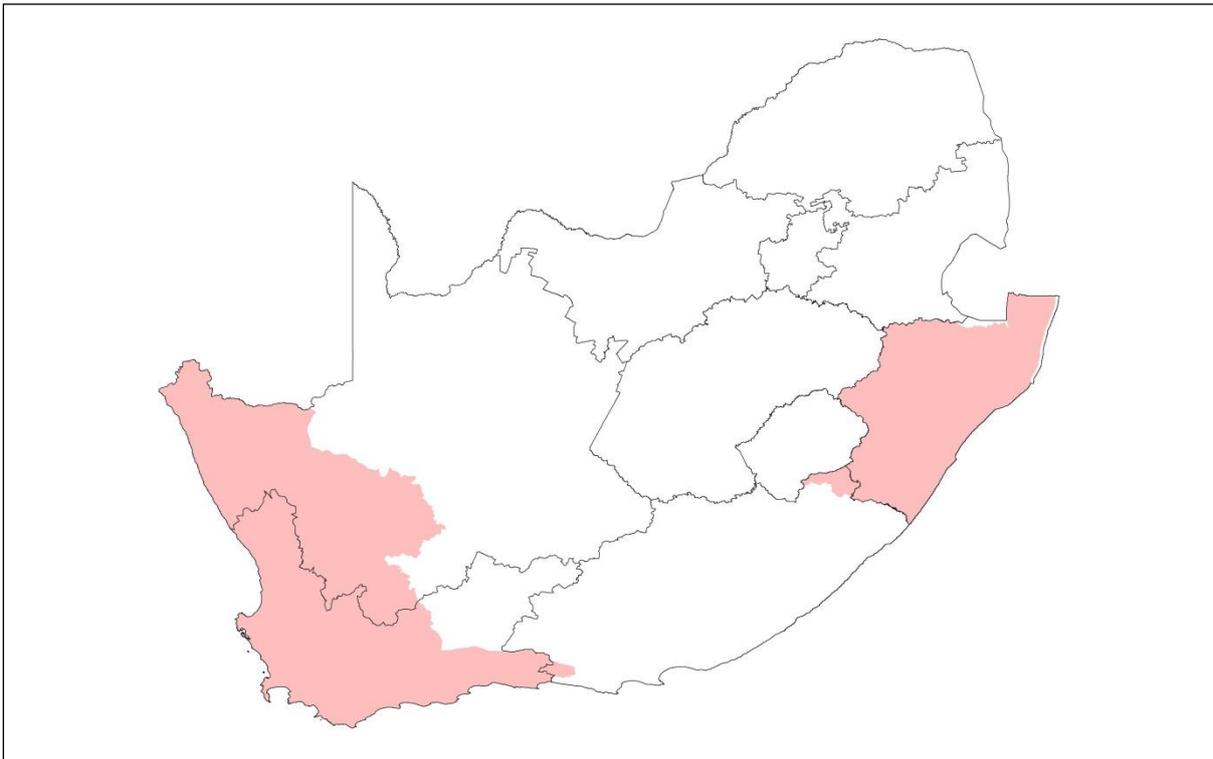


Figure 3.18 Veterinary regions affected by Rift Valley fever outbreaks in South Africa during 1983-84

1984-85

Small outbreaks of RVF were reported from the Utrecht district of Natal, the Kroonstad and Henneman Districts in the Highveld region, and a foetus sent from the Transvaal region tested positive for RVF (Figure 3.19) (Division of Veterinary Services 1985a). The report by the Division of Veterinary Services to SARCCUS for the year 1984 (Division of Veterinary Services 1985c) reported no RVF outbreaks during the period July 1984 to December 1984.

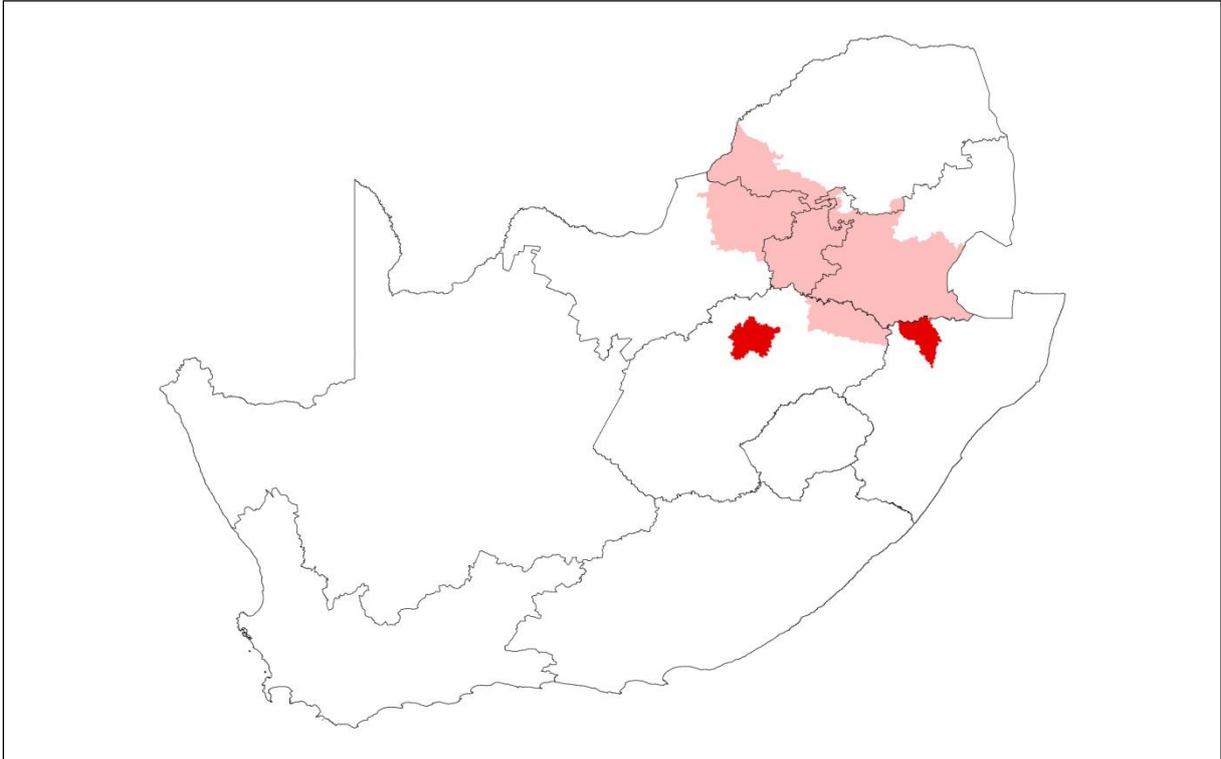


Figure 3.19 Veterinary regions (pink) and districts (red) affected by Rift Valley fever outbreaks in South Africa during 1984-85

1985-86

Thirteen outbreaks of RVF were reported from the Estcourt, Utrecht and Ubombo Districts of the Natal region (Natal 1986) and 7 outbreaks from the Port Elizabeth, Middelburg, Beaufort West, Hofmeyer and Graff Reinett districts of the Eastern Cape and Karoo region (Figure 3.20) (Eastern Cape and Karoo 1986; Directorate of Veterinary Services 1986b). The 1985 annual report to the OIE (Directorate of Veterinary Services 1985b) reports one outbreak during August 1985, without giving a geographic location. The Natal monthly report for August 1985 indicated that the outbreak in Estcourt district occurred during this month. The 1986 annual report to the OIE (Directorate of Veterinary Services 1986a) reported two outbreaks during February 1986. The Natal monthly reports (Director of the Natal region of Veterinary Services 1986a) indicate outbreaks in Ubombo during February 1986 and Hlabisa during March 1986.

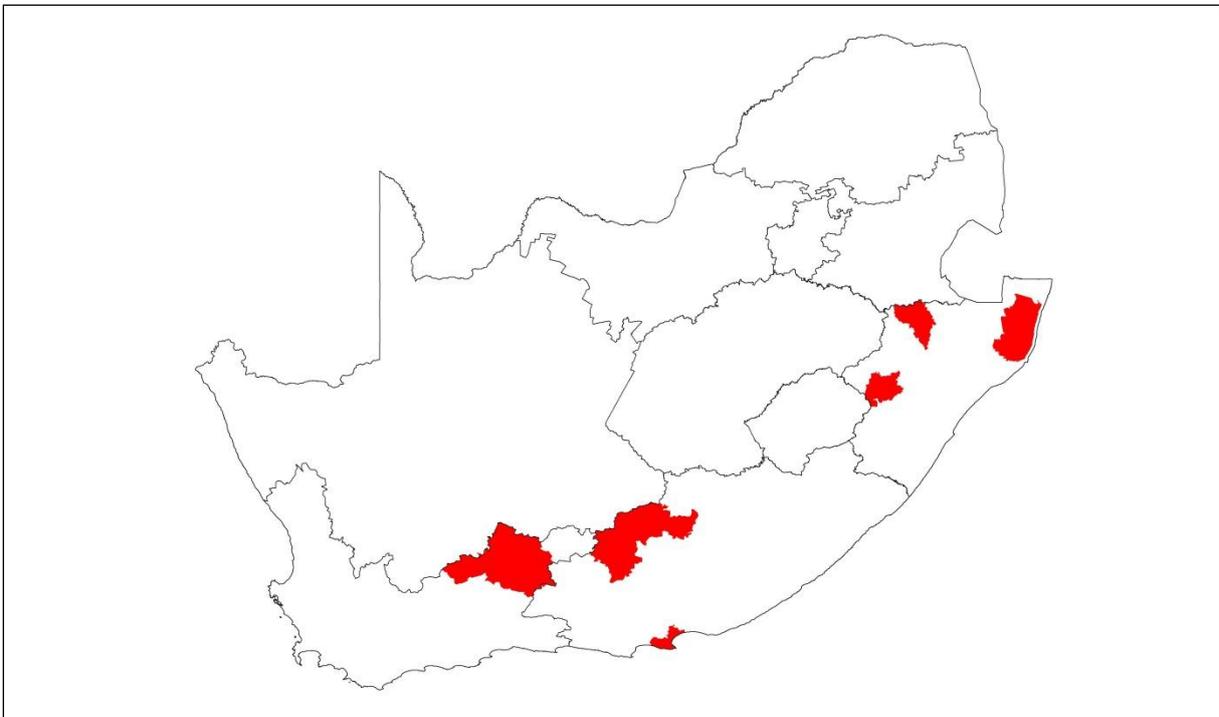


Figure 3.20 Districts affected by Rift Valley fever outbreaks in South Africa during 1985-86

1986-87

No cases of RVF were reported (Directorate of Veterinary Services 1987). The annual disease report to the OIE for 1987 reported one case in March 1987, but did not give a geographic location (Directorate of Veterinary Services 1989a) and the year of last occurrence was given as 1986.

1987-88

The annual disease report to the OIE for 1987 mentioned one case in October 1987, but did not give a geographic location (Directorate of Veterinary Services 1989b).

1988-89

Even though the climatic conditions were seemingly favourable for the disease and the veterinary services predicted outbreaks, no outbreaks were reported (Directorate of Veterinary Services 1989).

1989-90

The Directorate of Veterinary Services' report to the OIE (Directorate of Veterinary Services 1989) indicated one outbreak during the period January 1989 to March 1989, without any indication of the geographic location of the outbreak.

1990-91

During February 1991 the Estcourt district of Natal reported 5 outbreaks of RVF and the Kliprivier district of Natal reported 2 outbreaks (Figure 3.21) (Natal Veterinary region 1991).



Figure 3.21 Districts affected by Rift Valley fever outbreaks in South Africa during 1990-91

1991-1993

No outbreaks were reported during this period (Directorate of Animal Health 2010).

1993-1998

According to the Directorate of Animal Health/Veterinary Services Disease database (Directorate of Animal Health 2010), no outbreaks of RVF were reported.

1999

During January 1999 RVF was diagnosed in captive African buffalo (*Syncerus caffer*) in a boma (holding area for wildlife) at Skukuza in the Kruger National Park (Figure 3.22) (State Veterinarian Skukuza 1999; Directorate of Animal Health 2010). Six buffalo cows aborted and an investigation confirmed RVF with positive virus isolation.

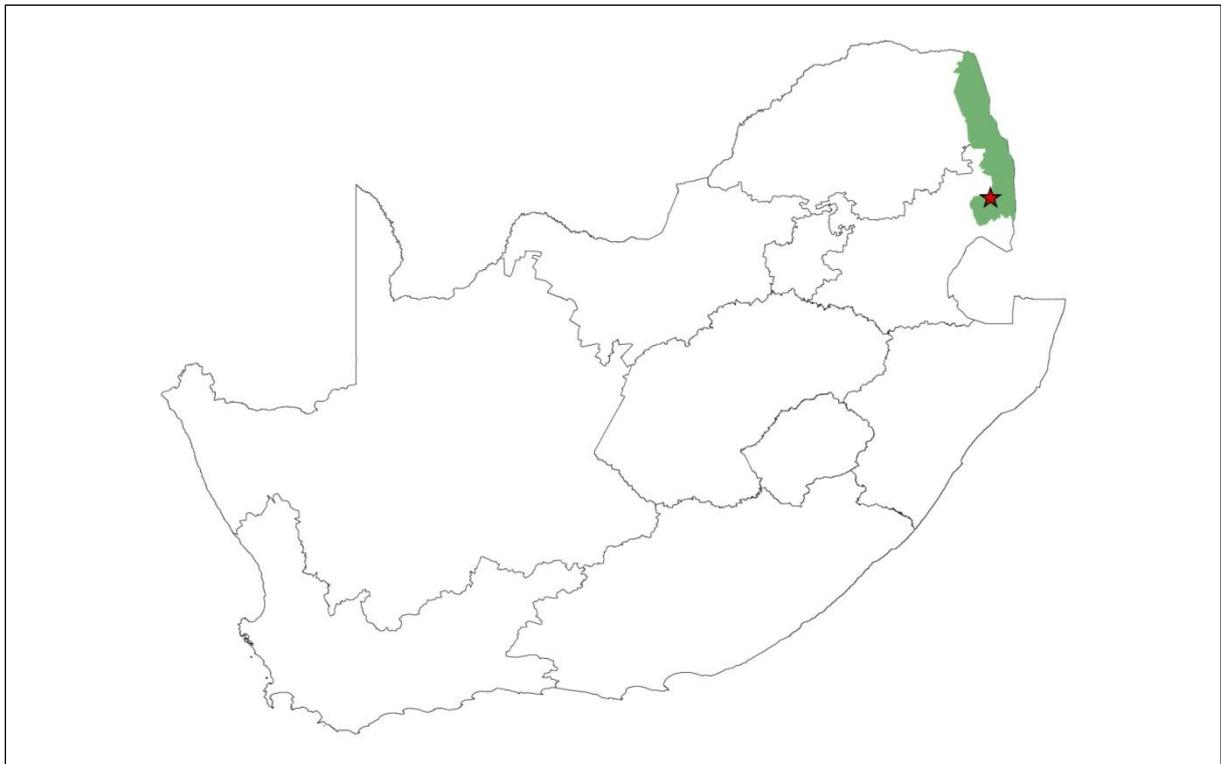


Figure 3.22 Rift Valley fever outbreak in captive African buffalo at Skukuza in the Kruger National Park during January 1999

2000-2007

No outbreaks of RVF were reported during this period (Directorate of Animal Health 2010).

2008

Between January and June 2008 RVF was reported from the Nkomazi, Mbombela and Dr JS Moroka Local Municipalities of Mpumalanga, the Bela-Bela and Ba-Phalaborwa Local Municipalities of Limpopo, the Nokeng tsa Taemane, Tshwane and Kungwini Local Municipalities of Gauteng and the Potchefstroom, Moretele and Madibeng Local Municipalities of the North West Province (Figure 3.23) (Directorate of Animal Health 2010)

A total of 15 outbreaks were reported with 353 animal cases and 103 animal deaths. The species affected were cattle, goats, sheep and African buffalo (*Syncerus caffer*) (Directorate of Animal Health 2010). The National Institute for Communicable Diseases (NICD) (2008) reported 14 human cases.

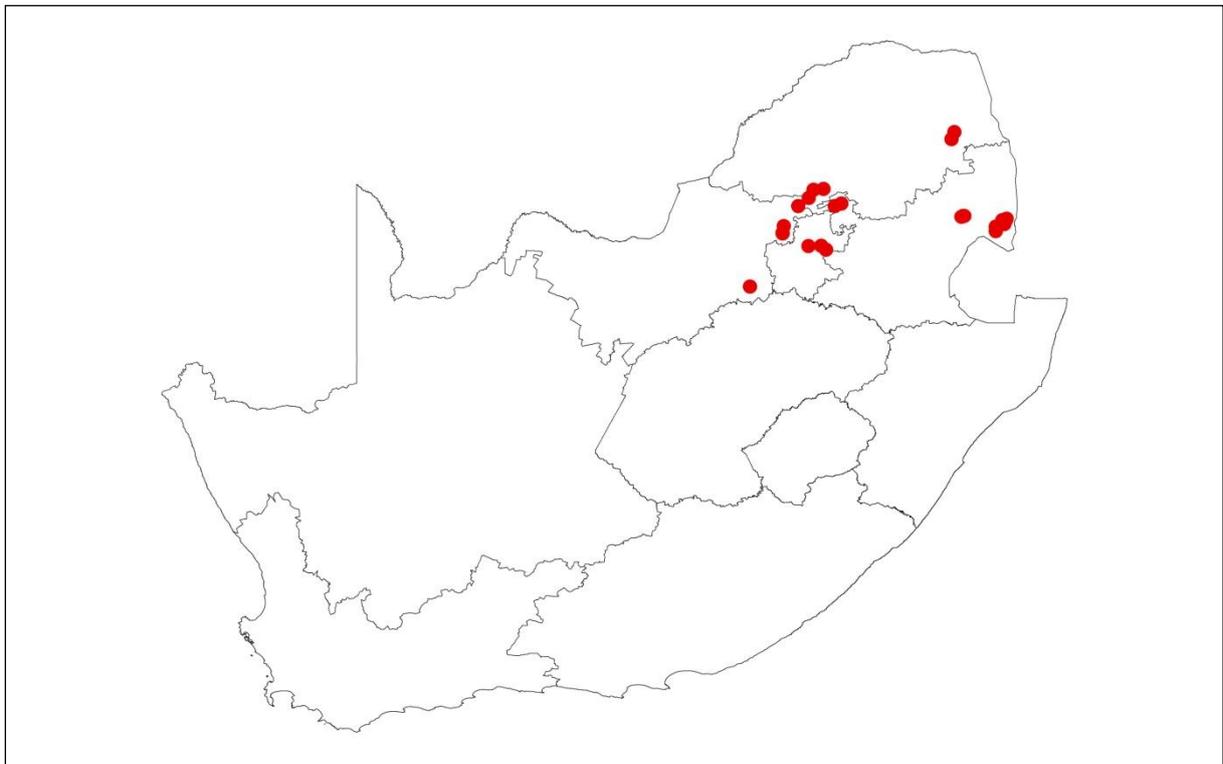


Figure 3.23 Rift Valley fever outbreaks in South Africa during 2008

2009

During February to June 2009 several outbreaks of RVF occurred in the Ingwe, Kwa Sani and uMngeni Local Municipalities of KwaZulu-Natal and the Matatiele Local Municipality of the Eastern Cape Province, and one outbreak occurred in the Mbombela Local Municipality of Mpumalanga (Figure 3.24) (Directorate of Animal Health 2010)

A total number of 19 outbreaks were reported with 210 animal cases and 66 animal deaths. The species affected were cattle and sheep ((Directorate of Animal Health 2010)



Figure 3.24 Rift Valley fever outbreaks in KwaZulu-Natal and Mpumalanga during February to June 2009

### Chapter 3: Results: Temporal and spatial history of Rift Valley fever

During October to November 2009 the Northern Cape Province experienced RVF outbreaks around the Orange River in the Kakamas region (Figure 3.25) (Directorate of Animal Health 2010).

A total number of 19 outbreaks were reported with 53 animal cases and 35 animal deaths. The species affected were cattle, sheep and goats (Directorate of Animal Health 2010). The NICD (2009) reported 7 human cases.

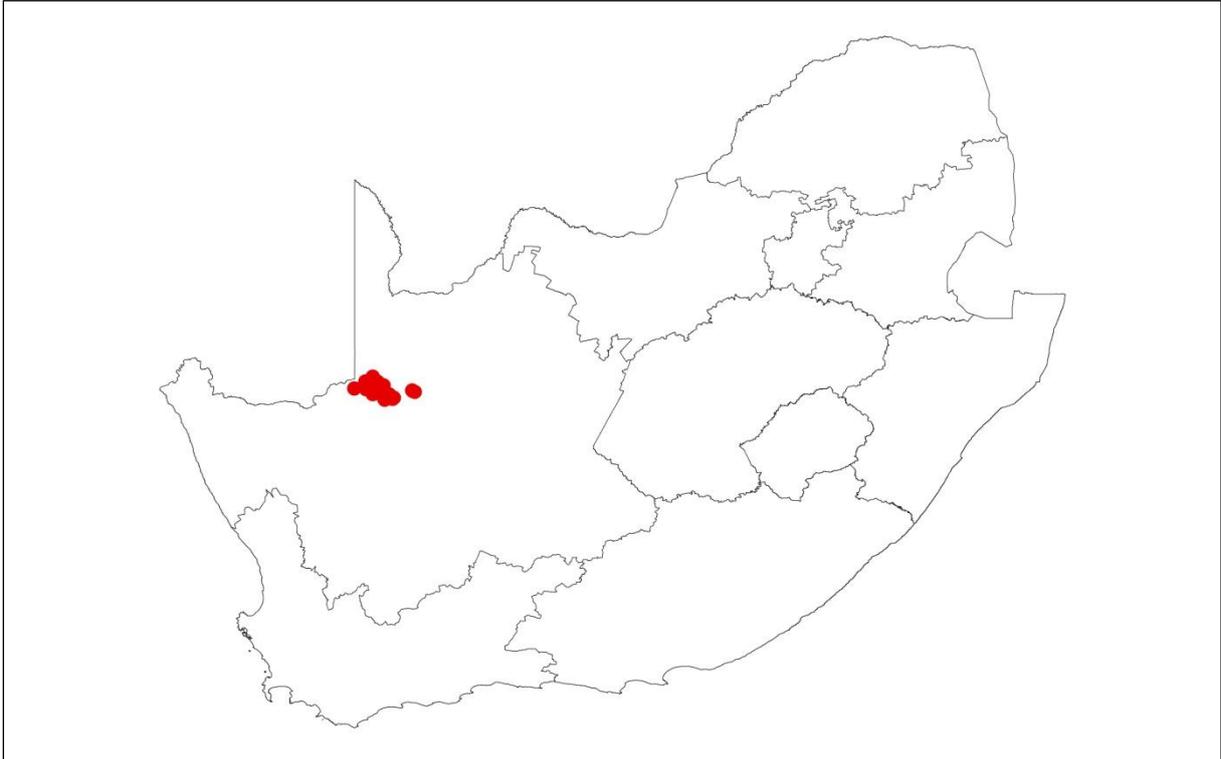


Figure 3.25 Rift Valley fever outbreaks in the Northern Cape Province during October and November 2009

2010

A major outbreak of RVF occurred during the first half of 2010. It started in the Bultfontein and Brandfort areas of the Free State Province and spread to all provinces except KwaZulu-Natal. The Free State Province, Northern Cape Province and Eastern Cape Province were the most severely affected (Figure 3.26). The outbreak started in February 2010 and continued until June 2010. For the first time in the history of RVF in South Africa, it occurred in the winter rainfall of the Western Cape Province (Directorate of Animal Health 2010).

A total of 484 outbreaks were reported with 14 342 animal cases and 8 877 animal deaths. The outbreak affected mostly sheep (13 117 cases reported) followed by cattle and goats. Indigenous wildlife that were reported to have shown signs of RVF were springbok (*Antidorcas marsupialis*), bontebok (*Damaliscus dorcas phillipsi*), waterbuck (*Kobus ellipsiprymnus*), buffalo (*Syncerus caffer*), sable (*Hippotragus niger*), nyala (*Tragelaphus angasii*), gemsbok (*Oryx gazella*), kudu (*Tragelaphus strepsiceros*) and blesbok (*Damaliscus dorcas dorcas*). Some exotic species that were affected were fallow deer (*Cervus dama*), llama (*Lama glama*), alpaca (*Lama pacos*), Asian buffalo (*Bubalus bubalis*) and ibex (*Capra ibex*). In most of these species (both indigenous and exotic) these were the first documented cases of RVF affecting these species (Directorate of Animal Health 2010).

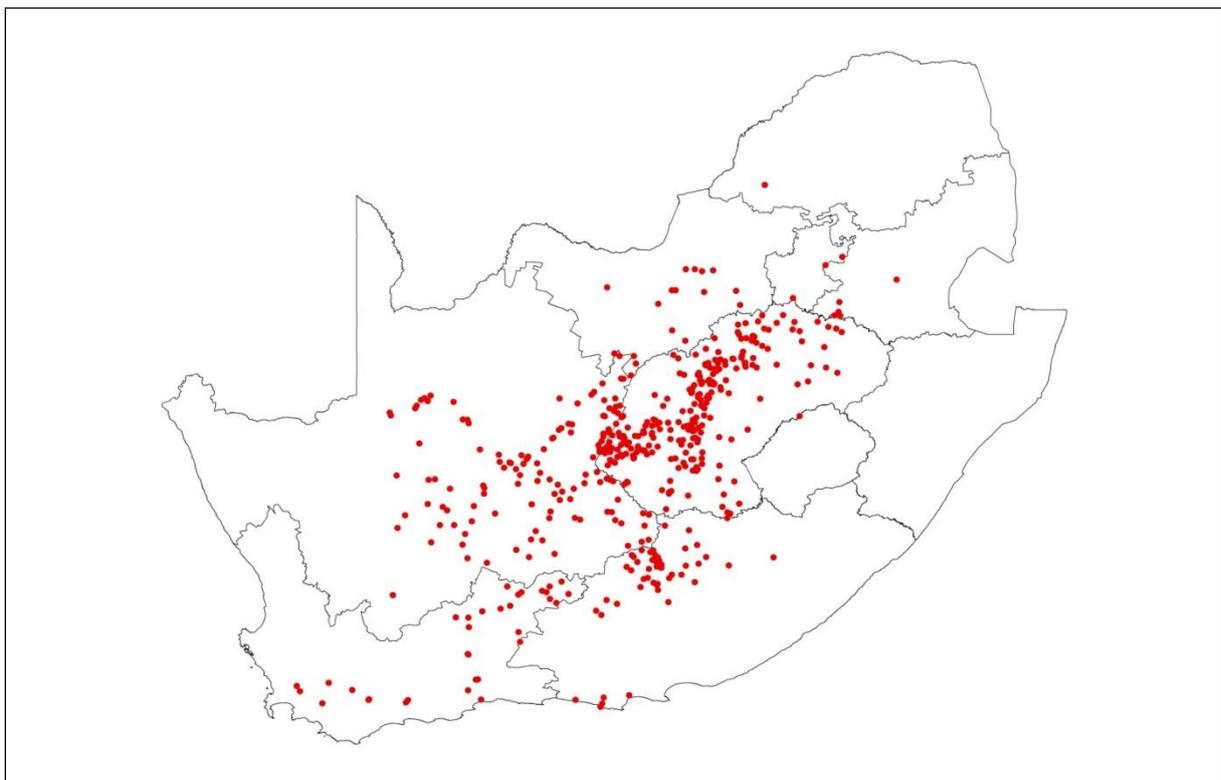


Figure 3.26 The 2010 Rift Valley fever outbreaks in South Africa

## Chapter 4 : Results: Statistical analysis of risk factors

### 4.1 Introduction

The methods used for the analysis of the created dataset were taken from Hosmer and Lemeshow (2000). Two sets of analyses were done. The first was the full multiple logistic regression analysis of all the other potential risk factors and the second was a comparison of the monthly RVF outbreaks with the Southern Oscillation Index. The first analysis consisted of creating variables to summarise or combine some of the variables, selecting appropriate variables, univariable logistic regression of the selected variables, selection of the significant variables, building the model and analysing the model.

### 4.2 Risk factor analysis

#### 4.2.1 Univariable analysis

The crude (univariable) associations between each of the independent variables (potential risk factors) and the outcome (Rift Valley fever outbreaks) were estimated using simple logistic regression. Table 4.1 gives the results of the univariable analysis for each of the selected variables.

Table 4.1 Univariable associations between potential risk factors and the occurrence of Rift Valley fever outbreaks in South Africa, 1950-2010

Variable and category	Odds Ratio (OR)	95% Confidence Interval for OR	P-value
Cumulative number of RVF outbreaks recorded in block <sup>a</sup>	1.02	1.00, 1.05	0.03
Rift Valley fever occurred in South Africa during the last 3 years <sup>a</sup>			
No	1 <sup>b</sup>	–	–
Yes	2.66	2.35, 3.00	<0.001
Rift Valley fever occurred in neighbouring countries during the last 3 years <sup>a</sup>			
No	1 <sup>b</sup>	–	–
Yes	0.72	0.64, 0.80	<0.001

Rift Valley fever occurred in Kenya during the last 3 years <sup>a</sup>			
No	1 <sup>b</sup>	–	–
Yes	0.41	0.37, 0.45	<0.001
Five month running average of the Southern Oscillation Index <sup>a</sup>	1.54	1.47, 1.61	<0.001
Biome <sup>a</sup>			
Albany Thicket Biome	1 <sup>b</sup>	–	–
Fynbos Biome	0.20	0.13, 0.32	<0.001
Grassland Biome	1.05	0.78, 1.39	0.761
Indian Ocean Coastal Belt	0.72	0.43, 1.22	0.222
Nama-Karoo Biome	1.38	1.04, 1.85	0.027
Savanna Biome	0.69	0.52, 0.93	0.014
Succulent Karoo Biome	0.54	0.37, 0.77	0.001
Presence of waterbodies <sup>a</sup>	0.86	0.70, 1.05	0.135
Area covered by wetlands <sup>a</sup>	1.00	1.00, 1.00	<0.001
Presence of pans <sup>a</sup>			
No	1 <sup>b</sup>	–	–
Yes	1.85	1.67, 2.06	<0.001
Large perennial river present			
No	1 <sup>b</sup>	–	–
Yes	1.01	0.91, 1.13	0.843
Concentration of cattle <sup>a</sup>	1.00	0.99, 1.00	0.158
Concentration of goats <sup>a</sup>	1.01	1.00, 1.01	0.108
Concentration of sheep <sup>a</sup>	1.00	1.00, 1.00	<0.001
Winter rainfall area <sup>a</sup>			
No	1 <sup>b</sup>	–	–
Yes	0.29	0.22, 0.37	<0.001
Number of months above average rainfall <sup>a</sup>	1.29	1.25, 1.32	<0.001
Three consecutive months of above average rainfall <sup>a</sup>			
No	1 <sup>b</sup>	–	–
Yes	1.83	1.65, 2.04	<0.001
High rainfall during the first 6 months of the season <sup>a</sup>			

No	1 <sup>b</sup>	–	–
Yes	0.61	0.33, 1.12	0.111
More than double the average rainfall during December, January and February <sup>a</sup>			
No	1 <sup>b</sup>	–	–
Yes	10.57	8.98, 12.45	<0.001
Average rainfall of the previous season <sup>a</sup>			
	1.00	0.99, 1.00	0.006
Average maximum temperature cooler than 60 year average <sup>a</sup>			
No	1 <sup>b</sup>	–	–
Yes	1.72	1.55, 1.91	<0.001
Average minimum temperature difference <sup>a</sup>			
	0.88	0.85, 0.92	<0.001

<sup>a</sup> Variable associated with outcome ( $P < 0.25$ ), therefore selected for inclusion in the multiple logistic regression model

<sup>b</sup> Reference category

From Table 4.1 it can be seen that all variables except the variable indicating the presence of a large perennial river met the requirement of a  $P$ -value of less than 0.25 for inclusion into the multivariable model. During univariable analysis the variable indicating high rainfall during the summer months (December, January and February) showed the strongest association with the outcome ( $OR = 10.57$ ;  $P < 0.001$ ).

Absolute values of the correlation coefficients for pairwise correlations between the selected predictor variables were all less than 0.7, therefore no variables were dropped because of potential collinearity.

#### **4.2.2 Linearity**

The assumption of linearity in the logit was tested for all selected continuous variables using the **lincheck** function in STATA (Gamma 2005). Due to non-linearity, the following variables were recoded into categorical variables:

- Cumulative number of RVF outbreaks [rvf\_cumulative] was recoded into a binary variable [RVFprevOutbreaksYN] indicating whether or not a RVF outbreak had previously occurred in the block

- Southern Oscillation Index 5 month running average [soi5avg] was recoded into a categorical variable [soi5avg\_cat] with [soi5avg]<-0.5 as 0, between -0.5 and 0.5 as 1 and larger than 0.5 as 2.
- Average number of cattle [avg\_cattlesqkm] was recoded into a categorical variable [cattle\_cat] recoding 0 to 0, between 0 and 20 to 1 and more than 20 to 2.
- Average number of sheep [avg\_sheepsqkm] was made categorical [sheep\_cat] by recoding between 0 and 10 to 0, more than 10 to 1 and more than 50 to 2.
- The previous season's rainfall [prev\_season\_rain\_avg] was replaced with a binary variable [prev\_high\_rain] indicating that the previous season's rainfall was higher than the 60 year average for the block.
- The variable indicating the surface area of wetlands [wetlandsNOTpans] was replaced with a categorical variable [wetlands\_cat] where 0 equals 0, between 0 and the median equals 1 and above the median equals 2.

#### **4.2.3 Multiple logistic regression model**

The list of predictors entered into the maximum multiple logistic regression model was as follows:

- Cumulative number of RVF outbreaks recorded in block
- Rift Valley fever occurred in South Africa during the last 3 years
- Rift Valley fever occurred in neighbouring countries during the last 3 years
- Rift Valley fever occurred in Kenya during the last 3 years
- Five month running average of the Southern Oscillation Index
- Biome
- Presence of water bodies
- Area covered by wetlands
- Presence of pans
- Concentration of cattle
- Concentration of goats
- Concentration of sheep
- Winter rainfall area
- Number of months above average rainfall
- Three consecutive months of above average rainfall
- High rainfall during the first 6 months of the season
- More than double the average rainfall during December, January and February
- Average rainfall of the previous season
- Average maximum temperature cooler than 60 year average
- Average minimum temperature difference

To develop the final logistic regression model, variables with a Wald  $P > 0.05$  were sequentially dropped from the model, each time dropping the variable with the highest  $P$ -value. The variables remaining significant in the model were as follows:

- Number of months that experienced above average rainfall
- Biome
- Presence of wetlands
- Presence of pans
- More than double the average rainfall during December, January and February
- Maximum temperatures for the season was cooler than the average
- Minimum temperatures for the season was cooler than the average

#### **4.2.3.1 Check for interaction**

Interaction or effect modification occurs when the effect of one variable on the outcome is dependent on the level of another variable (Hosmer & Lemeshow 2000). Amongst the abovementioned predictors there are several possibilities for interaction to occur. However, the only two biologically plausible interactions that were investigated were:

- The occurrence of pans [pansYN] may modify the effect of rainfall [HighRainSummer] on the occurrence of RVF, or vice-versa
- The occurrence of wetlands [wetlandsYN] may modify the effect of rainfall [HighRainSummer] on the occurrence of RVF, or vice-versa

Neither of these two interaction terms were significant, and were therefore not included in the final model.

The final multiple logistic regression model is given in Table 4.2 below.

Table 4.2 Final logistic regression model for factors influencing the occurrence of RVF outbreaks in South Africa (without interactions) with robust variance estimation ( $n = 18112$  observations)

	Odds Ratio (OR)	95% Confidence Interval for OR	P-value
Number of months that experienced above average rainfall	1.24	1.03, 1.50	0.03
<b>Biome</b>			
Albany Thicket Biome	1 <sup>a</sup>	–	–
Fynbos Biome	0.17	0.06, 0.50	<0.001
Grassland Biome	0.73	0.41, 1.30	0.28
Indian Ocean Coastal Belt	0.54	0.12, 2.34	0.41
Nama-Karoo Biome	0.92	0.56, 1.51	0.75
Savanna Biome	0.54	0.31, 0.92	0.03
Succulent Karoo Biome	0.38	0.12, 1.27	0.12
<b>Presence of wetlands</b>			
No	1 <sup>a</sup>	–	–
0 to median	1.42	0.90, 2.23	0.13
Median to maximum	1.92	1.27, 2.89	<0.001
<b>Presence of pans</b>			
No	1 <sup>a</sup>	–	–
Yes	1.62	1.17, 2.24	<0.001
<b>More than double the average rainfall during December, January and February</b>			
No	1 <sup>a</sup>	–	–
Yes	6.94	2.70, 17.84	<0.001
<b>Maximum temperatures for the season was cooler than the average</b>			
No	1 <sup>a</sup>	–	–
Yes	1.43	1.23, 1.65	<0.001
Minimum temperatures for the season was cooler than the average	0.84	0.75, 0.95	<0.001

<sup>a</sup> Reference category

#### **4.2.4 Assessment of multiple logistic regression model**

##### **4.2.4.1 Goodness-of-fit**

Hosmer and Lemeshow (2000) define goodness-of-fit as how effectively the model describes the outcome variable. The Hosmer-Lemeshow goodness-of-fit  $X^2$  statistic was 35.57 (8 d.f.) ( $P < 0.001$ ). The significant result indicated that the data did not fit the model well. This is very likely due to the fact that there are such a large number of factors that might have an influence on RVF outbreaks and that several important factors, for example vector distribution and the vaccination status of the animals, were not accounted for in the model.

##### **4.2.4.2 ROC curve**

The ROC curve for the final multiple logistic regression model is shown in Figure 4.1. The diagonal line indicates a model that predicts the outcome no better than pure chance. The higher the curve and the further away it is from the line, the greater the area under the ROC curve (AUC) and the better the model will be at discriminating between the categories of the outcome. Hosmer and Lemeshow (2000) indicate that an AUC of between 0.8 and 0.9 is considered as excellent discrimination. The AUC of 0.720 indicates that the model has moderate discrimination.

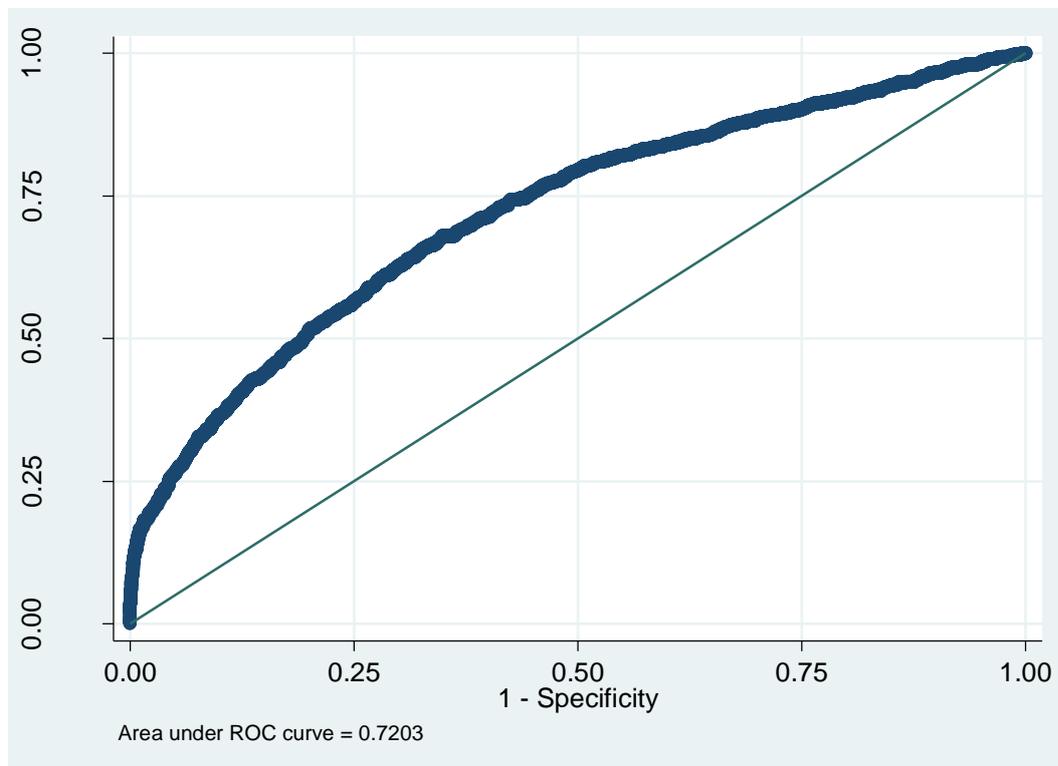


Figure 4.1 ROC curve for the prediction of Rift Valley fever outbreaks using the logistic regression model

### **4.3 Month by month analysis of the effect of SOI on RVF outbreaks**

The monthly Southern Oscillation Index (U. S. A. National Oceanic and Atmospheric Administration's Climate Prediction Centre 2010) and 5 month running average of the SOI were tested for association with the occurrence of RVF on a month by month basis. A separate dataset was created for this part of the study. Where the literature (as discussed in Chapter 3) indicated the months during which the outbreaks occurred, these were noted. Where the reference only indicated the season, the whole season was left out of the dataset. A simple logistic regression analysis was performed to determine the effect on the 5 month running average of the SOI on the occurrence of RVF outbreaks in South Africa and the results are shown in Table 4.3.

Table 4.3 Simple logistic regression model of the association between Southern Oscillation Index and the occurrence of Rift Valley fever outbreaks in South Africa ( $n = 440$  observations)

	Odds Ratio (OR)	95% Confidence Interval for OR	P- value
5 month running average of SOI	1.18	1.01, 1.38	0.031

Hosmer-Lemeshow goodness-of-fit  $X^2 = 6.2$  (8 d.f.),  $P = 0.6247$

There was a significant positive association between 5 month running average SOI and the odds of one or more RVF outbreaks occurring, indicating that the higher the SOI, the higher the chance of RVF occurring in South Africa. This is the opposite of the situation in Kenya as described by Anyamba, Linthicum and Tucker (2001) and agrees with findings on the effect of the SOI on the incidence of malaria in Southern Africa (Mabaso *et al.* 2006).

## Chapter 5 : Discussion

### **5.1 Temporal and spatial history of Rift Valley fever**

The search for documented outbreaks of RVF in South Africa yielded very useful results. For the first time the location and season of all the recorded RVF outbreaks in South Africa were documented. This will facilitate further research into the epidemiology of the disease in South Africa and will promote a better understanding of the disease. Hopefully this will result in better preparedness for the disease and also better response to outbreaks and in turn limit the loss of livestock and human life.

Several smaller outbreaks, which are not recorded in the literature, were documented during this study. This clearly illustrated that the occurrence of RVF is more frequent and more widespread than what is generally accepted. The reason for this is most likely the fact that the disease is often absent for very long periods and new farmers and veterinarians do not realise that an area experienced outbreaks in the past. It emerged that large outbreaks occur in the Free State Province, Eastern Cape Province and Northern Cape Province with long periods of absence and smaller outbreaks occur in KwaZulu-Natal, Mpumalanga and Gauteng at more frequent intervals.

This study will improve the knowledge base on the possible geographical distribution of the disease. Since the disease is vector borne and it is not fully understood yet, it will not be possible to eradicate this disease, so the cycle of forgetting and then experiencing a large outbreak will repeat itself. The occurrence of a large outbreak in 2010 will make farmers and veterinarians aware of the disease for several years to come, but it will likely disappear again and be forgotten in the future. This study can be used in the future to motivate vaccination programs during long periods of absence.

From the investigation of the month during which outbreaks occur it would seem as if most outbreaks occur during or after January. Where outbreaks occurred before January, it usually followed outbreaks late during the previous season, in other words the outbreak “survived” the winter. This was very well documented during the 1974-76 outbreak, where outbreaks occurred throughout the winter of 1975 and continued into the next season.

From the results, it is very clear that certain areas are more prone to RVF outbreaks. This agrees with studies done in Kenya (Murithi et al. 2010) where certain districts were identified

as being more prone to outbreaks. Districts where outbreaks occurred in the past were 5 times more likely to experience another outbreak. In South Africa this pattern also emerges, with one distinct difference: small outbreaks occur in the eastern part of the country (KwaZulu-Natal, Mpumalanga and Gauteng) and large epizootics occur in the central part of the country (Free State Province, Eastern Cape Province and Northern Cape Province). Outbreaks often occurred in both these areas during the same season, but several times the outbreaks in the eastern part of the country were apparently not associated with large outbreaks in the central region, e.g. 1991, 2008 and 2009. Reasons for this could not be identified during this study, but a possible explanation could be that different vectors are responsible for outbreaks of the disease in these two parts of the country (Jupp 2004).

The literature did not give enough detail on the spread of RVF within a season, but from the 2010 outbreak it is clear that the disease spreads from one area to the next once a large outbreak is triggered. A plausible explanation for this could be that the enzootic vectors triggers the outbreak and it is then spread by the epizootic vectors (Swanepoel 2009). Factors like animal movement could also play an important role in the spread of the disease during an epidemic.

From the results it also becomes evident that after a large epidemic, like the ones experienced during 1950-51 and 1974-76, outbreaks continue to occur for several years after the epidemic. This would indicate that South Africa may experience more outbreaks over the next few years in the wake of the 2010 outbreak.

## **5.2 Rainfall**

The rainfall factor that had the strongest association with the outcome was the variable indicating more than double the average rainfall for December, January and February. During the univariable analysis this was associated with the odds of having a RVF outbreak increasing by more than 1000% ( $OR = 10.6$ ). In the multivariable model, adjustment for the confounding effect of other variables reduced the magnitude of this association to  $OR = 6.9$ , which was nevertheless still a strong and highly significant effect. Similarly, the variable indicating the number of months that experienced above average rainfall during the season was shown to have a significant effect on the occurrence of RVF outbreaks during the season.

This agrees with the view that RVF outbreaks are caused by high rainfall events (Swanepoel & Coetzer 2004; Gerdes 2004). An important conclusion that can be drawn from this result,

which has not been published before, is the period during which the high rainfall should occur. High rainfall during any other combination of months did not show a similar strong association with the outcome. This therefore indicates that a high rainfall during December, January and February increases the likelihood for a RVF outbreak to occur in areas where the other factors are favourable. This increased likelihood during a certain part of the year could be related to the cycle or breeding requirements of the vectors with regard to, for example, temperature.

### **5.3 Pans and wetlands**

Areas with pans or wetlands present were shown to be more likely to experience outbreaks. This agrees with the literature regarding the endemic cycle of the disease as described by Swanepoel (2004). Swanepoel speculates that the virus survives during the inter-epidemic period through trans-ovarial transmission in *Aedes* sp. which is known to occur in the pans of the Western Free State Province (Jupp 2004). Several of the annual reports and reports in the literature mention that the disease is associated with the pans of the Free State Province and the Northern Cape (Alexander 1951; Van der Linde 1953; Gear *et al.* 1955). If it were possible to determine where each outbreak had started, this would very likely have been strongly associated with the presence of pans or wetlands.

It can be concluded that the large epidemics are triggered around the pans by the *Aedes* sp. mosquitoes and are then propagated by other mosquito species, associated with other water bodies like wetlands where these mosquitoes breed.

### **5.4 Temperature**

Cooler average minimum and maximum temperatures increased the chances of a RVF outbreak in the final model. The influence of temperature on the occurrence of RVF outbreaks was small, but significant. Because rainfall was also in the final model, the effect of temperature was already at least partially adjusted for rainfall. The apparently independent effect of temperature in the final model could therefore be due to residual confounding by rainfall or the cloud cover causing the higher rainfall. Another explanation could be that temperature has some undocumented effect on the lifecycle or distribution of the vectors or the survival of the vectors in the environment.

## **5.5 Biome**

The final model indicated that the variable indicating the biome was significant. This indicates that certain biomes were more likely to experience outbreaks than others, even after adjustment for rainfall, temperature and water bodies. Due to the spatial distribution of RVF this makes sense and it is likely that the biome variable incorporates and is confounded by one or more important ecological factors that could not be included in the model, such as the distribution and availability of susceptible vectors. There are very few studies on the distribution of the vectors in South Africa. Jupp (1996; 2004) gives some indication of the distribution of the vectors of RVF (KwaZulu-Natal and Inland plateau), but does not give any detail regarding the biome or vegetation type in which these mosquitoes occur.

## **5.6 El Niño, La Niña and the Southern Oscillation Index**

The analysis of the effect of the 5 month running average of the SOI on the occurrence of RVF yielded a very significant result. The simple logistic regression indicated that a positive SOI or La Niña event is associated with a higher incidence of RVF in South Africa, increasing the odds of RVF outbreaks by roughly 20%. This is the opposite of what happens in Kenya as found by Anyamba, Linthicum and Tucker (2001) which showed that RVF outbreaks in Kenya are associated with the El Niño cycle. This is due to the fact that a positive SOI causes higher rainfall in South Africa whereas a negative SOI causes higher rainfall in Kenya. This finding is significant, because it means that predictions that are made for Kenya or other parts of Africa using the SOI or El Niño/ La Niña cycle cannot simply be extended to predictions for South Africa. This finding agrees with the findings of Mabaso *et al.* (2006) regarding the influence of the El Niño Southern Oscillation (ENSO) on malaria incidence, where a negative SOI (El Niño) was associated with a lower incidence of malaria and a positive SOI (La Niña) was associated with a higher incidence of malaria. Malaria is, like RVF, a mosquito transmitted disease and a La Niña cycle will be expected to have the same effect on both diseases. It must, however, be remembered that there are many other factors that also influence the occurrence of RVF in South Africa and several of these factors might confound and interact with the SOI.

## **5.7 Constraints**

The constraints to this study are perceived to be:

### **5.7.1 Levels of reporting**

Over the 60 year period of this study, the levels of reporting of RVF outbreaks varied considerably. For some years, the only information available is that outbreaks occurred in a specific veterinary region. No indication is given regarding the exact location and number of outbreaks. This is due to two factors, the one is that RVF has never been a controlled disease in South Africa, so reporting of the disease was not strictly required and the other is that the disease reports from some of the specific state veterinary areas has been lost over time. The effect of varying levels of reporting would be misclassification of the outcome variable. False positive outcomes would have occurred when RVF was reported from an area or region, resulting in several blocks being classified as positive when in reality only one block was affected. False negative outcomes would have occurred when veterinarians or farmers did not recognise RVF due to a long period of absence of the disease or when the disease was not reported. These misclassifications may have led to some bias in the estimates of the associations between the predictors and the outcome.

### **5.7.2 Reliability of reporting and availability of laboratory reports**

It is very difficult to verify the reported occurrence of an outbreak, especially in years following very large outbreaks, because RVF was accepted to occur and was not investigated and/or reported as thoroughly as at the start or re-occurrence of outbreaks. The researcher could not find or gain access to any laboratory reports of outbreaks. In many of the annual reports, it is clearly stated that the outbreaks were confirmed in the laboratory or that suspected outbreaks could not be confirmed in the laboratory. A possible reason for the lack of laboratory reports is that in the past the laboratories were part of the government veterinary services, so the officials involved in the reporting from an area were directly involved with the laboratory diagnosis, in other words the two were not reported separately as it became the case later on in the study period.

### **5.7.3 Underreporting**

An important aspect of analysing disease data is that of underreporting. Missed diagnosis and the absence of veterinary support could play a very significant role in the reported history of a disease. It is therefore very likely that a large number of isolated RVF outbreaks

could have been missed and was never recorded or reported. Underreporting would cause several outbreaks to have been missed, resulting in misclassification of the outcome.

#### **5.7.4 Availability of vector data**

There is very little literature available on the distributions of the vectors involved in the transmission of Rift Valley fever, both in the endemic and epidemic cycles of the disease. The presence or absence of the vector plays a vital role in the occurrence of the disease. The absence of data on the geographical spread of these vectors is a serious constraint in any investigation into the epidemiology of the disease, especially if one wishes to distinguish between outbreaks caused by the endemic cycle vectors and those caused by the epidemic cycle vectors.

#### **5.7.5 Accuracy and reliability of climate data**

The rainfall and temperature data used for this study were in a very raw format with several errors and missing values. Attempts were made to correct some of the errors and to improve the dataset. The errors and missing values should not affect the analysis as a whole, but could have an effect on the individual season and block scale.

#### **5.7.6 Resolution of data**

The resolution of the outbreak data varied greatly between seasons and reports. Some reports gave the exact location of the outbreaks, most reports only stated the district and in some reports only the affected veterinary region was mentioned. The rainfall data spatial resolution was acquired at a much higher resolution than the outbreak data, whereas the temperature data spatial resolution was relatively coarse. The temporal resolutions of the rainfall and temperature data were much higher than the outbreak data. Rainfall and temperature data were on a monthly basis whereas the outbreaks were reported on a seasonal basis. The abovementioned discrepancies resulted in the values of predictors not always necessarily reflecting actual conditions at the time and place of the outbreak. The effect of these misclassifications, as well as any misclassification of the outcome discussed earlier is that the estimates of the associations between the predictors and the outcome may be biased. Due to the fact that misclassification may have been differential, i.e. it may have occurred to a different extent at different levels of certain predictors, the direction of the bias cannot necessarily be assumed to be towards the null.

## **5.8 Further research**

This study once again highlighted the need for further research into the geographical distribution of susceptible RVF vectors and the ecology and movement of vectors. Another aspect that needs further investigation is the specific conditions needed for vectors to trigger RVF outbreaks. One question is whether it is only vector numbers that trigger outbreaks, or whether there are other factors involved in the causation of outbreaks.

The presence or absence of the RVF virus in the vectors and non-domestic hosts during periods of absence of the disease is another factor that needs to be investigated in longitudinal studies, as well as the possibility of subclinical low-level circulation of the virus in domestic animals, especially in the areas where the disease often occurs.

There is also a need for research into the spread of the disease once a large outbreak has been triggered, focussing on factors like animal movement and the spread of the vectors. This would help to improve understanding of why certain outbreaks reach epidemic proportions.

## **Chapter 6 : Conclusions and recommendations**

### **6.1 Conclusions**

This study documented all the available information regarding the temporal and spatial distribution of RVF outbreaks in South Africa and highlighted which areas are susceptible to RVF outbreaks. It also showed that these areas are likely to experience outbreaks in the future and that animals in these areas should be kept fully vaccinated.

The result from the statistical analysis also indicated that high rainfall during December, January and February increases the probability of an outbreak of RVF occurring in all areas where the disease occurred in the past and it confirmed the influence of pans and wetlands on the occurrence of the disease as described in the literature.

It was also shown in this study that the influence of the El Niño / Southern Oscillation Index is opposite to the situation in Kenya. Rift Valley fever outbreaks are more likely to occur during positive SOI or La Niña events.

### **6.2 Recommendations**

In areas that have experienced RVF in the past, preventative measures against RVF should always be in place. Farmers in these areas should always include RVF vaccination in their vaccination schedules and veterinarians should always include this disease in their list of differential diagnosis for abortions and deaths. High rainfall events during the summer months should always serve as a warning signal for the possible occurrence of RVF.

Further research should be conducted on the distribution of vectors, the presence of RVF virus in vectors during inter-epidemic periods, and the possibility of low-level circulation of virus in domestic animals.

## Chapter 7 : References

- AGRO-CLIMATOLOGY STAFF 2010. ARC-ISCW Agro-Climatology Monthly Summary In ARC-ISCW Climate Information System.
- ALEXANDER, R.A. 1951. Rift Valley fever in the Union. *Journal of the South African Veterinary Medical Association*. 22:105-109.
- ALEXANDER, R.A. 1955a. Annual report for 1 July 1953 to 30 June 1954 of the Directorate of Veterinary Services. Department of Agriculture of South Africa.
- ALEXANDER, R.A. 1955b. Jaarverslag vir 1 Julie 1954 tot 1 Junie 1955 vir die Afdeling Veeartsenydiens. Department of Agriculture of South Africa.
- ALEXANDER, R.A. 1956. Jaarverslag vir 1 Julie 1955 tot 1 Junie 1956 vir die Afdeling Veeartsenydiens. Department of Agriculture of South Africa.
- ANONYMOUS 1976. Report on Rift Valley fever from the Western Cape Veterinary region. Division of Veterinary Services.
- ANYAMBA, A., LINTHICUM, K.J. & TUCKER, J.T. 2001. Climate-disease connections: Rift Valley fever in Kenya. *Cad. Saùde Pùblica*. 17(Suplemento):133-140.
- BALKHY, H.H. AND MEMISH, Z.A. 2003. Rift Valley fever: an uninvited zoonosis in the Arabian peninsula. *International Journal of Antimicrobial Agents*. 21:153-157
- BARNARD, B. AND BOTHA, M. 1977. An inactivated Rift Valley Vaccine. *Journal of the South African Veterinary Association*. 48(1):45-48.
- CENTER FOR OCEAN-ATMOSPHERIC PREDICTION STUDIES (COAPS), FLORIDA STATE UNIVERSITY 2010. ENSO Index According to JMA SSTA (1868-present). <http://coaps.fsu.edu/jma.shtml>
- CHEVALIER, V., DELAROCQUE, S., BALDET, T., VAIL, L. & ROGER, F. 2004. Epidemiological processes involved in the emergence of vector-borne diseases: West

Nile fever, Rift Valley fever, Japanese encephalitis and Crimean-Congo haemorrhagic fever. *Revue Scientifique Technique Office International Des Epizooties*. 23:535-555.

CHEVALIER, V. 2010. Rift Valley fever - a threat for Europe?. *Eurosurveillance*. 15 (10):19506.

CLEMENTS, A.C.A., PFEIFFER, D.U., MARTIN, V. & OTTE, M.J. 2007. A Rift Valley fever atlas for Africa. *Preventive Veterinary Medicine*. 82:72-82.

DAVIES, F.G., KILELU, E., LINTHICUM, K.J. & PEGRAM, R.G. 1992. Patterns of Rift Valley fever activity in Zambia. *Epidemiology and Infection*. 108:185-191.

DEPARTMENT OF LAND AFFAIRS 1998. Dams of South Africa shapefile.

DEPARTMENT OF LAND AFFAIRS 1998. Rivers of South Africa shapefile.

DIRECTORATE OF ANIMAL HEALTH 1980. Annual report for 1 July 1979 to 31 March 1980 of the Directorate of Animal Health. Department of Agriculture and Fisheries of South Africa.

DIRECTORATE OF ANIMAL HEALTH 1981. Jaarverslag vir 1 April 1980 tot 31 Maart 1981 van die Direkoraat Diergesondheid. Department of Agriculture and Fisheries of South Africa.

DIRECTORATE OF ANIMAL HEALTH 1982. Jaarverslag vir 1 April 1981 tot 31 Maart 1982 van die Direkoraat Diergesondheid. Department of Agriculture of South Africa.

DIRECTORATE OF ANIMAL HEALTH 1989. Annual report for 1 April 1988 to 31 March 1989 of the Directorate of Animal Health. Department of Agricultural Economics and Marketing.

DIRECTORATE OF ANIMAL HEALTH 1992. Annual report for 1 April 1991 to 31 March 1992 of the Directorate of Animal Health. Department of Agriculture of South Africa.

DIRECTORATE OF ANIMAL HEALTH 1993. Annual report for 1 April 1992 to 31 March 1993 of the Directorate of Animal Health. Department of Agriculture of South Africa.

DIRECTORATE OF ANIMAL HEALTH 2010. National Animal Disease Database of the Directorate of Animal Health. Department of Agriculture, Forestry and Fisheries of South Africa.

DIRECTORATE OF VETERINARY SERVICES 1985a. Annual report for 1 April 1984 to 31 March 1985 of the Directorate of Veterinary Services. Department of Agriculture of South Africa.

DIRECTORATE OF VETERINARY SERVICES. 1985b. Directorate of Veterinary Services report to the OIE for 1985. Department of Agriculture of South Africa.

DIVISION OF VETERINARY SERVICES 1985c. Disease report to the Southern African Regional Commission for the Conservation and Utilisation of the Soil (SARCCUS) for 1984. Department of Agriculture of South Africa.

DIRECTORATE OF VETERINARY SERVICES 1986a. Annual disease report to the OIE for 1986. Department of Agriculture of South Africa.

DIRECTORATE OF VETERINARY SERVICES 1986b. Annual report for 1 April 1985 to 31 March 1986 of the Directorate of Veterinary Services. Department of Agriculture of South Africa.

DIRECTORATE OF VETERINARY SERVICES 1987. Annual report for 1 April 1986 to 31 March 1987 of the Directorate of Veterinary Services. Department of Agriculture of South Africa.

DIRECTORATE OF VETERINARY SERVICES 1988. Annual report for 1 April 1987 to 31 March 1988 of the Directorate of Veterinary Services. Department of Agricultural Economics and Marketing.

DIRECTORATE OF VETERINARY SERVICES 1989a. Directorate of Veterinary Services report to the OIE for 1987. Department of Agriculture of South Africa.

DIRECTORATE OF VETERINARY SERVICES 1989b. Directorate of Veterinary Services report to the OIE for 1989. Department of Agriculture of South Africa.

DIRECTORATE OF VETERINARY SERVICES 2004. Livestock Figures. National Department of Agriculture.

DIRECTOR OF EASTERN CAPE AND KAROO REGION OF VETERINARY SERVICES 1986. Annual report for 1 April 1985 to 31 March 1986 of the Eastern Cape and Karoo region of the Directorate of Veterinary Services. Department of Agriculture of South Africa.

DIRECTOR OF NATAL REGION OF VETERINARY SERVICES 1986a. Monthly disease reports from the Natal region of the Directorate of Veterinary Services. Department of Agriculture of South Africa.

DIRECTOR OF NATAL REGION OF VETERINARY SERVICES 1986b. Annual report for 1 April 1985 to 31 March 1986 of the Natal region of the Directorate of Veterinary Services. Department of Agriculture of South Africa.

DIRECTOR OF THE NATAL VETERINARY REGION 1991. Annual report for 1 April 1990 to 31 March 1991 of the Natal Veterinary Region. Directorate of Animal Health, Department of Agricultural Economics and Marketing.

DIVISION OF VETERINARY SERVICES 1957. Jaarverslag vir 1 Julie 1956 tot 1 Junie 1957 vir die Afdeling Veeartsenydiens. Department of Agriculture of South Africa.

DIVISION OF VETERINARY SERVICES 1958. Annual report of the secretary for Agriculture for the period 1st July, 1957 to 30th June, 1958. Department of Agriculture of South Africa.

DIVISION OF VETERINARY SERVICES 1959. Annual report for 1 July 1958 to 30 June 1959 of the Division of Veterinary Services. Department of Agriculture of South Africa.

DIVISION OF VETERINARY SERVICES 1960. Jaarverslag vir 1 Julie 1959 tot 1 Junie 1960 vir die Afdeling Veeartsenydiens. Department of Agriculture of South Africa.

DIVISION OF VETERINARY SERVICES 1961. Jaarverslag vir 1 Julie 1960 tot 1 Junie 1961 vir die Afdeling Veeartsenydiens. Department of Agriculture of South Africa.

DIVISION OF VETERINARY SERVICES 1962. Jaarverslag vir 1 Julie 1961 tot 1 Junie 1962 vir die Afdeling Veeartsenydiens. Department of Agriculture of South Africa.

DIVISION OF VETERINARY SERVICES 1963. Jaarverslag vir 1 Julie 1962 tot 1 Junie 1963 vir die Afdeling Veeartsenydiens. Department of Agriculture of South Africa.

DIVISION OF VETERINARY SERVICES 1964. Jaarverslag vir 1 Julie 1963 tot 1 Junie 1964 vir die Afdeling Veeartsenydiens. Department of Agriculture of South Africa.

DIVISION OF VETERINARY SERVICES 1965. Jaarverslag vir 1 Julie 1964 tot 1 Junie 1965 vir die Afdeling Veeartsenydiens. Department of Agriculture of South Africa.

DIVISION OF VETERINARY SERVICES 1966. Jaarverslag vir 1 Julie 1965 tot 1 Junie 1966 vir die Afdeling Veeartsenydiens. Department of Agriculture of South Africa.

DIVISION OF VETERINARY SERVICES 1967. Annual report for 1 July 1966 to 30 June 1967 of the Division of Veterinary Services. Department of Agriculture of South Africa.

DIVISION OF VETERINARY SERVICES 1968. Annual report for 1 July 1967 to 30 June 1968 of the Division of Veterinary Services. Department of Agriculture of South Africa.

DIVISION OF VETERINARY SERVICES 1969. Annual report for 1 July 1968 to 30 June 1969 of the Division of Veterinary Services. Department of Agriculture of South Africa.

DIVISION OF VETERINARY SERVICES 1970. Annual report for 1969/1970 of the Division of Veterinary Services. Department of Agriculture of South Africa.

DIVISION OF VETERINARY SERVICES 1971. Annual report for 1 July 1970 to 30 June 1971 of the Division of Veterinary Services. Department of Agriculture of South Africa.

DIVISION OF VETERINARY SERVICES 1972. Annual report for 1 July 1971 to 30 June 1972 of the Division of Veterinary Services. Department of Agriculture of South Africa.

DIVISION OF VETERINARY SERVICES 1973. Annual report for 1 July 1972 to 30 June 1973 of the Division of Veterinary Services. Department of Agriculture of South Africa.

DIVISION OF VETERINARY SERVICES 1974. Jaarverslag vir 1 Julie 1973 tot 1 Junie 1974 vir die Afdeling Veeartsenydiens. Department of Agriculture of South Africa.

DIVISION OF VETERINARY SERVICES 1975. Annual report for 1 July 1974 to 30 June 1975 of the Division of Veterinary Services. Department of Agriculture of South Africa.

DIVISION OF VETERINARY SERVICES 1976a. Annual report for 1 July 1975 to 30 June 1976 of the Division of Veterinary Services. Department of Agriculture of South Africa.

DIVISION OF VETERINARY SERVICES 1976b. Monthly disease reports from veterinary regions during 1976. .

DIVISION OF VETERINARY SERVICES 1977a. Annual report for 1 July 1976 to 30 June 1977 of the Division of Veterinary Services. Department of Agriculture of South Africa.

DIVISION OF VETERINARY SERVICES 1977b. Monthly disease reports from veterinary regions during 1977. .

DIVISION OF VETERINARY SERVICES 1978a. Annual report of the Division of Veterinary Services, 1977-1978. Department of Agricultural Technical Services of South Africa.

DIVISION OF VETERINARY SERVICES 1978b. Monthly disease reports from veterinary regions during 1978. .

DIVISION OF VETERINARY SERVICES 1979. Monthly disease reports from veterinary regions during 1979. .

DIVISION OF VETERINARY SERVICES 1983a. Disease report to the Southern African Regional Commission for the Conservation and Utilisation of the Soil (SARCCUS) for 1982. Department of Agriculture of South Africa.

DIVISION OF VETERINARY SERVICES 1983b. Annual report for 1 April 1982 to 31 March 1983 of the Division of Veterinary Services. Department of Agriculture of South Africa.

DIVISION OF VETERINARY SERVICES 1984a. Disease report to the Southern African Regional Commission for the Conservation and Utilisation of the Soil (SARCCUS) for 1983. Department of Agriculture of South Africa.

- DIVISION OF VETERINARY SERVICES 1984b. Jaarverslag vir 1 Julie 1983 tot 1 Junie 1984 vir die Afdeling Veeartsenydiens. Department of Agriculture of South Africa.
- DUNGU, B., LOUW, I., LUBISI, A., HUNTER, P., VON TEICHMAN, B.F. & BOULOY, M. 2010. Evaluation of the efficacy and safety of the Rift Valley Fever Clone 13 vaccine in sheep. *Vaccine*.28:4581-4587
- ESRI CORPORATION 2010. ArcGIS 9.3.1 Geographic Information System software.
- GAGE, K.L., BURKOT, T.R., EISEN, R.J. & HAYES, E.B. 2008. Climate and Vectorborne Diseases. *American Journal of Preventive Medicine*. 35(5):436-450.
- GAMMA, A. 2005. LINCHECK: Stata module to graphically assess the linearity of a continuous covariate in a regression model. <http://ideas.repec.org/c/boc/bocode/s449401.html>
- GEAR, J., DE MEILLON, B., ROUX, A.F.L., KOFISKY, R., INNES, R.R., STEYN, J.J., OLIFF, W.D. & SCHULZ, K.H. 1955. A Study Of The 1953 Outbreak In The Orange Free State, With Special Reference To The Vectors And Possible Reservoir Hosts. *South African Medical Journal*. XXIX:514-518.
- GERDES, G.H. 2004. Rift Valley fever. *Revue Scientifique Technique Office International Des Epizooties*. 23:(2)613-623.
- GOULD, E.A. AND HIGGS, S. 2008. Impact of climate change and other factors on emerging arbovirus diseases. *Transactions of the Royal Society of Tropical Medicine and Hygiene*. 103:109-121.
- HOSMER, D.W. AND LEMESHOW, S. 2000. Applied Logistic regression. USA: John Wiley & Sons, Inc.
- JUPP, P.G. 1996. Mosquitoes of Southern Africa. Hartebeespoort: Ekogilde Publishers.
- JUPP, P.G. 2004. Vectors: Mosquitoes, in *Infectious Diseases of Livestock*, edited by J. A. W Coetzer and R. C. Tustin. Cape Town: Oxford University Press.

- KHASNIS, A.A. AND NETTLEMAN, M.D. 2005. Global Warming and Infectious Disease. *Archives of Medical Research*. 36:689–696.
- KRUGER, A.C. 2004. Climate of South Africa. Climate Regions. WS45. Pretoria: South African Weather Service.
- LINTHICUM, K.J., ANYAMBA, A., TUCKER, J.T., KELLEY, M.F. & PETERS, C.J. 1999. Climate and Satellite Indicators to Forecast Rift Valley fever Epidemics in Kenya. *Science*. 285:397-400.
- LINTHICUM, K.J., DAVIES, F.G., KAIRO, A. & BAILEY, C.L. 1985. Rift Valley fever virus (family Bunyaviridae, genus Phlebovirus). Isolations from Diptera collected during an inter-epizootic period in Kenya. *The Journal of Hygiene*. 95:197-209.
- MABASO, M.L.H., KLEINSCHMIDT, I., SHARP, B. & SMITH, T. 2006. El Niño Southern Oscillation and annual malaria incidence in Southern Africa. *Transactions of the Royal Society of Tropical Medicine and Hygiene*. 101:326-330.
- MAJEKE, B., POTI, L., RAMOELO, A., THOMPSON, M., FLEMING, G., MCFERREN, G. & VAN AARDT, J. 2000. National Land-Cover Database. Council for Scientific and Industrial Research and the Agricultural Research Council.
- MARTIN, V., CHEVALIER, V., CECCATO, P., ANYAMBA, A., DE SIMONE, L., LUBROTH, J., DE LA ROCQUE, S. & DOMENECH, J. 2008. The impact of climate change on the epidemiology and control of Rift Valley fever. *Scientific and Technical Review of the OIE*. 27(2):413-426
- MCINTOSH, B. 1972. Rift Valley fever - Vector studies in the field. *Journal of the South African Veterinary Association*. 43 (4):391-395.
- MCINTOSH, B., JUPP, P., DOS SANTOS, I. & BARNARD, B. 1980. Vector Studies on Rift Valley Fever Virus in South Africa. *South African Medical Journal*. 58:127-132.
- MCINTOSH, B.M., RUSSELL, D., DOS SANTOS, I. & GEAR, J.H.S. 1980. Rift Valley fever in Humans in South Africa. *South African Medical Journal*. LVIII:803-806.

- MEYERS, S.D. & O'BRIEN, J.J. 1995. El Niño Dates. [http://training-viz.globe.gov/viz-bin/show.cgi?page=help-elnino-elnino\\_dates.ht&l=ar&b=g&rg=n&enc=56&nav=0&](http://training-viz.globe.gov/viz-bin/show.cgi?page=help-elnino-elnino_dates.ht&l=ar&b=g&rg=n&enc=56&nav=0&)
- MUCINA, L. AND RUTHERFORD, M. (Eds) 2006. The vegetation of South Africa, Lesotho and Swaziland. *Strelitzia* 19. Pretoria: South African National Biodiversity Institute.
- MUNDEL, B. & GEAR, J. 1951. Rift Valley Fever. I. The occurrence of human cases in Johannesburg. *South African Medical Journal*. XXV:797- 800.
- MURITHI, R.M., MUNYUA, P., ITHONDEKA, P., MACHARIA, J., HIGHTOWER, A., LUMAN, E.T., BREIMAN, R.F. & NJENGA, M.K. 2010. Rift Valley fever in Kenya: history of epizootics and identification of vulnerable districts. *Epidemiology and Infection*. 1-9.
- NATIONAL INSTITUTE FOR COMMUNICABLE DISEASES. 2008. *Communicable Diseases Communique*. South African National Health Laboratory Service: National Institute for Communicable Diseases. 7:(6).
- NATIONAL INSTITUTE FOR COMMUNICABLE DISEASES. 2009. *Communicable Diseases Communique*. South African National Health Laboratory Service: National Institute for Communicable Diseases. 8:(11).
- NATIONAL INSTITUTE FOR COMMUNICABLE DISEASES. 2010. *Communicable Diseases Communique*. South African National Health Laboratory Service: National Institute for Communicable Diseases. 9:(8).
- ODENDAAL, L. AND PROZESKY, L. 2010. A review of the pathology and pathogenesis of Rift Valley fever. *Proceedings of the 9th annual congress of the Southern African Society For Veterinary Epidemiology and Preventive Medicine, 18 -20 August 2010 at Farm Inn Hotel, Pretoria, South Africa*.
- SMITH, H., PRETORIUS, D., NEWBY, T. & MORGENTHAL, T. 2006. Grazing Capacity in South Africa.
- SOUTH AFRICAN WEATHER SERVICE 2003. Information on El Nino. <http://old.weathersa.co.za/References/elnino.jsp>
- SOUTH AFRICAN WEATHER SERVICE 2010. South African Weather Station Data.

- STATACORP 2007. STATA Statistical Software: Release 10 IC. College Station Texas, USA: Statacorp LP.
- STATACORP 2007. STATA Release 10 Printed Manual. College Station Texas, USA: Statacorp LP.
- STATE VETERINARIAN SKUKUZA 2000. Annual Report for January 1999 to December 1999. Directorate of Veterinary Services.
- STEYNOR, A 2006. Map from Juta General atlas as cited in: Introduction to Climatology and Meteorology: Module 1. [http://www.csag.uct.ac.za/module\\_1](http://www.csag.uct.ac.za/module_1)
- SWANEPOEL, R. AND COETZER, J.A.W. 2004. Rift Valley fever, in *Infectious Diseases of Livestock*, edited by J. A. W. Coetzer and R. C. Tusten. Cape Town: Oxford University Press.
- SWANEPOEL, R. 2009. Keynote address at the *OIE regional seminar on "Re-emergence of Rift Valley fever in South Africa: how can we better predict and respond?" Bloemfontein, South Africa, 16 – 18 February 2009.*
- U. S. A. NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION'S CLIMATE PREDICTION CENTRE 2010. Southern Oscillation Index. <http://www.cpc.ncep.noaa.gov/data/indices/soi>
- VAN DER LINDE, N.T. 1953. A recent epidemic of Rift Valley fever in the Orange Free State. *Journal of the South African Veterinary Medical Association*. 24:(3)145-148.
- WALLACE, D. 2009. *New vaccines and vaccine development (2). Regional seminar: Re-emergence of Rift Valley fever in Southern Africa: how to better predict and respond.* Gaborone, Botswana: OIE.
- WILSON, M.L., CHAPMAN, L.E., HALL, D.B., DYKSTRA, E.A., BA, K., ZELLER, H.G., TRAORE-LAMIZANA, M., HERVEY, J.P., LINTHICUM, K.J. & PETERS, C.J. 1994. Rift Valley fever in rural Northern Senegal: Human risk Factors and potential vectors. *American Journal of Tropical Medical Hygiene*. 50:(6)663-675.

## **Annexure A: Datasets used**

DIRECTORATE OF ANIMAL HEALTH 1992-2010. National Animal Disease Database of the Directorate of Animal Health. Department of Agriculture, Forestry and Fisheries of South Africa.

DEPARTMENT OF LAND AFFAIRS 1998. Dams of South Africa shapefile.

DEPARTMENT OF LAND AFFAIRS 1998. Rivers of South Africa shapefile.

SOUTH AFRICAN WEATHER SERVICE 2010. South African Weather Station Data.

AGRO-CLIMATOLOGY STAFF 2010. ARC-ISCW Agro-Climatology Monthly Summary In ARC-ISCW Climate Information System.

Vegmap2006 from MUCINA, L. AND RUTHERFORD, M. (Eds) 2006. The vegetation of South Africa, Lesotho and Swaziland. Strelitzia 19. Pretoria:South African National Biodiversity Institute.

SMITH, H., PRETORIUS, D., NEWBY, T. & MORGENTHAL, T. 2006. Grazing Capacity in South Africa.

U. S. A. NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION'S CLIMATE PREDICTION CENTRE 2010. Southern Oscillation Index.  
<http://www.cpc.ncep.noaa.gov/data/indices/soi>

MAJEKE, B., POTI, L., RAMOELO, A., THOMPSON, M., FLEMMING, G., MCFERREN, G. & AARDT, J. 2000. National Land Cover Database. Council for Scientific and Industrial Research and the Agricultural Research Council.