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Old Dominion University

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A GIS ANALYSIS OF THE ENVIRONMENTAL VARIABLES RELATED TO RIFT VALLEY FEVER OUTBREAKS

by

Jacqueline Florette Jackson
B.S. May 2004, Old Dominion University
M.P.H. August 2006, Eastern Virginia Medical School

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Approved by:

Holly Gaff (Director)

Anna Jeng (Member)

Joshua Behr (Member)

ABSTRACT

A GIS ANALYSIS OF THE ENVIRONMENTAL VARIABLES RELATED TO RIFT VALLEY FEVER OUTBREAKS

Jacqueline Florette Jackson
Old Dominion University, 2010
Director: Dr. Holly Gaff

Rift Valley fever is a mosquito-borne disease that causes widespread febrile illness and mortality in domestic animals as well as humans (Gaff, 2007). Rift Valley fever virus was first isolated in 1931 (Daubney, 1931), and since then, outbreaks have occurred in sub-Saharan Africa, southern Africa, Egypt, Saudi Arabia, Yemen and Madagascar, proving it to be a virus able to invade ecologically diverse regions (Gaff, 2007). The potential introduction of Rift Valley fever into the United States suggests the potential for human infection and major economic disruption. It is important to understand the role environmental variables have played in historical outbreaks to further understand the disease and the possibility of translocation of the virus.

This study examines the relationship between both temperature and rainfall rates and Rift Valley fever outbreaks in Kenya, Madagascar, and South Africa. Datasets employed in the analysis are several including a long term dataset (1982-2004), short term datasets (1999-2005; 1999-2007) and datasets covering the Rift Valley fever outbreaks in Kenya (2006, 2007), Madagascar (2008, 2009), and South Africa (2008, 2009). Geographic information systems analysis, time series analysis, and statistical analyses are used to gauge the relationships among temperature, rainfall, and Rift Valley fever outbreak events.

Results of this study show a relationship between rainfall and Rift Valley fever in Kenya, but not in Madagascar or South Africa. Although a positive rainfall anomaly was found at the beginning of the Rift Valley fever outbreak in Kenya, further analysis finds above average rainfall anomalies prior to the outbreak with no Rift Valley fever activity reported. No significant differences are found among the historical temperature ranges and temperature ranges during Rift Valley fever outbreaks in Kenya, Madagascar or South Africa.

By better understanding these two important variables, disease transmission models for Rift Valley will later be able to predict future outbreaks and spread of disease. Studies about variables related to disease transmission models like this further strengthen these models, thus providing policymakers the ability to design systems to enhance preventative and control measures.

Co-Directors of Advisory Committee: Dr. Anna Jeng
Dr. Joshua Behr

To my parents, Kenneth and Florette Henry

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CHAPTER I

Introduction

Problem Statement

Rift Valley fever virus is a mosquito-borne pathogen that causes widespread febrile illness and mortality in domestic animals such as sheep, cattle, goats as well as humans (Gaff, 2007). Rift Valley fever virus was first described in peer-reviewed research in 1931 (Daubney, 1931) and is often considered a disease primarily of sub-Saharan and southern Africa (Gaff, 2007). In 1977, the disease moved outside of sub-Saharan and southern Africa with an outbreak occurring in Egypt. Since then, outbreaks have occurred in Saudi Arabia and Yemen, proving it to be a virus able to invade ecologically diverse regions (Gaff, 2007). The potential for an exotic arbovirus to be introduced and widely established across North America has been shown with the introduction and rapid spread of West Nile viral activity across North America in 1999 (Turell, 2008). Currently, Rift Valley fever is listed as a Category A agent on the Center for Disease Control bioterrorism list and considered a major threat to the United States. The potential introduction of Rift Valley fever and the possibility of human infection suggest the potential for major economic disruption due to loss of livestock and trade restrictions. Within this context, it is important to understand the role environmental variables have played in historical outbreaks.

Over the past few decades, significant changes in the distribution and intensity of Rift Valley fever (RVF) has been recorded (WHO, 2007). Since the isolation of the virus in 1931 in the Rift Valley in Kenya, it has been held responsible for several epizootics in small ruminants, causing abortions and stillborn droppings in the ovine species in Eastern and Southern Africa (Gerdes, 2004). Epizootics first occurred in regions of high altitude such as South Africa in 1951 (which resulted in the death of an estimated 100,000 sheep), Zimbabwe in 1958, Nigeria in 1958, and Chad and Cameroon in 1967 (WHO, 2007). Until the 1970's, human infection remained low, and the agent mostly affected breeders in contact with affected or dead animals. In 1973, after the first source of infection appeared in the White Nile in Sudan, a human epidemic soon began in South Africa with the first recognized human deaths (Peters, 1994). Then in 1977, human outbreaks occurred in Egypt causing 598 human deaths (Gerdes, 2004) and in 1987 causing 200 human deaths. An epidemic followed in Kenya and Somalia in 1997 causing 478 human deaths (CDC, 1998). In 2000, cases of RVF were discovered in Saudi Arabia and Yemen marking the spread of the disease outside of Africa and the Rift Valley (Jupp, 2002). By November 2000, over 500 cases of serious RVF were discovered in Saudi Arabia with 87 deaths. In Yemen, between August and November 2000, there were over 1,000 suspected occurrences of the disease among humans. The result of the outbreak in Yemen was 121 deaths. Since 2000, outbreaks have occurred in Kenya and Somalia (2006), Tanzania and Sudan (2007) and Madagascar and South Africa (2008).

Rift Valley fever outbreaks in Kenya have been associated with abnormally heavy and widespread rainfall (Anyamba, 2001). It is thought that heavy rainfall increases the number of breeding sites for the mosquito species responsible for the spread of RVF. This, in turn, results in an increase in the number of vectors and therefore more intense virus transmission and circulation (Bicout, 2004). Temperature can also play a major role in determining the ability of a potential arthropod vector to transmit an arbovirus (Turell, 1993). Studies have shown that the temperature at which mosquitoes are held after an infectious blood meal is inversely related to the time interval between ingestion of the virus and subsequent ability to transmit the virus by a mosquito (Davies 1932, Hurlbut 1973, Turell 198, Turell 1989). RVF is both a widespread vector-borne disease and an environmental-sensitive virus, yet no studies have been done comparing the effect of the environment on various RVF affected countries.

In the study of the various mosquito borne diseases, such as malaria and West Nile Virus (WNV), geographic analysis has illuminated the relationship among the vectors and environmental variables. The relationship between the environment and RVF has only been studied in Kenya and Senegal, yet the relationships neither have been fully studied nor understood. Geographic information systems provide the tools and the data to make clear the geographic relationships between environment and the occurrence of disease (Guptill, 2009). Geographic analysis of environmental variables, such as temperature and rainfall in relation to periods during Rift Valley fever outbreaks, will allow for further understanding of the predictive indicators needed to forecast future RVF outbreaks in Africa and beyond.

Purpose of the Study

The purpose of this study is to identify the relationships between environmental variables, temperature and rainfall, and Rift Valley fever outbreaks. By understanding the variables, the drivers of mosquito abundance, and the subsequent occurrence of RVF, future patterns of disease maintenance and transmission may be predicted, and efficient mosquito control operations can be initiated prior to a major disease outbreak. Also, understanding when and why disease outbreaks occur could be useful in differentiating between a naturally occurring outbreak of disease and a biologic attack. It is hypothesized that weather conditions influence mosquito community dynamics, which ultimately play a role in the occurrence of RVF infections. The relationship between rainfall and RVF has been studied in Kenya and Senegal, but not in any other countries. It is important to understand the relationship between environmental variables and RVF in other countries. Therefore, the specific purpose of the study could be categorized as follows:

1. Investigate the relationship between temperature and rainfall in Kenya prior to, during, and after the 2006-2007 Rift Valley fever outbreak.
2. Investigate the relationship between temperature and rainfall in Madagascar prior to and during the 2008-2009 Rift Valley fever outbreak.
3. Investigate the relationship between temperature and rainfall in South Africa prior to and during the 2008-2009 Rift Valley fever outbreak.

Background

History

The virus that causes Rift Valley fever was first isolated in 1931 near Naivasha Lake in the region of the Rift Valley, in Kenya (Daubney, 1931). Epizootics first occurred in regions of high altitude such as South Africa in 1951 (which resulted in the death of an estimated 100,000 sheep); Zimbabwe in 1958; Nigeria in 1958; and Chad and Cameroon in 1967, before it begin to infect the Saharan barrier and the river valleys (WHO, 2007). Until the 1970s, human infection remained low, and the agent mostly affected breeders in contact with affected or dead animals. The summer of 1977 brought about the first cases in High Egypt around the Assuan district; in the fall, the epidemic broke out in the North, in the Nile delta (El-Akkad, 1978). The Egyptian outbreak is estimated to have caused around 18,000 clinical cases with 598 deaths reported (El-Akkad, 1978). In 1987, RVF broke out in Mauritania following the opening of Diama Dam at the mouth of the Senegal River. The virus was previously present in this area but not generally recognized (Gerdes, 2004). It is suspected that the dam project created additional breeding grounds for mosquitoes carrying the disease, resulting in more than 200 human deaths from RVF (House, 1992). The 1993 Egypt outbreak followed the opening of the Aswan Dam (Gerdes, 2004). Other outbreaks, such as the 1997 outbreaks in Kenya and Somalia, have been associated with periods of heavy rain. The 1997 outbreak resulted in large losses of domestic animals, as well as 478 deaths (CDC, 1998). Reports suggest that close to 89,000 people were affected (Gerdes, 2004). East African beef exports were embargoed for nearly a year and a half during this outbreak. In the 1900s, RVF was primarily confined to sub-Saharan and southern Africa with only one outbreak outside of this area in Egypt from 1977-1978. In 2000, RVF jumped from continental Africa into the Arabian Peninsula. Two outbreaks occurring in Saudi Arabia and Yemen marked the spread of the disease outside of Africa and the Rift Valley (Jupp, 2002). The Saudi Arabian outbreak caused nearly 500 serious cases and 87 deaths. In Yemen, there were over 1,000 suspected occurrences of the disease among humans resulting in 121 deaths. Since 2000, outbreaks have occurred in Kenya, Somalia, South Africa, Tanzania, Sudan, and most recently, Madagascar (WHO, 2009). These events further strengthened the possibility of translocation to the United States, as was seen with West Nile Virus in 1999 (Turell, 2008).

Environmental Variables

Rift Valley fever virus (RVFV) outbreaks in Kenya have been known to follow periods of abnormally heavy rainfall (Anyamba, 2001). It is assumed that excessive rainfall increases the number of breeding sites for mosquitoes, especially for the genus *Aedes*, resulting in an increase in the number of vectors that may be infected with RVF. Mosquito eggs have the potential to be infected with the RVF virus through maternal transmission and, once they hatch, the adult mosquitoes can transfer the RVF virus to the livestock on which they feed. Infected livestock can then experience spontaneous abortions; the virus has a 90% fatality rate among young livestock. Once the livestock becomes infectious, *Aedes,* as well as other species of mosquitoes, can become infected through feeding on these animals. The result is the further spread of disease (Anyamba, 2001).

Among diseases, there is much concern about mosquito-borne diseases. The vectors are extremely sensitive to weather conditions: cold conditions limit the range of mosquitoes and disease transmission (Epstein, 2000); alternatively, warmer conditions cause the disease transmission cycle to occur more rapidly due to increases in both the rate of larval development and the extrinsic incubation period of diseases (Shope, 1991). Thus, weather may condition the epidemic spread of disease through water for continued mosquito breeding and temperature in the range conducive to the expansion of the vector (Shope, 1991). It is also posited that increasing temperatures can also cause intensified floods and/or droughts, which create breeding sites for mosquitoes (Shope, 1991).

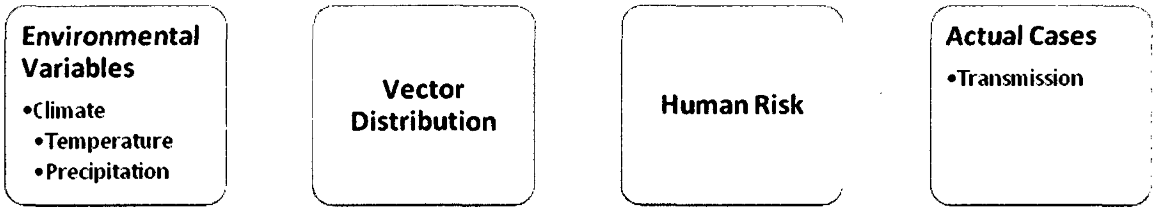
Human Epidemiology

Humans typically become infected with the virus through bites of infected female mosquitoes. Humans develop influenza-like symptoms with fever of 100-104° F (37.8-40° C), headache, muscular pain, weakness, nausea, plus epigastric discomfort and photophobia (WHO, 2007). Although most people infected with the virus recover in 4 to 7 days, a small percentage of infected individuals will develop complications. Some of those infected may develop a hemorrhagic syndrome of jaundice, hematemesis, melena, and petechiae 2 to 4 days after becoming febrile and die. Others will develop a meningoencephalitis or a retinopathy 5 to 15 days after becoming febrile. The case-fatality rate for persons with this syndrome is approximately 50% (WHO, 2007). The encephalitic syndrome typically occurs 1-3 weeks after the onset of symptoms. It can occur concurrently with the hemorrhagic fever. Both of these syndromes occur in only about 1% of human cases (Peters, 1994). As of now, there is no established course of treatment for infected patients.

Theoretical Model

Landscape epidemiology involves the identification of geographical areas where disease is transmitted; it involves the interactions and associations between elements of the physical and cultural environments (Curran, 2000). The theory behind landscape epidemiology was expressed in 1966 by the Russian epidemiologist, Pavlovsky. He stated that by knowing the vegetation and geologic conditions necessary for the maintenance of specific pathogens in nature, one can use the landscape to identify the spatial and temporal distribution of disease risk (Pavlosky, 1966). Pavlosky's historical concept of landscape epidemiology consisted of three basic observations. First, diseases tend to be limited geographically. Second, spatial variation arises from underlying variation in the physical and/or biological conditions that support the pathogen and its vectors and reservoirs. Third, if those abiotic and biotic conditions can be delimited on maps, then both contemporaneous risk and future change in risk should be predictable. It states that environmental elements, such as elevation, temperature, rainfall, and humidity, influence the presence, development, activity, and longevity of pathogens, vectors, zoonotic reservoirs of infection, and their interactions with humans (Meade, 1988). A conceptual model of this theory in relation to this study is presented below in Figure 1.

Figure 1: Conceptual model of the relationship between environmental variables and Rift Valley fever



Landscape epidemiology has been used to study Eastern Equine Encephalitis, Lyme disease, malaria (Kitron, 1998), and dengue (Rotela, 2007). In 2007, landscape epidemiology was used to study the dengue fever outbreak that occurred in 2004 in Tartagal, Northern Argentina (Rotela, 2007). In this study, variables are classified into micro-scale variables, medium-scale variables, and macro-scale variables. Micro-scale variables include mosquito breeding sites, and medium-scale variables include houses. Macro-scale variables include environmental variables such as rivers, vegetation, wetness, temperature, and some man-induced variables like edifications and roads. The effects of macro-habitat conditions on the spatial pattern of a particular outbreak are estimated, and an environmental risk prediction model developed. Most recently, a landscape epidemiology approach using geographic information systems mapping and ecological niche modeling is used to identify geographical areas of disease transmission risk for Lyme disease in British Columbia, Canada (Mak, 2010). The findings from this study are being used to increase public and physician awareness of Lyme disease risk and prioritize future field sampling for ticks in British Columbia. Geographic information systems (GIS) has been used successfully in landscape epidemiology by allowing users the ability to store, integrate, query, display, and analyze data from the molecular level to that of satellite resolution (CDC, 1994).

Significance of the Study

Climate and temperature affects the distribution of vector-borne diseases as well as the timing and intensity of outbreaks of these diseases. Weather such as temperature and rainfall affect the biology of the vector (Gubler, 2001). The distribution of vector-borne diseases is limited by temperature and rainfall as the range of the vector and/or vertebrate host is limited by temperature and rainfall (Shope, 1991). There is much concern surrounding mosquito-borne diseases, such as Rift Valley fever, since mosquitoes are extremely sensitive to weather conditions. Colder conditions may limit the range of mosquitoes and disease transmission; whereas, warmer conditions may cause the disease transmission cycle to occur more rapidly (Epstein, 2000). Mosquito vectors are very diverse in their biology with some species preferring wet climates and others dry climates. The relationship among the environmental variables affecting the mosquito vectors responsible for the spread of malaria, dengue fever, and West Nile virus has been heavily studied, but the relationship between the environmental variables and Rift Valley fever activity has not been neither fully studied nor understood.

The 1999 introduction and rapid spread of West Nile Virus (WNV) across the United States demonstrate our vulnerability to emerging mosquito-borne viruses. Fortunately, it also shows the abilities of the U.S. public health and animal health systems to identify weaknesses and develop reduction strategies (CDC, 1998). Rift Valley fever virus (RVFV) is classified by both the Centers for Disease Control and Prevention (CDC) and the Animal and Plant Inspection Service (APHIS) as an overlap select agent, as it affects both humans and non-human animals. It is also listed as a Category A agent on the CDCs bioterrorism list. If introduced into the United States, RVFV could be spread in fashion similar to WNV, but could also be spread by contact with infected vertebrate tissues or aerosols. Unfortunately, no approved human or animal vaccines exist for use in the United States. GIS–based modeling will allow for the improvement of disease transmission models for RVF and thus allow for a better understanding of the risk associated with the spread of RVFV to the United States.

Limitations of the Study

There are many variables that may influence the resurgence of Rift Valley fever including changes at the social, ecological and global level. Social changes include the excessive use of antibiotics and pesticides, as well as economic disparities. Ecological level changes include loss of habitat (which may greatly affect the diversity that allows for resilience to stress and resistance to pathogens), water and agricultural development, and urbanization. The global level includes changes in climate and stratospheric ozone (Epstein, 1999). The spread of arthropod vectors of disease from tropical areas into temperate areas has been facilitated by increases in populations and urbanization, degradation of the natural environment, and international trade and travel (Rogers, 1993). Increased human contact with disease vectors combined with global climate change is believed to be attributed to the appearance and geographic range of many new vector-borne diseases (Winch, 1998). Emerging and reemerging vector-borne diseases such as RVF present challenges to public health officials who must identify these new pathogens and their potential vectors, understand the dynamics of their maintenance and transmission, and investigate the numerous variables that may be responsible for the new outbreaks (Winch, 1998). Combined efforts among various researchers are needed in order to understand the dynamics of the maintenance and transmission of arboviruses such as Rift Valley fever. Although various social, ecological and global variables are at play in this disease, environmental variables heavily influence mosquito biology and, as such, are the focus of this study. This study does not include all variables that may affect the transmission and translocation of RVF, but it does include a focus on two important variables.

CHAPTER II

Literature Review

This chapter examines studies of Rift Valley fever outbreaks; the focus is toward understanding the epidemiology of RVF, the use of GIS in epidemiological studies and the biology of mosquitoes. Literature related to disease and mosquito biology and the use of GIS in modeling efforts is reviewed.

Disease Biology

Rift Valley fever virus, a member of the genus *Phlebovirus* (family *Bunyaviridae*), was first isolated in the Rift Valley in Kenya in 1931 (Gerdes, 2004). The disease was first reported among livestock in Kenya in the early 1900's, but it wasn't until 1930 that RVF was first described. In 1930, Daubney, Hudson, and Garnham investigated an outbreak of disease in sheep in the Rift Valley in Kenya; it was characterized by heavy mortality among lambs and abortions in ewes (Davies, 1975). Major epizootics have occurred in Kenya during 1930-31, 1968, and 1978-79 and in South Africa during 1950-51, 1969 and 1974-76. Severity of Rift Valley fever outbreaks is illustrated by 100,000 deaths of sheep and cattle and 20,000 human infections during the 1950-51 South African outbreak, and 18,000 human cases and 600 deaths during the 1977-78 Egyptian outbreak (House, 1992). Prior to the 1977 Egyptian outbreak, Rift Valley fever had only been described in sub-Saharan and southern Africa. Since, outbreaks have occurred in Saudi Arabia, Yemen, Mauritania, and most recently, Madagascar with 17 deaths in 2008 (WHO, 2007).

Virology

The *Bunyaviridae* is a large family of viruses that contain five genera, four of which infect vertebrates (Gerdes, 2004). Of the four genera that infect vertebrates, three (*Bunyavirus*, *Phlebovirus* and *Nairovirus*) are associated with arthropods. Rift Valley fever virus in physical, chemical and morphological terms is a typical member of the *Bunyaviridae* of the genus *Phlebovirus*. Rift Valley fever virus is an enveloped virus, 90-100 nm in diameter with helical symmetry of the nucleocapsid (House, 1992). The nucleic acid is a single stranded RNA present in three segments, large (L), medium (M), and small (S), that replicates in the cytoplasm and buds into the Golgi apparatus. Intranuclear inclusion bodies formed in the infected cells are composed of microfilamentous structures that may be involved in viral replication. The S segment of the RNA has bi-directional coding or ambisense RNA while the other two segments have negative sense RNA genomes (Gerdes, 2004)

Epidemiology and Transmission

Many species can be infected by the RVF virus, including humans. Rift Valley fever can affect many species of animals including sheep, cattle, goats, buffalo, camels, and monkeys, as well as gray squirrels and other rodents. Sheep and cattle are the primary amplifying hosts (Iowa State, 2006). Viremia without severe disease may be seen in adult cats, dogs, horses, and some monkeys. Severe disease can occur in newborn puppies and kittens. Rabbits, pigs, guinea pigs, chickens and hedgehogs are not known to become viremic. It is not known if animals, such as ungulates, are capable of becoming viremic.

Mosquitoes are primarily responsible for the spread of RVF among animals and humans. Infected mosquitoes develop and transmit the virus to ruminants (cattle, sheep, or goats), allowing for other types of mosquitoes to become infected and rapidly spread the disease to animals and humans. There are two major different types of secondary cycles by which the virus is transmitted to humans: the sylvatic cycle and the urban periodomestic cycle. In both types of cycles, humans are the dead end host (Gerdes, 2004). In the sylvatic cycle, humans become infected through contact with animals to which the virus has been transmitted by zoophilic mosquitoes. In the urban periodomestic cycle, humans become infected through the bites of anhropophilic mosquitoes. A conceptual diagram of the RVF transmission cycle is found below.

Figure 2: Conceptual diagrams of the Rift Valley fever transmission cycle

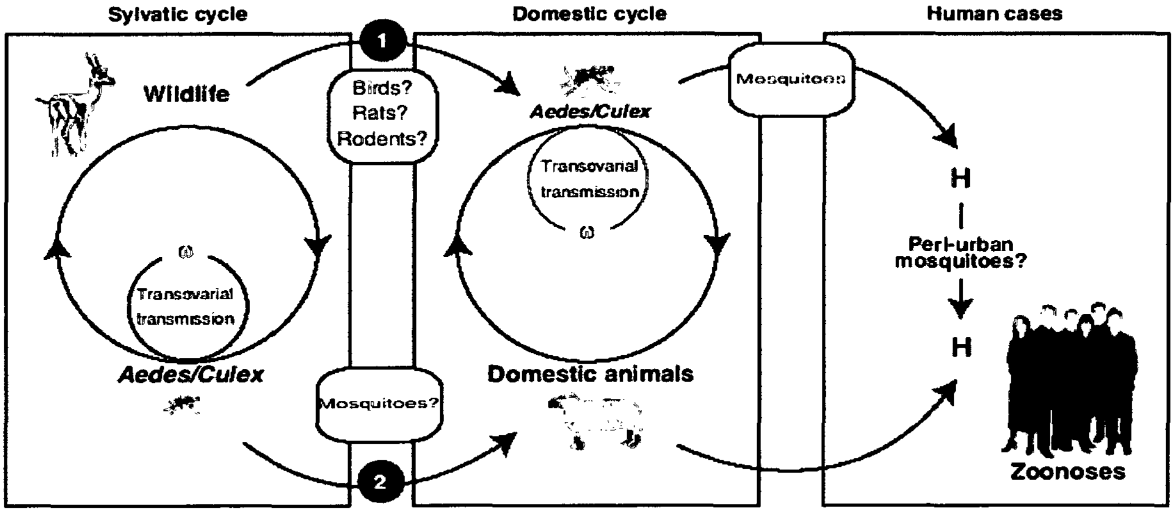


*Diagram by Bernard Mondet (IRD)

Rift Valley fever consists of both epizootic and interepizootic cycles (Gerdes 2004). Outbreaks of RVF are neither seasonal nor annual, but are believed to be linked to the presence of water. Water is very important to most blood-feeding insects, as they have aquatic or semi-aquatic immature stages. Epizootics of RVF are cyclical in nature and characterized by long inter-epizootic periods that may be comparatively short (5 to 15 years in wetter areas) or much longer (15 to 30 years in drier areas). In the interepizootic periods, the virus may be present in forest edge habitats in an endemic cycle between mosquitoes and an unknown vertebrate host. There also may be virus activity each year with low level transmission to livestock associated with *Aedes* mosquitoes that breed in low-lying depressions which flood, when abnormally heavy rainfall raises the water table. Once there is evidence of past RVF virus activity, countries are likely to remain permanently infected. Inter-epizootic survival depends on transovarial transmission of the virus or venereal transmission between mosquitoes with low-level circulation in livestock. It is suspected that outbreaks not attributed to rainfall can be linked to adult mosquitoes coming out of hibernation or re-introduction of the virus via the transport of infected animals.

Mosquito Biology

Rift Valley fever virus has been biologically transmitted by numerous species of mosquitoes under laboratory conditions, including members of the genera *Aedes, Anopheles, Culex*, and *Eretmapodites* (House, 1992). RVF virus has been isolated from at least 30 species of mosquitoes with eight genera, with the *Aedes* species appearing to be involved in the enzootic maintenance cycle. In the epizootic/epidemic cycles, the *Culex* species appear to play a dominant role. Many variables affect the ability of a given mosquito species to transmit a particular arbovirus including intrinsic variables such as susceptibility to oral infection, the ability of the virus to disseminate from the midgut to the hemacoel and infect the salivary glands, and finally for the virus to be secreted in the saliva. Environmental temperature also plays a role in mosquito survival during the interval between an infectious blood meal and when a mosquito is capable of transmitting RVF virus by bite. Mosquito density, vertebrate host density and immune status, viremia levels produced in vertebrates, feeding preference of the mosquito, and longevity of the mosquito also affect whether a mosquito species would be a potential vector of RVF virus.

Mosquito Classification

Mosquitoes belong to the family Culicidae in the Order Diptera, Class Insecta, Phylum Arthropoda (Darsie, 2005). Culicidae is divided into three subfamilies: Anophelinae, Culicinae, and Toxorhynchitinae. There are 38 genera of mosquitoes, of which 34 are in the subfamily Culicinae. There are approximately 3,200 recognized species in Culicidae, with the potential of many more to be discovered in tropical rain forests (Foster, 2002). Table 1 presents the species thus far involved in RVF outbreaks.

Table 1: Mosquito species linked to Rift Valley fever outbreaks in Egypt, Saudi Arabia, Senegal, Kenya and South Africa

Countries	Species
Egypt	*Culex pipiens*
Saudi Arabia	*Culex tritaeniorhynchus*
Senegal	*Aedes vexans*
Egypt	*Aedes caspius*
Senegal	*Aedes ochraceus*
Senegal	*Culex poicilipes*
Senegal	*Aedes dalzieli*
Kenya	*Aedes cumminsii*
Kenya	*Aedes furcifer*

Kenya	*Aedes mcintoshi*
Kenya	*Culex zombaensis*
Kenya	*Mansonia africana*
South Africa	*Culex zombaensis*
South Africa	*Aedes unidentatus*
South Africa	*Aedes circumluteolus*
South Africa	*Aedes dentatus*

Mosquito Life Cycle and General Morphology

The mosquito's life cycle takes place in both the aquatic environment and the terrestrial environment (Foster, 2002). Eggs are typically laid on or near water, and the resulting larvae and pupae live in the aquatic environment, while adults complete their life cycle in the terrestrial environment (Foster, 2002). The mosquito life cycle consist of four phases: eggs, larvae, pupae and adults.

Eggs: Mosquito eggs are often laid in or on water surfaces and in areas subject to flooding (Foster, 2002). *Aedes* eggs are resistant to desiccation and are typically laid in areas that flood, while the eggs of members of the genera *Anopheles*, *Culex*, and *Culiseta*, must be laid on the water surface to avoid desiccation. Embryogenesis begins immediately after the eggs are laid, and depending on the temperature, may take a few days to a week or longer to complete (Becker, 2003). *Culex* spp. and *Culiseta* spp. eggs are non-dormant, and larvae can hatch within a short time period (one day at 30°C and three days at 20°C), whereas the eggs of *Aedes* spp. take much longer time for embryonic development to be completed as they are dependent on flooding (Becker, 2003). If conditions are unfavorable for hatching at 20°C, *Aedes* eggs after eight days are capable of going into a period of diapauses (Becker, 2003). Once immersed in floodwaters, hatching in the *Aedes* species is influenced by dissolved oxygen and water temperature (Becker, 2003).

Larvae: Mosquito larvae (wrigglers or wigglers) can develop in a variety of habitats, as long as there is a film of water present throughout the larval and pupal stages (Foster, 2002). Suitable habitats include temporary to permanent surface water like rain pools, floodwaters, streams, and lakes as well as natural and artificial water-holding containers such as tree holes and discarded tires (Foster, 2002). Larval stage length is dependent upon temperature with various species developing more quickly with increasing temperature. For example, at 30°C *Aedes vexans* and *Culex pipiens* larvae can complete development in about a week, whereas at 15°C development takes about three weeks (Becker, 2003). Larvae can be classified as filter feeders, browsers, or predators, and feed on a variety of food items including microorganisms, algae, protozoa, invertebrates, and detritus (Becker, 2003). Larval control of mosquitoes is typically accomplished using degradable oils that disrupt the surface tension of water and penetrate the tracheal systems of larvae, resulting in suffocation due to their need to obtain oxygen from air (Foster, 2002).

Pupae: Mosquito pupae (tumblers) are comma-shaped, with their body consisting of a cephalothorax (fused head and thorax) and abdomen (Foster, 2002). The pupal stage is very short, lasting only about two days, during which metamorphosis takes place and larval features are lost (Becker, 2003). The pupae's cephalothorax has a pair of respiratory trumpets that provide the developing adult with oxygen, and they do not require food (Becker, 2003). At the pupae stage, rainfall becomes less important as pupae are resistant to desiccation, and adults can emerge even if breeding sites have almost dried out (Becker, 2003).

Adults: Adult mosquitoes emerge from the pupal stage at the water surface by increasing their hydrostatic pressure; this in turn causes the cuticle of the pupa to split (Becker, 2003). The legs and wings are stretched as the mosquito increases the hemolymph pressure, and the soft tissue becomes sclerotized within a few minutes, allowing the mosquito to fly (Becker, 2003). The adult body consists of a head, thorax, and abdomen and is typically covered with patterns of scales, setae, and fine pile. These are characteristics that aid in species identification (Foster, 2002).

Mosquito Mating and Feeding

Mating in mosquitoes occurs when a female enters a lek (swarm of males) and is seized by a male; they copulate face-to-face while flying outside the swarm (Becker, 2003). Female mosquitoes only mate once and store the sperm to fertilize future eggs, whereas the male mosquitoes may mate with multiple females (Becker, 2003). Most female mosquitoes are anautogenous and must take a blood meal from a host animal to acquire adequate protein for the eggs to complete oogenesis (Foster, 2002). Female mosquitoes locate their potential blood meal hosts through sensory cues, such as olfactory, visual, and thermal stimuli, and through the use of host odors detected by antennal receptors (Becker, 2003). First, in order to locate a host, female mosquitoes use a non-orientated flight pattern characterized by a random motion in search of carbon dioxide, lactic acid, octenol, acetone, butanone, or phenolic compounds which they are attracted to (Becker, 2003). When a stimulus is detected, the flight behavior is changed and oriented towards the host's location and the mosquito flies upwind in a zigzag pattern that brings it closer to the stimulus. As the mosquito nears the host, it visually locates the host, and compound eyes discriminate between form, movement, light contrast, and color (Becker, 2003).

Once the host is located, using temperature and thickness of the skin as stimuli, the female probes the skin several times with her proboscis in order to find a capillary (Becker, 2003). The mosquito's proboscis contains the mouthparts, which include the labrum, paired mandibles, hypopharynx, paired maxillae, and labium, in which all but the labium have evolved into hardened, fine stylets that form a tightly fitting fascicle that penetrates the host's skin (Foster, 2002). When feeding, the fascicle of stylets penetrates the skin as the labium is bent backward on the surface of the skin (Foster, 2002). The stylets penetrate epidermal and subepidermal tissue in search of small arterioles or venules (Foster, 2002). The hypopharynx releases saliva that contains an antihemostatic enzyme, called apyrase, which inhibits platelet aggregation and allows blood to flow freely from punctured vessels, and anticoagulants, which prevent the blood from clotting (Foster, 2002). The stylets work with the apyrase to aid the mosquito in finding a blood vessel, shortening the time required for feeding on a host (Foster, 2002). After finding a vessel, the fascicle is inserted into the lumen of the vessel. Blood is ingested up the food canal using the cibarium and pharyngeal pumps, is transported through the esophagus, and accumulates in the midgut (Foster, 2002). Receptors in the abdomen signal the mosquito that there is sufficient blood in the midgut, and the female mosquito must use her forelegs to remove the fascicle from the skin (Foster, 2002). Once the female mosquito is fully engorged with blood, she is unable to fly long distances and will seek a suitable resting site in which to digest the blood meal and allow for egg development

(Foster, 2002). Oviposition normally occurs two to four days after ingestion of a blood meal, but this process may be longer depending on the temperature (Becker, 2003). Mosquitoes may lie between 50 to 500 eggs, and the life cycle repeats for these eggs (Becker, 2003).

Mosquitoes and Disease Transmission

Mosquitoes, since they feed on human and animal blood and may thereby transmit diseases, are of significant public health and veterinary importance, (Foster, 2002). The blood-feeding process introduces mosquito saliva containing foreign proteins into the host's bloodstream, resulting in a histamine reaction that may be antigenic and lead to hypersensitivity, and may directly introduce microorganisms that cause disease (Foster, 2002). Blood feeding also creates a wound at the bite site that may allow for secondary infection by bacteria or other microorganisms (Foster, 2002). Diseases transmitted by mosquitoes typically fall into three categories: viruses, malaria protozoans, and filarial nematodes (Foster, 2002). Of the over 520 viruses transmitted by arthropods (arboviruses), approximately half of these are transmitted by mosquitoes (Foster, 2002). About 100 of these are zoonoses, and thus infect humans as well as animals, with the most significant of these viruses belonging to four genera in the three families: Togaviridae, Flaviviridae, and Bunyaviridae (Foster, 2002). The family Togaviridae, genus *Alphavirus*, includes eastern equine encephalitis (EEE), western equine encephalitis (WEE), and Venezuelan equine encephalitis (VEE), among others. The family Flaviviridae, genus *Flavivirus*, includes dengue, yellow fever, Japanese encephalitis, and St. Louis encephalitis (SLE) among others. The family Bunyaviridae, genus *Bunyavirus*, includes California encephalitis, Jamestown Canyon virus, and La

Crosse encephalitis among others. Included in the family Bunyaviridae is the genus *Phlebovirus*, which includes Rift Valley fever. These viruses may be transmitted by a wide range of mosquito vector species, including those belonging to the genera *Aedes*, *Culex*, *Culiseta*, *Ochlerotatus*, and others (Foster, 2002).

Most mosquito-borne viruses are similar in the disease symptoms in that they generally cause flu-like symptoms, including fever, as well as joint and muscle pain (Foster, 2002). In diseases such as Rift Valley fever, hemorrhagic fever and encephalomyelitis may also occur. Morbidity may be high for cases involving fever, while the case mortality rate is generally low. Although chronic illness does not often occur in humans with these mosquito-borne viruses, the consequences of these infections may be long-lasting. Additionally, since these viruses have RNA (ribonucleic acid) genomes and are capable of multiplying in both vertebrate and invertebrate cells, they have the capacity to rapidly evolve into antigenically variable strains with widespread virulence, which may result in the emergence of highly virulent, epidemic strains (Foster, 2002).

The transmission mechanisms for mosquito-borne viruses are fairly well known. Arboviruses cause cytopathic effects and cell destruction in vertebrate cells and chronic cellular infection without cytopathology occurs in invertebrate cells (Foster, 2002). If there is a sufficient amount of circulating virus in its blood to provide an infectious dose to the mosquito in the vertebrate, the mosquito becomes infected during blood feeding (Foster, 2002). The blood enters the midgut of the mosquito and virions bind to and pass through the microvilliar membrane and into midgut epithelial cells. The viruses then replicate and virions bud off from these cells (Foster, 2002). Virions pass through the basal lamina, enter the hemolymph, and are then disseminated throughout the body of the mosquito to infect and replicate in the mosquito's tissues, to include the salivary glands, fat bodies, ovaries, and nerves (Foster, 2002). Transmission of infectious virions to another host occurs when a mosquito salivates as it probes the tissue of a host (Foster, 2002). Transovarial transmission, in which the female mosquito infects her progeny, allows females of the next generation to transmit the virus during their first blood meal (Foster, 2002). In some species and viruses, venereal transmission from male to female mosquitoes has also been documented, but this phenomenon has not been studied in Rift Valley fever (Foster, 2002).

Temperature Thresholds

Temperature plays an important role in the life cycle of mosquitoes and in the replication and transmission of diseases such as Rift Valley fever. Mosquitoes are critically dependent on climate for their survival; the climate circumscribes the distribution of mosquito-borne diseases and affects the timing and intensity of outbreaks (Githeko, 2000). The effect of climate change on transmission is most often observed at the extremes of the range of temperatures at which transmission occurs, 14 -18 degrees Celsius at the lower end and 35-40 degrees Celsius at the upper end. Warmer temperatures speed the development of the parasites in mosquitoes, raising the odds of disease transmission while cooler temperatures slow reproduction rates and disease replication with extreme cold weather killing adult mosquitoes and over-wintering eggs and larvae (Epstein, 2000). A threshold temperature above which death is inevitable and the minimum temperature below which the mosquito cannot become active vary among mosquito species.

Studies have been conducted on the effect of environmental temperature on the susceptibility of *Aedes fowleri, Aedes taeniorhynchus, Aedes albopictus*, and *Culex pipiens* to Rift Valley fever (Brubaker, 1998, Turell, 1993, Turell, 1989). In Brubaker *et al.*, (1998) it is found that significantly fewer *Culex pipiens* contain detectable virus when they were held at cooler temperatures (13°C, 17°C and 19 °C) than at the warmer temperature (26 °C). This finding is in contrast to the finding that the adult holding temperature after a viremic blood meal affected infection rates in females. Overall, the study finds that significantly fewer mosquitoes contain detectable virus when they are held at cooler temperatures than warmer temperatures. This study determines that the role of environmental temperature needs to be considered in studies on the epidemiology of arthropod-borne viruses such as Rift Valley fever.

Another study was conducted to determine the effect of environmental temperature on the susceptibility of *Aedes taeniorhynchus* mosquitoes on Venezuelan equine encephalitis (VEE) and Rift Valley fever viruses (Turell, 1993). In this study it was found that mosquitoes reared at low temperature (19°C) are significantly more susceptible to infection with RVF virus than are those mosquitoes reared at 26°C, regardless of the temperature at which mosquitoes are held after exposure to virus. The infection rate for those raised at the lower temperature is 70 percent, which is greater when compared to an infection rate of 48 percent for those mosquitoes raised at the higher temperature. Also, for *Aedes taeniorhynchus* exposed to VEE virus, similar results are found where the infection rate in mosquitoes reared at low temperature was significantly greater than was that for mosquitoes reared at 26°C, regardless of the temperature at which mosquitoes are held after exposure to virus (19°C or 26°C). This study concludes that a combination of low larval-rearing temperature and warm adult-holding temperature results in the most efficient mosquito transmission of both viruses.

Another major study was conducted on the effects of environmental temperature on the ability of Senegalese *Aedes fowleri* to transmit Rift Valley fever virus mimicked the temperatures to which a mosquito might be exposed in October in southeastern Senegal and includes three test groups (Turell, 1989). In one group, the temperature tested was 17°C, in another group the temperature tested was 28°C and a third group had a cyclic (17°C-28°C) temperature regimen. In all three groups, infection rates are similar. However, it is found that RVF virus disseminated to the haemocoel more rapidly in mosquitoes held at higher temperatures, with peak dissemination rates reached at 11, 18 and greater than 42 days after the infectious blood meal for mosquitoes held at 28°C, cyclic and 17°C, respectively. It is also found that the time interval between ingestion of the viremic blood meal and the first transmission by bite was inversely related to environmental temperature. This study concludes that environmental temperature significantly affects the vectorial capacity of *A. fowleri* for RVF virus, with transmission occurring earlier and at a higher rate in mosquitoes held at higher temperatures.

Rainfall Thresholds

Rift Valley fever outbreaks are known to follow periods of widespread and heavy rainfall associated with the development of the intertropical convergence zone, the region in the equatorial tropics where air currents from the north and south converge and produce rainfall (Linthicum, 1999). These heavy rainfalls flood mosquito breeding habitats in East Africa, which contain infected *Aedes* mosquito eggs, and subsequently serve as good habitats for other *Culex* species mosquito vectors. The effect of rainfall on mosquitoes as vectors has in the past been done on other arthropod borne diseases such as malaria (Koenraadt, 2004). In Koenraadt *et al.* (2004), the population dynamics of the larval and adult life stages of the malaria vector, *Anopheles gambiae,* are studied in Miwani, Western Kenya, in relation to meteorological conditions (Koenraadt, 2004). In this study, the larval density within a habitat, the number of larval habitats, and sibling species composition are investigated as determinants of larval population dynamics. The female vector densities inside local houses and sibling species composition are investigated as determinants of adult population dynamics. Rainfall is found to be significantly correlated with the number of *A. gambiae* larval habitats during the first 6 weeks. Correlations over the entire 5-month study period are less clear. Rainfall is significantly correlated with the number of female *A. gambiae* collected from CDC-light traps in the study houses. Overall, the researchers conclude that both larval and adult populations show a significant increase in the proportion of *A. gambiae* within the mixed population of *A. gambiae* and *A. arabiensis* over time and that rainfall played a role.

Climate and satellite indicators have been used to forecast Rift Valley fever epidemics. In Linthicum *et al.* (1999), climate and satellite indicators are used to forecast RVF epidemics. In this study, it is found that Rift Valley fever virus outbreaks in Kenya from 1950 to May 1998, and probably earlier, followed periods of abnormally high rainfall. An analysis of this record and Pacific and Indian Ocean sea surface temperature anomalies, coupled with satellite normalized difference vegetation index data, show that prediction of Rift Valley fever outbreaks may be made up to 5 months in advance of outbreaks in East Africa. Although this study finds that concurrent near-real-time monitoring with satellite normalized difference vegetation data may identify actual affected areas, it also identifies the need for future research regarding the role of rainfall in the transmission of RVF.

GIS and Vector-Borne Diseases

Although modeling the biology and transmission characteristics of vector-borne diseases is complex, a parsimonious model should maximize predictions without model over-parameterization. Existing GIS-based models are reviewed below for Lyme disease and malaria, both of which are vector-borne diseases.

Lyme disease

Lyme disease is a tick transmitted bacterial infection that affects not only humans but also domestic animals. Studies on Lyme disease have shown the ability to generate risk models using GIS. In Glass *et al.* (1995), a GIS-based system is used to identify and locate residential environmental risk variables for Lyme disease. It is found that eleven of the fifty-three variables are associated with an increased risk of acquiring Lyme disease. Once these significant variables are discovered, a risk model is generated that combines the GIS with logistic statistical analysis. The authors concluded that combining GIS with epidemiologic methods could rapidly identify risk variables of zoonotic diseases over large areas. Nicholson *et al.* (1996), also use GIS to identify variables that may regulate tick distribution, and thus, Lyme disease risks. The researcher's findings are combined to create a model that predicts Lyme disease transmission risk, thereby demonstrating the utility of incorporating geospatial-modeling techniques in studying the epidemiology of Lyme disease.

Malaria

Malaria is a vector-borne infectious disease caused by a protozoan parasite that can be fatal in humans. Studies on malaria have demonstrated the ability to generate risk models using GIS. Beck *et al.* (1994), integrate remotely sensed data and Geographic Information Systems capabilities to identify villages with high vector-human contact risk. Results indicate that villages with high malaria vector-human contact risk can be identified using remote sensing and GIS technologies. In Srivastava *et al.* (2001), a model is also developed that predicts malaria risk. A predictive habitat is developed for forest malaria vector species using GIS and a Boolean operator to map areas where the species is likely to be found. The results indicate that GIS-based distribution can pinpoint areas of occurrence of *Anopheles dirus* at the micro-level, where species-specific environmental friendly control measures can be strengthened. Srivastava *et al.* (2001), points out that accurate delineation of favorable mosquito habitats is closely linked with disease risk. Both studies suggest the utility of GIS in modeling vector-borne diseases.

It is estimated that by the end of the 21st century, the region of potential malaria transmission will increase from 45% of the world's population to about 60% due to climate change (Epstein, 2000). Other studies have shown that these models are too simplistic and may exaggerate the risk of malaria resurgence, or that even under the most extreme scenarios, there will be few changes in malaria distribution (Hay, 2002; Rogers, 2002). Malaria has begun to reappear in areas to the north and south of the tropics, and during the 1990s, when the United States was experiencing one of the hottest decades on record, outbreaks of locally transmitted malaria occurred in Texas, Florida, Georgia, Michigan, New Jersey, and New York (Epstein, 2000). It has been suggested that as temperate areas become warmer and more humid with climate change; the risk of malaria will increase (Epstein, 2000). The tropical highlands of Africa, typically a defense against malaria because of the lower temperatures, are also at risk for the introduction of malaria, even with only a minor temperature increase (Martens, 1999).

CHAPTER III

Methodology

Research Questions and Hypothesis

The purpose of this study is to identify the relationship between temperature and rainfall and Rift Valley fever outbreaks in Kenya, Madagascar and South Africa. To be specific the following research questions will be answered:

1. Did positive rainfall anomalies occur prior to and during the 2006-2007 Rift Valley fever outbreaks in Kenya?
2. Did positive rainfall anomalies occur prior to and during the 2008-2009 Rift Valley fever outbreaks in South Africa?
3. Did positive rainfall anomalies occur prior to and during the 2008-2009 Rift Valley fever outbreaks in Madagascar?
4. Were the temperature ranges during the 2006-2007 Rift Valley fever outbreaks in Kenya different than historical temperature ranges for Kenya?
5. Were the temperature ranges during the 2008-2009 Rift Valley fever outbreaks in Madagascar different than historical temperature ranges for Madagascar?
6. Were the temperature ranges during the 2008-2009 Rift Valley fever outbreaks in South Africa different than historical temperature ranges for South Africa?

Hypothesis:

1. **H_0**: There will be no difference in the rainfall ranges from 1982-2005 than from 2006-2007 in Kenya.

H_A: Higher than average rainfall ranges will be found from 2006-2007 surrounding the RVF outbreak in Kenya than from 1982-2005.

2. **H_0**: There will be no difference in the rainfall ranges from 1982-2007 than from 2008-2009 in Madagascar.

   H_A: Higher than average rainfall ranges will be found from 2008-2009 surrounding the RVF outbreak in Madagascar than from 1982-2007.

3. **H_0**: There will be no difference in the rainfall ranges from 1982-2007 than from 2008-2009 in South Africa.

   H_A: Higher than average rainfall ranges will be found from 2008-2009 surrounding the RVF outbreak in South Africa than from 1982-2007.

4. **H_0**: There will be no difference in the temperature ranges from 1982-2005 than 2006-2007 in Kenya.

   H_A: Higher than average temperature ranges will be found from 2006-2007 surrounding the RVF outbreak in Kenya than from 1982-2005.

5. **H_0**: There will be no difference in the temperature ranges from 1982-2007 than from 2008-2009 in Madagascar.

   H_A: Higher than average temperature ranges will be found from 2008-2009 surrounding the RVF outbreak in Madagascar than from 1982-2007.

6. **H_0**: There will be no difference in the temperature ranges from 1982-2007 than from 2008-2009 in South Africa.

   H_A: Higher than average temperature ranges will be found from 2008-2009 surrounding the RVF outbreak in South Africa than from 1982-2007.

Research Design

Description of the Data Set

Rift Valley fever outbreak information was retrieved from the World Organization for Animal Health (OIE) World Animal Health Information System (WAHIS). The main mission of the OIE is to ensure the transparency of the world animal health situation. In January 2000, based on the commitment of OIE Member Countries and Territories to notify cases of the main animal diseases detected in their territories (including zoonoses), WAHIS was launched. Members of the OIE must notify the OIE whenever an important epidemiological event occurs by sending an immediate notification. Immediate notification reports must include the reason for the notification, the name of the disease, the affected species, the geographical area affected, the control measures applied and any laboratory tests carried out or in progress. Rift Valley fever is identified as a transmissible disease that has the potential for very serious and rapid spread, irrespective of national borders by the OIE and thus is a reportable disease. Kenya, Madagascar and South Africa are current members of the OIE who have provided notification reports of Rift Valley fever activity since 2000.

Because Kenya, Madagascar and South Africa had recent outbreaks with valid and reliable outbreak information, these three geographically different countries were chosen for the analysis. For each country four datasets were created including a long term dataset, a short term dataset and two datasets for the years when outbreaks occurred. For the long term dataset for each country the years 1982-2004 were chosen as this provided a minimum of 20 years of data which would allow for a sufficient long term average. Although during the years 1982-2004 Madagascar and South Africa experienced no reported RVF activity, Kenya had an outbreak occurring in 1997-1998, therefore the long term dataset for Kenya includes years with and without RVF activity. Consequently, short term datasets were created for each country during years when no RVF activity was reported in all three countries. For Kenya a short term dataset was created for the years 1999-2005 and for Madagascar and South Africa short term datasets were created for the years 1999-2007. Datasets were also created for each year of the outbreaks under analysis. For Kenya a dataset was created with rainfall and temperature data for the year 2006 as well as 2007. For Madagascar and South Africa datasets were created for the years 2008 as well as 2009. Analysis for the study began in August of 2009 and therefore data for 2009 ended in July of 2009 for Madagascar and South Africa. Table 2 presents the RVF outbreaks occurring in the countries of Kenya, Madagascar and South Africa as well as the datasets for each country chosen for the study.

Table 2: RVF outbreaks for Kenya, Madagascar and South Africa and datasets under analysis for the study

Country	RVF Outbreaks	Outbreak under analysis for this study	Datasets under analysis for study
Kenya	• 1930-1931 • 1997-1998 • 1968 • 1978-1979 • 1997-1998 • 2006-2007	• 2006-2007	• Long term dataset (1982-2004) • Short term dataset (1999-2005) • Outbreak dataset (2006) • Outbreak dataset (2007)
Madagascar	• 2008-2009	• 2008-2009	• Long term dataset (1982-2004) • Short term dataset (1999-2007) • Outbreak dataset (2008) • Outbreak dataset (2009)
South Africa	• 1950-1951 • 1969 • 1974-1976 • 2008-2009	• 2008-2009	• Long term dataset (1982-2004) • Short term dataset (1999-2007) • Outbreak dataset (2008) • Outbreak dataset (2009)

The environmental variables used in the GIS analysis were selected based on their direct and indirect influence on the ecology of RVF (mainly vectors and reservoirs). These variables are temperature and rainfall. Gridded rainfall data for Africa was acquired from the National Oceanic & Atmospheric Administration (NOAA) Climate Prediction Center Famine Early Warning System Rainfall Estimate archives. Temperature data was acquired from the NOAA Global Data Assimilation System Temperature archive:

- **National Oceanic & Atmospheric Administration Climate Prediction Center Famine Early Warning System Rainfall Estimate archives RFE 2.0**– Rainfall estimates are from 4 sources; 1) Daily GTS rain gauge data for up to 1000 stations 2) AM SU microwave satellite rainfall estimates up to 4 times per d ay 3) SSM /I satellite rainfall estimates up to 4 times per day 4) GPI cloud-top IR temperature rainfall estimates on a half-hour basis. Three satellite estimates are first combined linearly using predetermined weighting coefficients, then are merged with station data to determine the final African rainfall. Binary graphical output files are produced daily at approximately 3pm EST with a resolution of 0.1° and spatial extent from 40°S-40°N and 20°W-55°E. Data is archived and available from 1982 to present day.
- **National Oceanic & Atmospheric Administration Climate Prediction Center Famine Early Warning System Little Endian Directory -** The Climate Prediction Center's FEWS-NET staff monitor meteorological and climatic phenomena for the continent and collect maximum and minimum temperatures

for weather monitoring stations throughout the continent of Africa. Data is archived in a directory entitled Little Endian and is produced at a 0.5 degree resolution product. Data is available from 1982 to present day.

This is a retrospective evaluation of temperature and rainfall variability and their possible relationship to historical Rift Valley fever outbreaks. GIS can provide a suitable framework within which such variables can be integrated, analyzed and modeled. The present work deals with the use of GIS technology to analyze the environmental variables (temperature, rainfall) in relation to RVF outbreaks in Kenya, Madagascar and South Africa. GIS functions will be used to identify how these environmental variables have played a role in historical GIS outbreaks. Identification of the environmental variables associated with the disease will not only allow for mapping its current spatial patterns, but for predicting its distribution under future developmental and/or environmental changes. Table 3 presents the variable, theoretical and operational definitions for this study.

Table 3: Variable, Theoretical and Operational Definitions

Variable	**Theoretical Definition**	**Operational Definition**
Environmental Variables:		
Temperature	Temperature is a degree of hotness or coldness that can be measured using a thermometer. Temperature is measured in degrees on the Fahrenheit, Celsius, and Kelvin scales (Kerlin, 1982)	• Monthly maximum daily temperature (tmax) • Monthly minimum daily temperature (tmin)
Rainfall	Any product of the condensation of atmospheric water vapor that is deposited on the earth's	• Monthly total rainfall (rain)

	surface (Groisman, 2005)	
Outcome Variable:		
Outbreak	The occurrence in a community or region of cases of an illness with a frequency clearly in excess of normal expectancy (CDCU, 2009)	• Morbidity • Mortality

Study sample and setting

The virus which causes Rift Valley fever was first isolated in 1931 near Naivasha Lake in the region of the Rift Valley in Kenya (Daubney, 1931). Since then Rift Valley fever outbreaks have occurred in the countries of Kenya, South Africa, Mozambique, Egypt, Tanzania, Madagascar, Zimbabwe, Sudan, Somalia, Saudi Arabia and Yemen. Outbreaks in Kenya occurred in 1930, 1968, 1978, 1997 and 2006, South Africa in 1950, 1969, 1974 and 2006, Mozambique in 1969, Egypt in 1997, Tanzania in 1997 and 2007, Madagascar in 2008, Zimbabwe in 1976, Sudan in 2007, Somalia in 1997, and Saudi Arabia and Yemen in 2000. Reliable and valid outbreak information for animal outbreaks of Rift Valley fever is only available from 2000 when the OIE World Animal Health Information Database first became available. Therefore for the purpose of this study the three ecologically different countries of Kenya, South Africa and Madagascar were chosen that have had RVF outbreaks occur since 2000.

The country of Kenya is 582,646 sq km and contains most of the world's major climatic conditions (Nations Encyclopedia, 2009). Kenya's topography is a study of contrasts with features ranging from deserts to snow capped mountains, sandy coastlines to freshwater lakes, savannah grasslands to fertile agricultural plantations, extinct volcanoes to coral reefs. The eastern half of the country slopes gently downward towards sea level while to the west a series of hills and plateaus alternate upward to the Rift Valley. Although less than 8% of the land in Kenya is used for crop and feed production, agriculture remains the most important economic activity with 80% of the work force engaging in agriculture of food processing. Farming is typically carried out by small producers who usually only cultivate around 5 acres of land using limited technology for the purpose of growing cash crops. Around 3 million farming families currently can be found in Kenya and account for 75% of the total production. European-owned coffee, tea and sisal plantations account for the remaining total production. Most small farmers in Kenya in addition to crop production also keep livestock with about 50% of the livestock being kept by low-income households (Ishana, 2002). Livestock typically found on Kenyan farms include cattle, chickens, pigs, goats and sheep with most of these animals roaming freely on the farm. Livestock keepers in Kenya often do not vaccinate their animal and have very limited knowledge on zoonotic diseases such as Rift Valley fever. It is often only due to farmers reporting spontaneous abortions in their livestock population and veterinarians testing that data is reported to the OIE. Detailed Rift Valley fever animal outbreak information reported to the OIE in Kenya is presented in Table 4. Animal outbreaks in Kenya were the focus of analysis as human outbreak information in Kenya coincided with animal outbreaks. Information of the Rift Valley fever human outbreaks in Kenya is presented in Table 5. Human Rift Valley fever is presented for informational purposes and is based on World Health Organization (WHO) reports.

Table 4: Rift Valley fever animal outbreaks in Kenya, 2006-2007

Region	Start Date	End Date	Affected Animals			
Galmagara, Garissa, NORTH-EASTERN	12/4/06	6/24/07	**Species**	**Susceptible**	**Cass**	**Deaths**
			Cattle	4000	500	30
			Goats	10000	1500	95
			Camelidae	4000	500	5
			Sheep	9000	1500	105
Hola, Tan River, COAST	12/4/06	4/5/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		2	0
Kilifi, Kilifi, COAST	1/21/07	4/18/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		39	
Ikanga, Ndetani, Maliku, Kyoani, Ngungi, Kituti, Kitui, EASTERN	1/21/07	4/18/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		44	
Olot, Marakwet, RIFT VALLEY	1/21/07	4/18/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		2	
Baibariu, Meru North, EASTERN	12/4/06	2/22/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		4	
Ngare Ndare Meru Central, EASTERN	12/4/06	5/4/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		3	
Giathugu, Nyeri, CENTRAL	12/4/06	4/5/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		1	
Gatandu, Gikambura, Kiambu, CENTRAL	2/6/06	4/16/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		4	
Mwatate Sisal, Lualenyi Ranch,	12/4/06	1/16/07	**Species**	**Susceptible**	**Cases**	**Deaths**

Taveta, Tiata Taveta, COAST			Sheep / goats		16	
Kenol, Maragua, CENTRAL	1/22/07	6/16/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		7	
Njoguini, Rurii, Murang'a, CENTRAL	12/4/06	6/24/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		5	
Dantu, Kutulo, Gari, Didkuro, Mandera, NORTH-EASTERN	12/4/06	3/3/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		24	
Lango Baya, Viriku, Malindi, COAST	1/8/07	4/10/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		17	
Karia, Meru Central, EASTERN	12/4/06	5/4/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		3	
Tebere, Kirinyaga, CENTRAL	12/4/06	5/4/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		6	
Longewan, Sindani, Kiserian, Maji Ndege, Baringo, RIFT VALLEY	2/2/07	5/4/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		29	
Dadaab, Galmagara, Bura, Shantabak, Mbalambala, Danyiri, Garissa, NORTH-EASTERN	12/4/06	1/19/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		6	

Kavuti, Ikime, Malawa, Mwingi, EASTERN	1/22/07	4/12/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		26	
Kibao, Machakos, EASTERN	2/12/07	2/26/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		8	
Nanyuki, Laikipia, RIFT VALLEY	1/25/07	2/25/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		10	
Masalani, Ijara, NORTH-EASTERN	12/4/06	3/3/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		2	
Kinango, Musiu, Lunga Lunga, Kidzumbani, Kwale, COAST	12/4/06	4/16/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		59	
Kasuvi, Kathyaka, Ntahnge, Makueni, EASTERN	1/23/07	5/14/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		35	
Township, Meru South, EASTERN	1/31/07	4/7/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		7	
Ruiru, Thika, CENTRAL	12/4/06	6/22/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		4	
Kasarani, Nairobi, NAIROBI AREA	12/4/06	4/5/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		3	
Lamu, Lamu, COAST	12/4/06	2/23/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		1	

Mombasa, Mombasa, COAST	1/4/07	2/3/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep /goats		13	
Evurore, Karaba, Waschoro, Mutito, Mbeere, EASTERN	12/4/06	5/10/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		6	
Karurumo, Embu, EASTERN	12/4/06	3/3/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		1	
Adadi Jole, Wajir, NORTH-EASTERN	12/27/06	1/29/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		18	
Godoma, Moyale, EASTERN	1/29/07	3/30/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		11	
Tara, Machakos, EASTERN	12/4/06	1/26/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		1	
Nodnyo, Laresoro, Lerata, Sereolipi, Samburu, RIFT VALLEY	2/5/07	4/1/07	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		15	
Marula, Nakuru, RIFT VALLEY	12/4/06	3/8/06	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep / goats		2	

Table 5: Rift Valley fever human outbreaks in Kenya 2006-2007

Region	**Start Date**	**End Date**	**Human Cases and Death**		
Garissa district, North Eastern Province	11/30/06	3/12/07	**Suspected Cases**	**Confirmed Cases**	**Suspected Deaths**
			208	58	57
Ijara district, North Eastern Province	11/30/06	3/12/07	**Suspected Cases**	**Confirmed Cases**	**Suspected Deaths**
			125	22	23
Coast Province, Wajir district	11/30/06	3/12/07	**Suspected Cases**	**Suspected Deaths**	
			15	12	
Coast Province,	11/30/06	3/12/07	**Suspected**	**Suspected**	

Tana River district			**Cases**	**Deaths**	
			15	6	
Coast Province, other areas	11/30/06	3/12/07	**Suspected Cases**		
			111		
Eastern Province *Isiolo*			**Suspected Cases**	**Confirmed Cases**	
			8	3	
Eastern Province, other areas			**Suspected Cases**		
			6		
Central Province, Kirinyanga	11/30/06	3/12/07	**Suspected Cases**	**Confirmed Cases**	**Suspected Deaths**
			4	4	1
Central Province, Kajiado	11/30/06	3/12/07	**Suspected Cases**	**Confirmed Cases**	**Suspected Deaths**
			3	1	3
Central Province, Maragua	11/30/06	3/12/07	**Suspected Cases**	**Confirmed Cases**	
			1	1	
Central Province, Thika	11/30/06	3/12/07	**Suspected Cases**	**Confirmed Cases**	
			2	1	
Central Province	11/30/06	3/12/07	**Suspected Cases**		
			4		
Rift Valley Province	11/30/06	3/12/07	**Suspected Cases**		
			183		

Madagascar is the fourth largest island in the world consisting mainly of a block of crystalline rocks (Rasambainarivo, 2009). It is generally described as a plateau rising sharply from the narrow plain of the east coast and descending in a series of steps to the strip of sedimentary rocks along the west coast. The eastern edge of the island consists of a high plateau cut by deep gorges and waterfall. Scattered around the island are numerous volcanic outcrops that produce heights over 6,000 ft (the highest point being Tsaratanan at 9,450 ft). Ankaratra and Andringingtra are two former volcanic areas, which are over 8,500 feet. Agriculture, including forestry and fishing is a mainstay of the economy, accounting for more than one-fourth of the gross domestic product and employing 80% of the population. Malagasy farmers typically cultivate around 4 acres of land and farming activities normally include both crops and livestock, the products of which are aimed mostly at domestic sustenance. Cattle, sheep, goats, pigs, oxen and chickens are the livestock found most often on Madagascar farms. Detailed Rift Valley fever animal outbreak information reported to the OIE in Madagascar is presented in Table 6. Animal outbreaks in Madagascar were the focus of analysis as human outbreak information in Madagascar coincided with animal outbreaks. Information of the Rift Valley fever human outbreaks in Madagascar is presented in Table 7. Human Rift Valley fever is presented for informational purposes and is based on World Health Organization (WHO) reports.

Table 6: Rift Valley fever animal outbreaks in Madagascar 2008-2009

Region	**Start Date**	**End Date**	**Affected Animals**			
Antady, Fianarantsoa, Fianarantsoa I, HAUTE MATSIATRA	11/16/08	1/31/09	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	9	3	3
Nasandratrony, Isandra, HAUTE MATSIATRA	11/16/08	1/31/09	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle		2	1
Ambanimaso, Fianarantsoa,	11/22/08	1/31/09	**Species**	**Susceptible**	**Cases**	**Deaths**

Fianarantsoa I, HAUTE MATSIATRA			Cattle	9	4	3
Imandry, Fianarantsoa, Fianarantsoa I, HAUTE MATSIATRA	11/24/08	1/31/09	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	8	3	3
Tsaramandroso, Fianarantsoa, Fianarantsoa I, HAUTE MATSIATRA	11/29/08	1/31/09	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	9	4	4
Antanifotsy, Fianarantsoa, Fianarantsoa I, HAUTE MATSIATRA	12/10/08	1/31/09	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	7	2	0
Ampasina, Sahambavy, Lalangina, HAUTE MATSIATRA	12/11/08	1/31/09	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	3	2	2
Ambonifehidrano, Fianarantsoa, Fianarantsoa I, HAUTE MATSIATRA	12/13/08	1/31/09	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	2	1	1
Marodinta, Nasandratony, Isandra, HAUTE MATSIATRA	12/13/08	1/31/09	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	1	1	1
Avaradrano, ANTANANARIVO	2/4/08	10/30/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	9	2	
Andohasahalava, Vohitsaoka, Ambalavao, HAUTE MATSIATRA	3/12/09	5/29/09	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	3	1	1

Table 7: Rift Valley fever human outbreaks in Madagascar 2008

Region	**Start Date**	**End Date**	**Human Cases and Death**		
Alaotra Mangoro, Analamanga, Itasy,	4/9/08	4/18/08	**Suspected Cases**	**Confirmed Cases**	**Suspected Deaths**

Vakinakaratra and Anosy Regions			418	59	17

South Africa is a middle-income, emerging market with an abundant supply of natural resources as well as having developed financial, legal, communications, energy and transport sectors (CIA, 2009). However, unemployment remains high, lack of empowerment among the disadvantaged groups remain and outdated infrastructure has constrained growth. Most of South Africa has elevations of over 3,000 ft and at least 40% of the surface is at an elevation of over 4,000 ft. The land rises steadily from west to east to the Drakensberg Mountains, the tallest of which is Mont-aux-Sources with an elevation of 10,823 ft. The coastal belt in the west and south is between 500 ft to 600 ft above sea level, and is very fertile. North of the coastal belt stretch, we find the The Karoo, which are bounded by mountains, lie higher than the coastal belt, and are semi-arid to arid, merging into sandy wastes that ultimately join the Kalahari Desert. South Africa is divided into a number of farming regions according the climate, natural vegetation, soil type and farming practices with agricultural activities ranging from intensive crop production and mixed farming in high rainfall areas to cattle ranching in the bushveld and sheep farming in more arid regions. Livestock is the largest agricultural sector, with a reported 13.8 million cattle and 28.8 million sheep being found in South Africa. Detailed Rift Valley fever animal outbreak information in South Africa reported to the OIE is presented in Table 8. No human Rift Valley fever activity was reported in South Africa in 2008 or 2009.

Table 8: Rift Valley fever animal outbreaks in South Africa 2008 - 2009

Region	Start Date	End Date	Affected Animals			
Ngwenya, Ehlanzeni, MPUMALANGA	1/14/08	3/14/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Buffaloes	371	7	7
Grootboom, Nkomazi, MPUMALANGA	2/7/08	3/7/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	316	126	19
Marlothi, Nkomazi, MPUMALANGA	2/7/08	3/7/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	147	78	1
One Tree Hill, Nkomazi, MPUMALANGA	2/27/08	3/27/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	462	2	2
Buiskop, Bela-Bela, LIMPOPO	3/1/08	4/1/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	300	7	7
Grietjie, Ba-Phalaborwa, LIMPOPO	3/7/08	5/7/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	20		
			Buffaloes	60	2	2
Paul, Ba-Phalaborwa, LIMPOPO	3/7/08	4/7/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	60	2	2
Leeuwkraal, Cullinan, GAUTENG	3/7/08	4/7/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Goats	140	41	20
Doornkloof, Pretoria, GAUTENG	4/7/08	5/7/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	430	13	13
Leeuwkraal, Moretele, NORTH WEST PROVINCE	4/23/08	5/17/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Sheep	321	26	16
Witpoort, Bronkhorstspruit, GAUTENG	4/22/08	5/22/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	150	4	4
Mamagalieskraal, Madibeng, NORTH WEST PROVINCE	4/23/08	5/23/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	50	19	4
Krokodildrift, Madibeng, NORTH WEST PROVINCE	4/23/08	5/23/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	73	22	6
Blinkwater, Mbombela, MPUMALANGA	5/1/08	6/1/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	38	3	
Curlews settlement,	5/1/08	6/1/08	**Species**	**Susceptible**	**Cases**	**Deaths**

Mbombela, MPUMALANGA			Cattle		2	
Hooggelegen, Mbombela, MPUMALANGA	5/1/08	6/1/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle		2	
Ten Bosch, Nkomazi, MPUMALANGA	1/15/08	2/15/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle		7	7
Vyeboom, Nkomazi, MPUMALANGA	2/1/08	3/1/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle		1	1
Richtersnek, Nkomazi, MPUMALANGA	2/12/08	3/1/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle		3	3
Witpoort, Kungwini, GAUTENG	5/1/08	6/1/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle		4	4
Doornkloof, City of Tshwane, GAUTENG	4/1/08	5/1/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle		13	13
Langkuil, Bela-Bela, LIMPOPO	3/1/08	4/1/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle		1	1
Leewdoorns, Bela-Bela, LIMPOPO	4/1/08	5/1/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle		2	2
Krokodildrift, Potchefstroom, NORTH WEST PROVINCE	4/1/08	5/1/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle		22	6
Vaalbank, Dr JS Moroka, MPUMALANGA	5/1/08	6/1/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Goats		26	15
Ten Bosch, Nkomazi, MPUMALANGA	2/1/08	3/1/08	**Species**	**Susceptible**	**Cases**	**Deaths**
			Buffaloes		4	4
Conference, Ingwe, KWAZULU-NATAL	2/25/09	3/15/09	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	500	10	3
Allandale, Ingwe, KWAZULU-NATAL	2/25/09	3/15/09	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	100	1	1
Tyrone, Ingwe,	2/27/09	3/15/09	**Species**	**Susceptible**	**Cases**	**Deaths**

KWAZULU-NATAL			Cattle	1000	50	27
Stockton, Ingwe, KWAZULU-NATAL	2/18/09	3/15/09	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	800	5	1
Eastwold, Ingwe, KWAZULU-NATAL	2/27/09	3/15/09	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	800	2	2
Ringstead, Kwa Sani, KWAZULU-NATAL	3/3/09	5/15/09	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	1000	35	22
Mount Hermon, Ubuhlebezwe, KWAZULU-NATAL	3/9/09	4/15/09	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	600	3	1
Burnview, Ingwe, KWAZULU-NATAL	3/23/09	4/30/09	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	800	6	1
Greenstead, Lions River, KWAZULU-NATAL	3/17/09	3/31/09	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	12	1	
Ikwezi Trust, KwaSani, KWAZULU-NATAL	4/1/09	4/10/09	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	800	1	1
Ilynton, KwaSani, KWAZULU-NATAL	4/2/09	4/15/09	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	800	11	1
Firle, Mooi Mpofana, KWAZULU-NATAL	4/2/09	4/15/09	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle		2	2
The Meads, Matatiele, KWAZULU-NATAL	4/24/09	5/15/09	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	500	1	1
Rustfontein, Matatiele, KWAZULU-NATAL	4/24/09	5/15/09	**Species**	**Susceptible**	**Cases**	**Deaths**
			Cattle	500	1	

Data analysis

Overview

There were three major parts to this study: data preparation/conversion, GIS mapping and analysis and statistical analysis. The majority of the effort for data preparation involves several steps to get the original occurrence data consistent and in a form that could be used in the analysis. Once this was completed, the other variables were prepared for analysis. GIS analysis included understanding the data distribution, identifying patterns and identifying clusters. Basic statistical analysis was also performed.

Data Conversion

Temperature and rainfall data was retrieved from the Famine Early Warning System (FEWS) Data Archives. One day estimates of accumulated rainfall for the African continent are prepared operationally at the Climate Prediction Center (CPC) for the United States Agency for International Development (USAID) as a part of the Famine Early Warning System Network (FEWS NET) and these estimates are archived and disseminated by the United States Geological Survey (USGS) from the Earth Resources Observation Systems (EROS) Data Center. For rainfall RFE 2.0, the data was gridded at 0.1 decimal degrees for the whole continent of Africa running from 1982 to present. For temperature, a daily product at a much coarser resolution product (0.5 degrees) from NOAA entitled Little Endian was used for the years 1982 to present. Rainfall data was retrieved as bin files from http://www.cpc.noaa.gov/products/fews/data.shtml and temperature data retrieved from ftp://ftp.cpc.ncep.noaa.gov/fews/gdas/little_endian/ and converted to a data file usable in ArcGIS 9.3. The conversion process included the use of

PERL scripts on a Linux based station to open the data and retrieve gridded daily maximum temperature (tmax), daily minimum temperature (tmin) and daily rainfall rates (rain). Attribute tables were created with monthly tmax, tmin and rain data. Data was added into a personal geodatabase using ArcCatalog 9.3 before being added into ArcMap 9.3.

GIS Mapping and Analysis

Outbreak data collected from the World Animal Health Information System for Kenya, Madagascar and South Africa was geocoded based on latitude and longitude of specific administrative boundaries. Outbreak data was collected in Microsoft Excel files and joined with shapefiles from CDC EpiInfo using ArcMap 9.3. For Kenya 132 grid points were overlaid on the Kenya shapefile, for Madagascar 216 grid points were overlaid on the Madagascar shapefile and for South Africa 391 grid points were overlaid on the South Africa shapefile. Rift Valley fever animal outbreaks were the focus of the analysis and specific locations of the administrative boundary locations for these outbreaks is presented for Kenya in Figure 3, for Madagascar in Figure 4 and for South Africa in Figure 5.

Figure 3: Rift Valley fever animal outbreak locations in Kenya

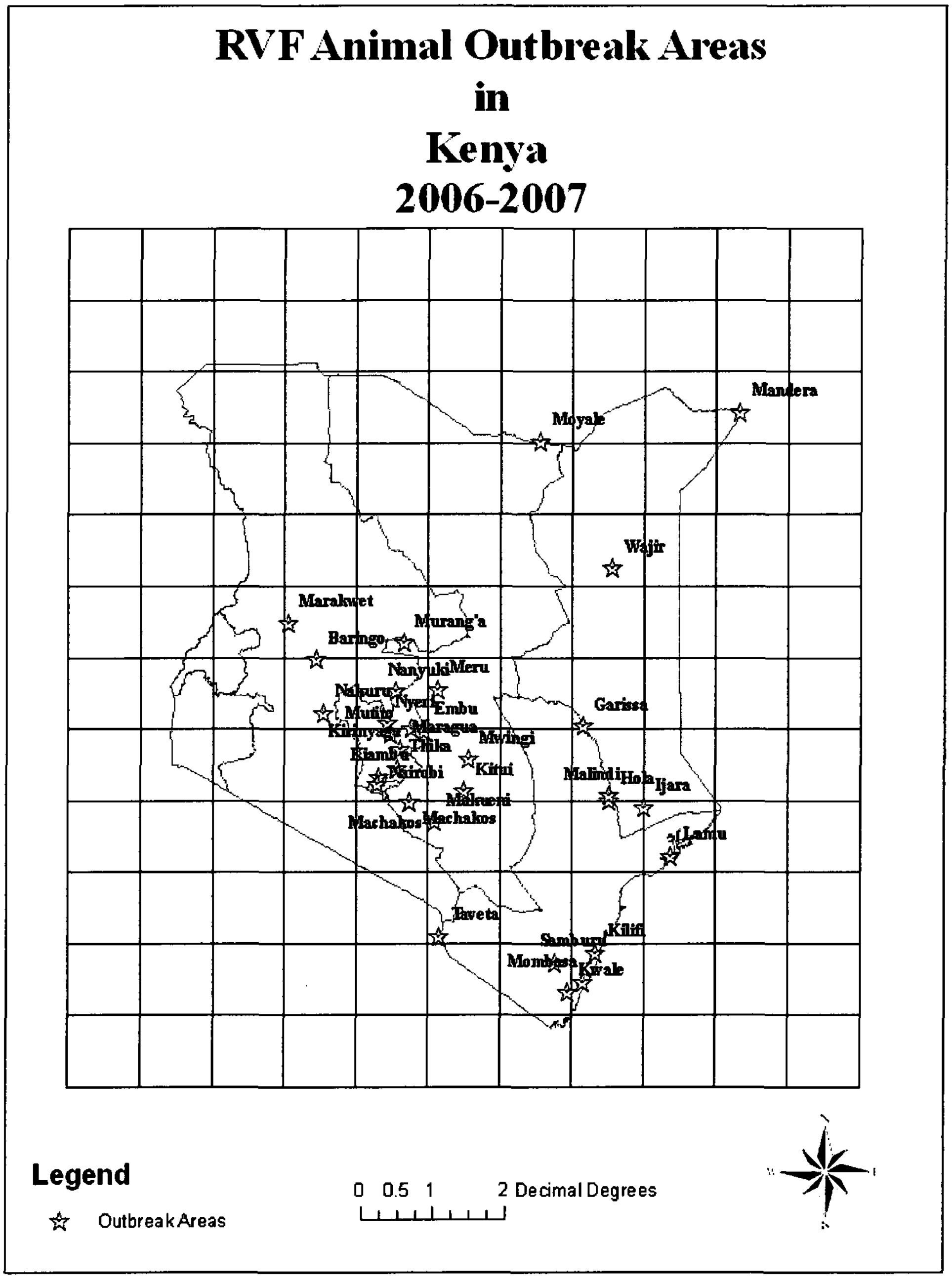


Figure 4: Rift Valley fever animal outbreak locations in Madagascar

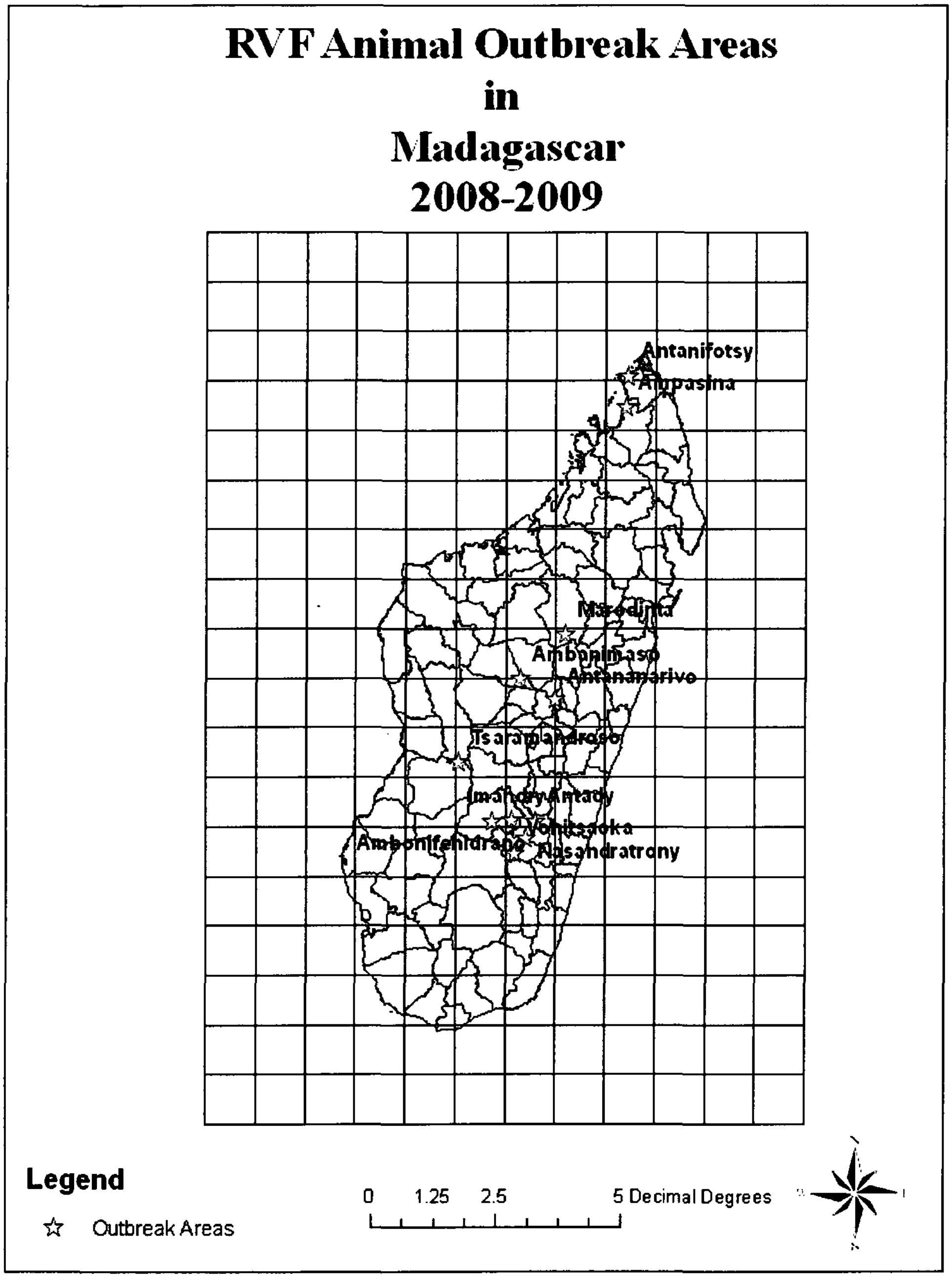
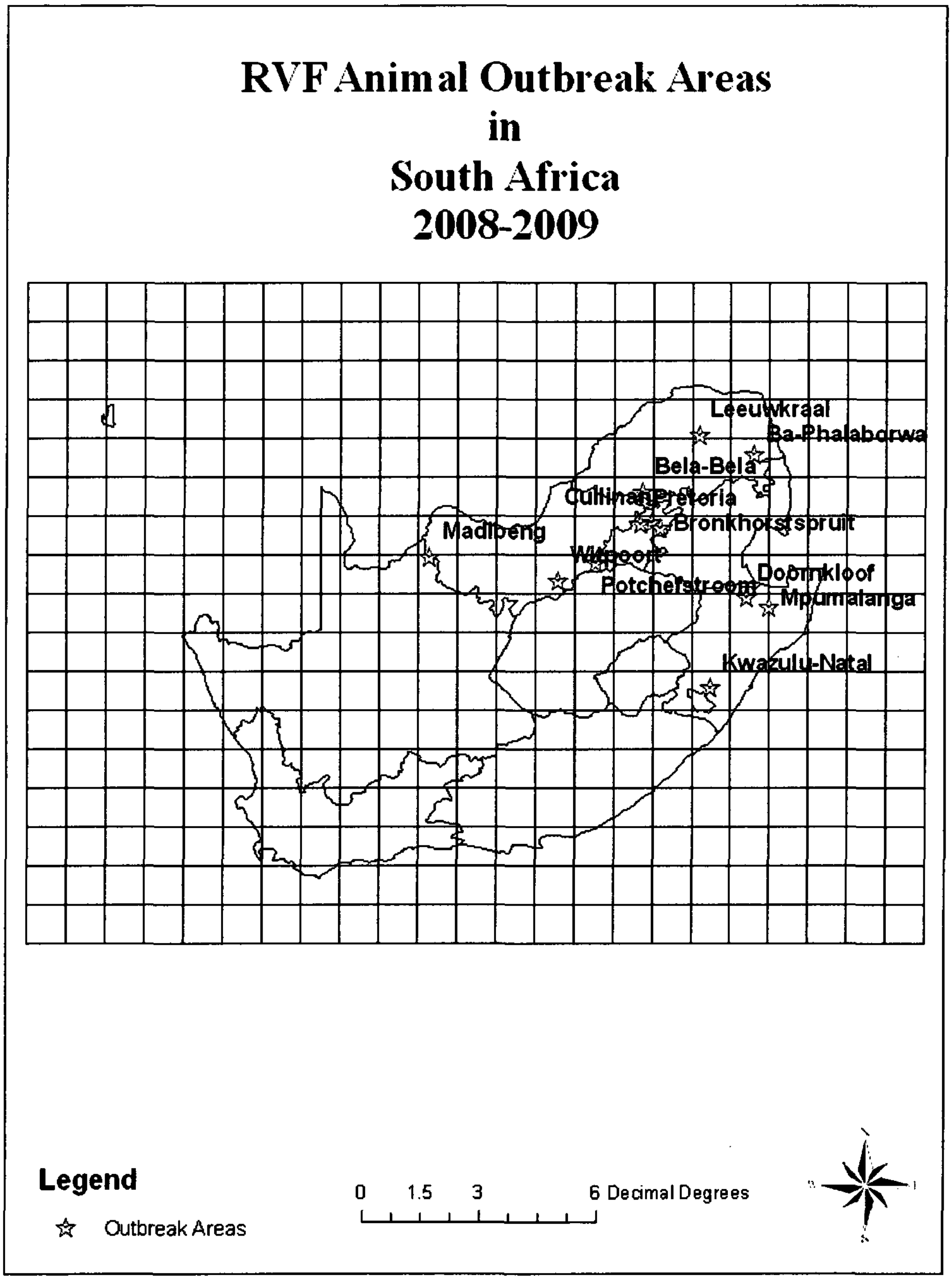


Figure 5: Rift Valley fever animal outbreak locations in South Africa



Data files were created in order to analyze long term and short term temperature and rainfall trends and compare to years of RVF outbreaks. Long term datasets consisted of monthly data from 1982 through 2004 with average maximum daily temperature, average minimum daily temperatures and rainfall events for each month for the countries of Kenya, Madagascar and South Africa individually. A total of 36 maps was created for maximum temperature (tmax), 36 maps for minimum temperature (tmin) and 36 maps for rainfall (rain) for a total of 108 maps for the long term datasets ((Kenya * 12 months *tmax*tmin*rain) + (Madagascar*12 months*tmax*tmin*rain) + (South Africa *12 months * tmax * tmin * rain) = 108 maps)). Short term datasets consisted of monthly data from the years 1999 through 2005 for the country of Kenya and monthly data from the years 1999 through 2007 for the countries Madagascar and South Africa. Average maximum daily temperature, average minimum daily temperatures and rainfall events for each month were used in short term datasets. For the short term dataset for Kenya a total of 36 maps was created (Kenya * 12 months * tmax * tmin * rain = 36 maps) and for the short term datasets for Madagascar and South Africa a total of 72 maps was created ((Madagascar * 12 months * tmax * tmin * rain) + (South Africa * 12 months * tmax * tmin * rain) = 72 maps)). The outbreak in Kenya under analysis occurred in 2006 and 2007 therefore two separate datasets were created for each of these years for a total of 72 maps ((Kenya * 12 months * tmax * tmin * rain) + (Kenya * 12 months *tmax * tmin * rain) = 72 maps)). The outbreaks in Madagascar and South Africa under analysis occurred in 2008 through 2009 and therefore four datasets were created resulting in a total of 144 maps created ((Madagascar * 12 months * tmax * tmin * rain) + (Madagascar * 12 months *tmax * tmin * rain) + (South Africa * 12 months * tmax * tmin * rain) +

(South Africa * 12 months *tmax * tmin * rain) = 72 maps = 144 maps)) . Maps were created using ArcMap 9.3 with a resulting 432 maps created for GIS analysis.

The created maps were analyzed for each outbreak area to discover the maximum temperature, minimum temperature and rainfall amounts for that particular grid point covering outbreak area for the months the outbreak occurred in that area for the long term, short term and outbreak datasets. For most areas results were presented at the 3 degrees Celsius range for tmax and tmin and 3 inches for rainfall data. Results are presented for the months of the outbreak in that particular area for all three countries comparing the long term average and short term average to the results found during years of outbreak. Regional data for each country is presented as well as fully detailed data for each area is presented in the appendices.

Time series analysis

Unlike the analyses of random samples of observations that are discussed in the context of most other statistics, the analysis of time series is based on the assumption that successive values in the data file represent consecutive measurements taken at equally spaced time intervals. Time series analysis is used to identify the nature of the phenomenon represented by the sequence of observations requiring that the pattern of observed time series data is identified and more or less formally described. In order to complete time series for the temperature and rainfall data time series mean (x) monthly values for all datasets was calculated and graphed for the countries of Kenya, Madagascar and Kenya using Excel 2007. Mean values were used due to the nature of the gridded rainfall dataset. Mean values have been used before in time series analysis in order to study rainfall and vector borne diseases. In Bicout & Sabatier (2004) mean values were used to study rainfall variations in relation to Rift Valley fever vectors and prevalence. This technique has also been used in the study of rainfall in relation to Lyme disease. In McCabe & Bunnell (2004) mean values for rainfall were used to study rainfall and the occurrence of Lyme disease in the Northeastern United States.

For Kenya a time series graph comparing the long term dataset (1982-2004), short term dataset (1999-2005), and years 2006 and 2007 during the RVF outbreak was created. For Madagascar a time series graph comparing the long term dataset (1982-2004), short term dataset (1999-2007) and for the years 2008 and 2009 during which their RVF outbreaks occurred was created. For South Africa a time series graph comparing the long term dataset (1982-2004), short term dataset (1999-2007) and for the years 2008 and 2009 during which their RVF outbreak occurred was created. Time series models were used in order to identify patterns within each dataset. Time series analysis was also used to assist in comparing a monthly dataset consisting of data from 1999 through 2005 for Kenya and 1999 through 2009 for Madagascar and South Africa in order to discover months when rainfall anomalies had occurred. In order to complete the analysis time series graphs were created for each of the countries for each of the twelve months.

Cluster Analysis

Spatial cluster analysis plays an important role in quantifying geographic variation patterns such as rainfall (Jacquez, 2008). Information to be clustered may be event-based, population-based, field-based, or feature-based. Event-based data include point locations, population-based data incorporate information on the population from which the events arose, and field-based data are observations that are continuously distributed over space, and include values such as rainfall. A spatial cluster for event based data such as rainfall might then be defined as an excess of values in geographic space. Cluster analysis allows for the identification and description of spatial patterns such as outliers, clusters, hotspots, cold spots, trends and boundaries. It first involves pattern recognition using visualization, spatial statistics and geostatistics to identify the locations, magnitudes and shapes of statistically significant pattern descriptors. This then allows for hypothesis generation to specify realistic and testable explanations for the geographic patterns. In order to determine a statistical pattern a statistics (such as spatial cluster statistic or autocorrelation) is calculated that quantifies a relevant aspect of spatial pattern in the data. The numerical value of this statistic is then compared to the distribution of that statistic's value under a null spatial model, which provides a probabilistic assessment of how unlikely an observed spatial pattern is under the null hypothesis (Gustafson 1998).

Global cluster statistics are sensitive to spatial clustering, or departures from the null hypothesis, that occur anywhere in the study area. Many early tests for spatial pattern were global in nature, and provided one statistic that summarized spatial pattern over the entire study area. While global statistics can identify whether spatial structure exists, they do not identify where the clusters are, nor do they quantify how spatial dependency varies from one place to another. Local statistics quantify spatial autocorrelation and clustering within the small areas that together comprise the study area. Many local statistics have global counterparts that often are calculated as functions of local statistics and thus can tell you the nature of spatial dependency in a given locality, while also providing a global test. Getis and Ord cluster analysis is such a test, allowing for the identification of hot spots and was thus used in the analysis.

Getis and Ord cluster analysis works on the premise that any distribution of features or attribute values within a defined area will create a pattern and the patterns can range from completely clustered at one extreme to completely disperse at the other. A pattern that falls within the extremes is said to be random and knowing a pattern in data is useful in order to compare patterns and track changes such as changes in temperature and rainfall. In order to identify patterns in the datasets statistics will be used to measure the extent to which the temperature and rainfall values are clustered, dispersed or random. Using statistics in GIS to measure patterns involves the comparison of the actual distribution of features (often referred to as the observed distribution) to a hypothetical random distribution of the same number of features over the same area. The GIS calculates the statistic for the observed distribution as well as the statistic for a random distribution and the extent to which the observed distribution deviates from the random is the extent to which the pattern is more clustered or dispersed than a random distribution. The process of measuring a pattern by comparing an observed distribution to a random distribution is based on the scientific method.

In order to discover if rainfall events are clustered and where the clusters might be located, Getis and Ord hot spot analysis was run in ArcToolbox in ArcMap 9.3. First, a spatial join was done and data aggregated for the monthly data for the rainfall datasets. Hot spot analysis was run for the outbreak areas in Kenya, Madagascar and South Africa for each of the rainfall datasets. Hot spots analysis was not run on the temperature dataset due to the fact temperature cannot truly be defined as an event and, therefore break the general assumptions. It was unclear whether or not rainfall could be truly defined as an event as well at the beginning of the analysis. Hot spot analysis for rainfall rates produced Getis-Ord Gi* values which is a calculated Z scores. A high Z score indicates a hot spot while a low Z score indicates a cool spot. For this study, the confidence level was 0.05 and the critical value for the Z-score at a confidence level of 0.05 was 2.00. The critical values of -2.00 and 2.00 are standard deviation from the mean. Ninety five percent of the area underneath the standard normal curve falls between plus and minus 2.00 standard deviations from the mean, while the other 5% of the area is termed the rejection region. If the Z-score is within the range -2.00 to +2.00 the null hypothesis cannot be rejected and if it falls outside the range, you can reject the null hypothesis. Z scores are a measure of standard deviation and a high Z score indicates to reject the null hypothesis, while a low Z score indicated that we cannot reject the null hypothesis. If the Z-score falls within the rejection region, there's only a 5% chance that it would be wrong to reject the null hypothesis.

Statistical Analysis

Spatial analysis, such as hot spot analysis, provides effective tools for quantifying spatial patterns. Statistical analysis allows you to model, examine, and explore spatial relationships, and can help explain the variables behind observed spatial patterns. For the purpose of this study statistical analysis was used to determine when rainfall anomalies have occurred. A rainfall anomaly means the difference in rainfall from the average. A positive rainfall anomaly indicates a mean value higher than the average while a negative rainfall anomaly indicates a mean value lower than the average. GIS analysis was used to determine if an above average amount of rainfall had occurred at the beginning of the Rift Valley fever outbreak in each perspective country. If GIS analysis signified that an above average rainfall amount had occurred analysis was run on the dataset beginning with the year 1999 through the year prior to the outbreak. If it was not signified by GIS analysis that an above average rainfall amount had occurred at the beginning of the Rift Valley fever outbreak, statistical analysis was run on the dataset beginning with the year 1999 and through the last year of the outbreak to determine when rainfall anomalies had occurred during and before the outbreak.

SPSS 16.0 and Microsoft Excel 2007 were used in order to run statistical analysis. Statistical analysis was run by first calculating mean and standard deviations for each dataset under analysis. For Kenya each of the twelve months for the years 1999-2005 were analyzed. For Madagascar and South Africa each of the twelve months for the years 1999 through July of 2009 were analyzed. Using an alpha value of .01, standard deviation and number of data points, 99% confidence intervals were attained for each monthly series of each dataset. Values falling underneath the lower end of confidence intervals were considered negative rainfall anomalies and values falling above higher end of confidence intervals were considered positive rainfall anomalies. For all months found to have had a positive rainfall anomaly the average temperature for that month is presented as well. Descriptive statistics were run on all datasets as part of the statistical analysis. Means, medians, and modes were calculated as well as histograms created. The range, the interval between the minimum and maximum value, was attained for the long term, short term and datasets during outbreaks for Kenya, Madagascar and South Africa using SPSS 16.0 and graphed using Microsoft Excel 2007.

Assumptions and Limitations of the Data

Due to the less than optimal density of the rain gauge network over the African continent, rainfall is not adequately measured, necessitating the use of a statistical algorithm for rainfall estimation. The method utilizes the available surface data with remotely sensed data in order to produce estimates of accumulated rainfall. The data utilized for the purposes of this study are gridded at a 1.0 decimal degree for the whole continent of Africa. Due to the fact that valid and reliable outbreak data was available only from 2000, only RVF outbreaks occurring after 2000 could be completely analyzed. In addition to this limitation as a result of the rainfall data being indirectly measured, there are also problems with the algorithm that produces the rainfall estimates. If a rain gauge is sparse there is a higher degree of uncertainty in the data as well as there are issues with cold-cloud estimation. With cold-cloud estimation of rainfall in arid and semi-arid regions the satellite sees cold clouds that may be producing rainfall but the rainfall evaporates before reaching the ground, possibly leading to overestimates in these areas. Despite these limitations, the datasets utilized for this study are the only largely available datasets for the continent of Africa producing daily estimates of rainfall and temperature in a gridded format.

Usefulness for global health

Rift Valley fever is proving itself to be an arbovirus able to infect many ecologically diverse regions as has been shown with the outbreaks in Saudi Arabia and Yemen in 2000 (Gaff, 2007). The threat that RVF affords to the Americas or any area outside of sub-Saharan Africa depends upon numerous variables including (1) means of spread for the virus; (2) detection of the virus in a nonenzootic area; (3) prevalence and competence of mosquito vectors; (4) prevalence of suitable vertebrate hosts; and (5) availability of effective control programs (Lupton, 1982, House, 1992). Infection with RVF virus can produce viremias at > 10 infectious particles/mL, high enough to infect numerous species of mosquitoes (Turell, 1988). Although vector movement and interactions represent an unpredictable threat should RVF virus be introduced into a nonendemic area, amplification of the virus is required for an epizootic/epidemic. The presence of competent vectors, suitable vertebrate host and appropriate environmental conditions would be required for amplification of the virus. Numerous North American mosquito species are competent laboratory vectors of RVF virus (Turell, 2008). Amplifying hosts such as cattle sheep, and goats with levels of viremia high enough to infect vectors would also be required for a North American outbreak. The ideal environmental conditions for an outbreak to occur in North American are not known and this study will hopefully provide insight into answering this question. This study will allow for the comparison of three different outbreaks in three ecologically diverse countries with different mosquito vectors and control programs. Results of this study will possibly add to our understanding of the environmental variables that play a role in Rift Valley fever outbreaks and thus allow for the better prediction and containment of the disease.

CHAPTER IV

Results

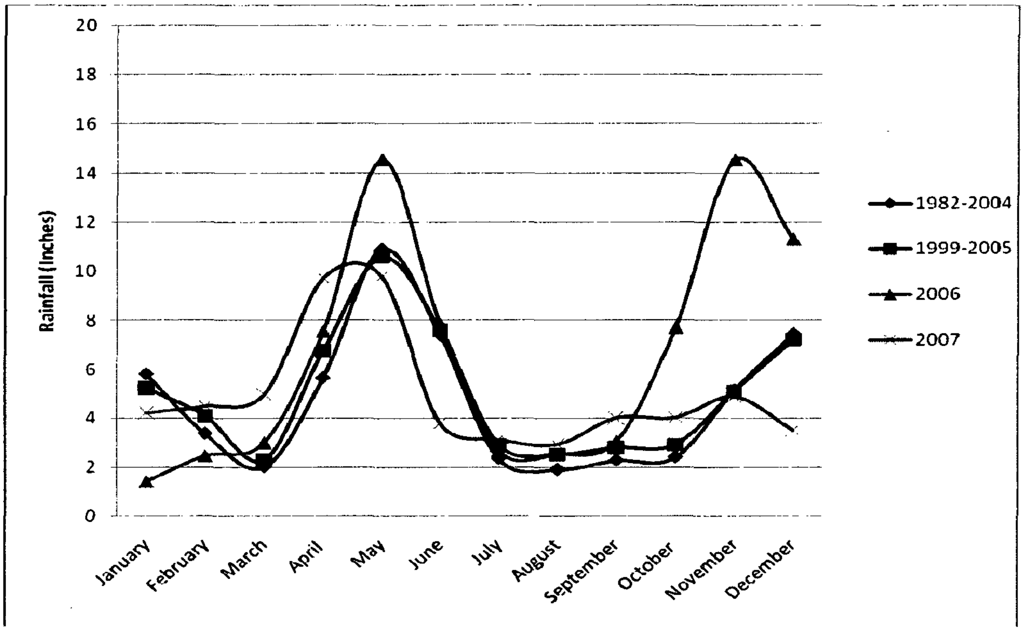
Research Question 1

Did positive rainfall anomalies occur prior to and during the 2006-2007 Rift Valley fever outbreaks in Kenya?

Time series analysis

Prior to the 2006-2007 Rift Valley fever outbreak rainfall was highest in the month of May and lowest in March and August according to the long term (May x=10.89; March x =2.02; August x=1.91) and short term dataset (May x=10.59; March x=2.29; August x=2.80) for the country of Kenya. In the year 2006, although rainfall was highest in May an above average amount of rainfall was found in the months of October, November and December (October x=7.70; November x=14.54; December x=7.44) as compared to the long term (October x=2.41; November x=5.14; December x=11.31) and short term data set (October x=2.92; November x=5.11; December x=7.22). In 2007, rainfall rates in Kenya were relatively stable with May (May x=9.78) being the month with the highest amount of rainfall and August (August x=2.94) the lowest amount of rainfall. On average, mean rainfall tends to be highest in the months of April through June and October through December, while lowest in July through September. Figure 6 presents the trends for the long term dataset (1982-2004), short term dataset (1999-2005), and for the years of the outbreak (2006, 2007) in Kenya illustrating these points.

Figure 6: Monthly rainfall in Kenya for long term dataset (1982-2004), short term dataset (1999-2005) and the years of the Rift Valley fever animal outbreak (2006, 2007)



GIS Analysis

Despite a Rift Valley fever outbreak in Kiambu, Kenya, that began in February 2006 and ended in April 2007, most RVF animal outbreaks occurring in Kenya began in December of 2006 and ended in April of 2007. For all outbreaks beginning in December of 2006, a higher than average amount of rainfall was found for December of 2006, as compared to the long term and short term dataset. Generally amounts of rainfall in the months of 2007 remained equal, less or only slightly above the average amounts of rainfall for the area in comparison to the short term and long term dataset. In Kiambu, the amount of rainfall prior to November of 2006 remained relatively stable and equal to average amounts of rainfall seen in the short term and long term dataset. A higher than average amount of rainfall was found in November and December of 2006 in Kiambu. Table 9 presents the areas in Kenya where RVF outbreaks occurred and higher than average amounts of rainfall were found for the beginning of the month of the RVF outbreak as compared to the long term and short term datasets. Figure 7, 8 and 9 display GIS maps with gridded rainfall data for Kenya showing average amount of rainfall in the long term and short term dataset and the higher than average amount of rainfall found in 2006 for the month of December. Rainfall amounts are given in average three inch ranges. A fully detailed comparison of rainfall amounts for all outbreak areas in Kenya for the long term, short term and outbreak datasets for Kenya is presented in Appendix A.

Table 9: RVF outbreak area's in Kenya with above average amounts of rainfall for December of 2006 as compared to the long term (1982-2004) and short term (1999-2005) dataset

Region	December (1982-2004)	December (1999-2005)	December (2006)
Galmagara, Garissa, NORTH-EASTERN	9-12	9-12	12-15
Hola, Tan River, COAST	9-12	9-12	12-15
Baibariu, Meru North, EASTERN	3-6	3-6	18-21
Ngare Ndare Meru Central, EASTERN	3-6	3-6	18-21
Giathugu, Nyeri, CENTRAL	9-12	6-9	15-18
Gatandu, Gikambura, Kiambu, CENTRAL	9-12	9-12	18-21
Mwatate Sisal, Lualenyi Ranch, Taveta, Tiata Taveta, COAST	6-9	9-12	12-18
Njoguini, Rurii, Murang'a, CENTRAL	9-12	9-12	18-21
Dantu, Kutulo, Gari, Didkuro, Mandera, NORTH-EASTERN	3-6	3-6	6-9
Karia, Meru Central, EASTERN	3-6	3-6	18-21
Tebere, Kirinyaga, CENTRAL	9-12	9-12	18-21
Dadaab, Galmagara, Bura, Shantabak, Mbalambala, Danyiri, Garissa, NORTH-EASTERN	9-12	6-9	12-15

Masalani, Ijara, NORTH-EASTERN	9-12	9-12	12-15
Kinango, Musiu, Lunga Lunga, Kidzumbani, Kwale, COAST	6-9	9-12	9-12
Ruiru, Thika, CENTRAL	9-12	9-12	18-21
Kasarani, Nairobi, NAIROBI AREA	9-12	9-12	18-21
Lamu, Lamu, COAST	6-9	6-9	9-12
Evurore, Karaba, Waschoro, Mutito, Mbeere, EASTERN	9-12	9-12	18-21
Karurumo, Embu, EASTERN	3-6	3-6	18-21
Tara, Machakos, EASTERN	9-12	9-12	18-21
Marula, Nakuru, RIFT VALLEY	6-9	6-9	12-15

Figure 7: GIS map of average amount of rainfall in December of 2006

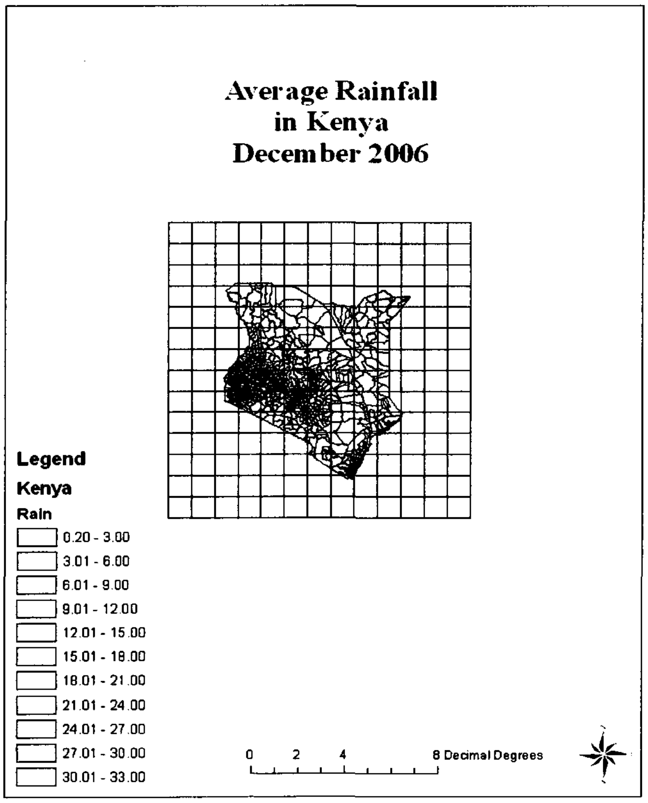


Figure 8: GIS maps of average amount of rainfall in December 1982-2004

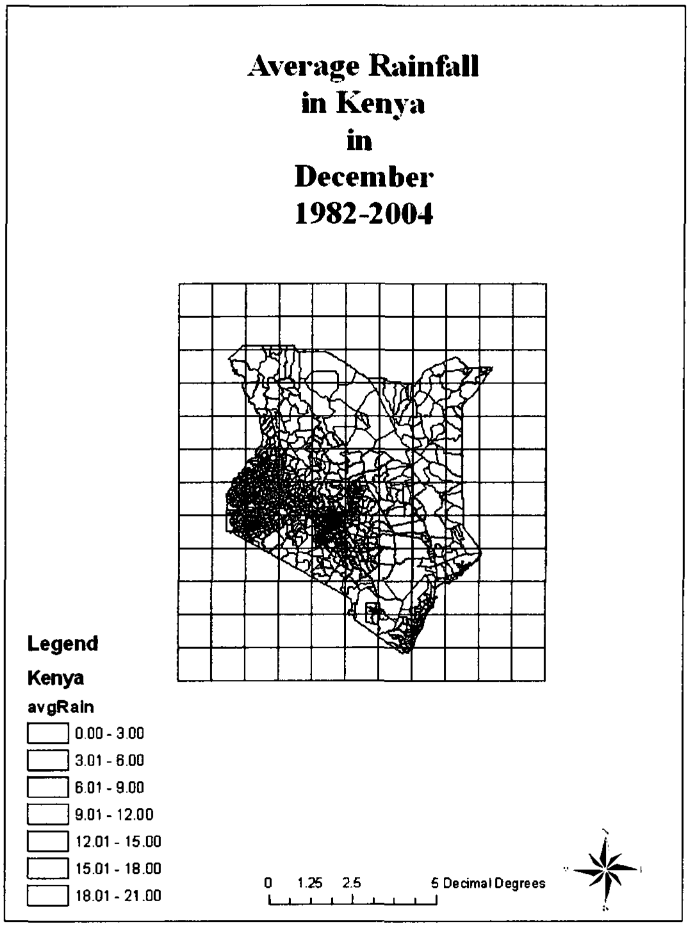
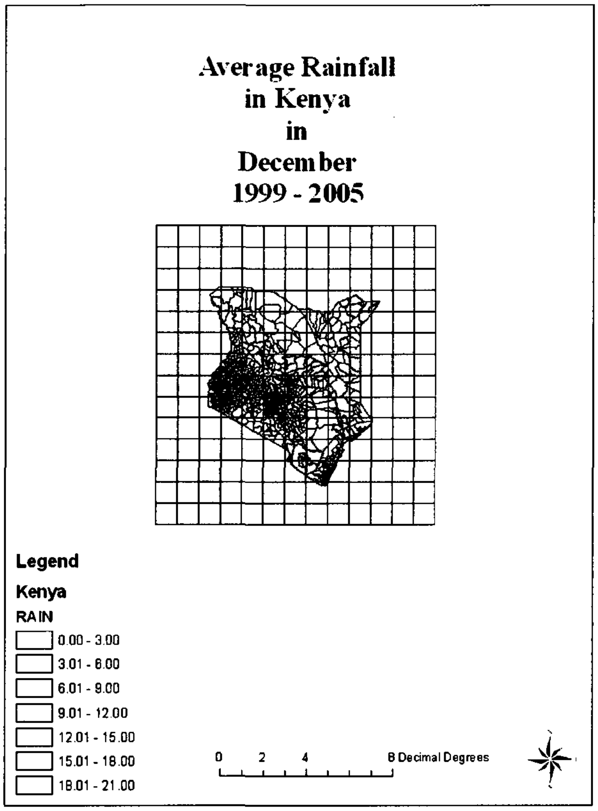


Figure 9: GIS maps of average amount of rainfall in December 1999-2005



Statistical analysis

Since GIS analysis signified a relationship exist between rainfall and Rift Valley fever activity, rainfall data for the years 1999-2005 was further analyzed to discover when a positive rainfall anomaly may have occurred with no Rift Valley fever activity detected. The standard deviation for the January 1999-2005 dataset in Kenya was 2.17 resulting in a lower 99% confidence interval of 3.25 and an upper 99% confidence interval of 7.20. The standard deviation for the February 1999-2005 dataset in Kenya was 1.47 resulting in a lower 99% confidence interval of 2.75 and an upper 99% confidence interval of 5.44. The standard deviation for the March 1999-2005 dataset in

Kenya was 2.29 resulting in a lower 99% confidence interval of 1.54 and an upper 99% confidence interval of 3.04. The standard deviation for the April 1999-2005 dataset in Kenya was 2.55 resulting in a lower 99% confidence interval of 4.42 and an upper 99% confidence interval of 9.06. The standard deviation for the May 1999-2005 dataset in Kenya was 2.60 resulting in a lower 99% confidence interval of 8.22 and a 99% upper confidence interval of 12.96. The standard deviation for the June 1999-2005 dataset in Kenya was 2.88 resulting in a lower 99% confidence interval of 4.99 and an upper 99% confidence interval of 10.23. The standard deviation for the July 1999-2005 dataset in Kenya was 1.08 resulting in a lower 99% confidence interval of 1.92 and an upper 99% confidence interval of 3.89. The standard deviation for the August 1999-2005 dataset in Kenya was 1.04 resulting in a lower 99% confidence interval of 1.58 and an upper 99% confidence interval of 3.48. The standard deviation for the September 1999-2005 dataset in Kenya was .88 resulting in a lower 99% confidence interval of 2.01 and an upper 99% confidence interval of 3.60. The standard deviation for the October 1999-2005 dataset in Kenya was .70 resulting in a lower 99% confidence interval of 2.28 and an upper 99% confidence interval of 3.56. The standard deviation for the November 1999-2005 dataset in Kenya was 1.86 resulting in a lower 99% confidence interval of 3.42 and an upper 99% confidence interval of 6.81. The standard deviation for the December 1999-2005 dataset in Kenya was 3.63 resulting in a lower 99% confidence interval of 3.91 and an upper 99% confidence interval of 10.53. Using these confidence intervals, average amounts of rainfall for each year was graphed along with the upper and lower confidence intervals calculated for each month. Positive rainfall anomalies were those falling above the upper 99% confidence intervals. Figures 10 through 16 presents average rainfall for the years 1999 through 2005 during which no RVF activity was detected.

Figure 10: Rainfall for 1999 in Kenya with lower and upper 99% confidence intervals

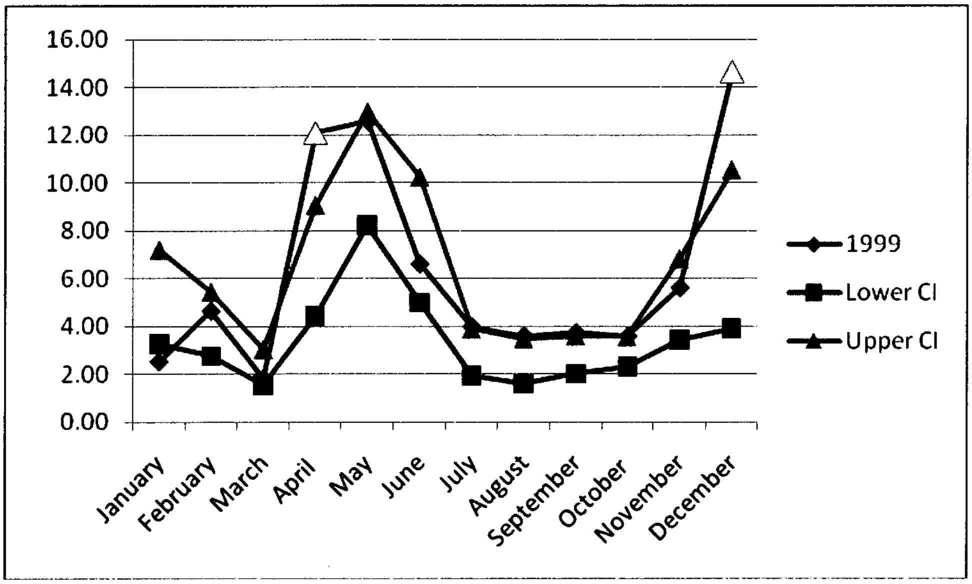


Figure 11: Rainfall for 2000 in Kenya with lower and upper 99% confidence intervals

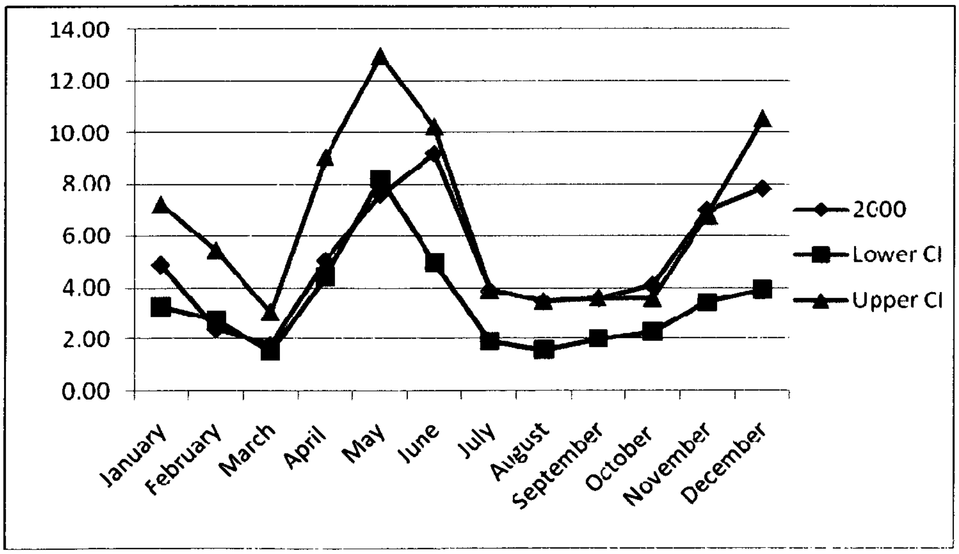


Figure 12: Rainfall for 2001 in Kenya with lower and upper 99% confidence intervals

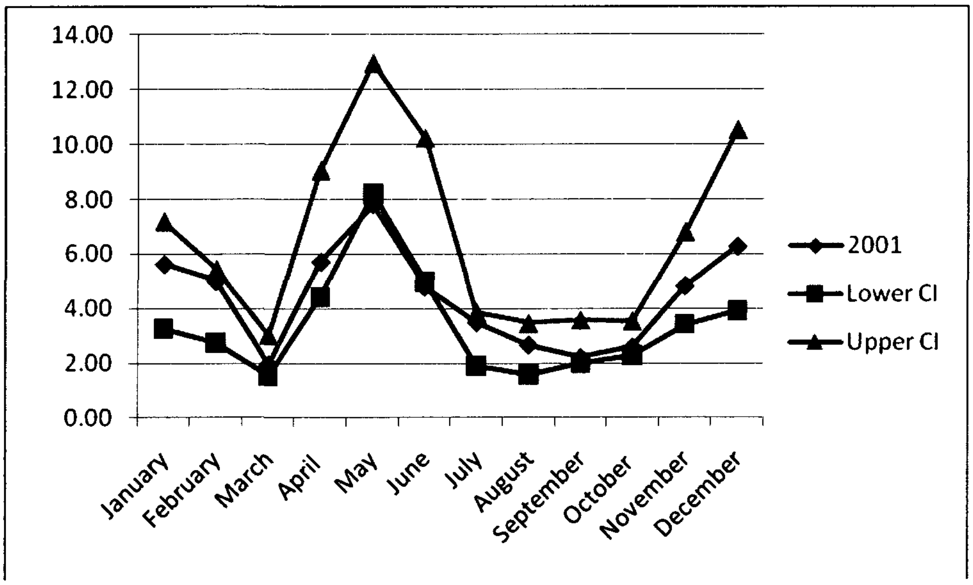


Figure 13: Rainfall for 2002 in Kenya with lower and upper 99% confidence intervals

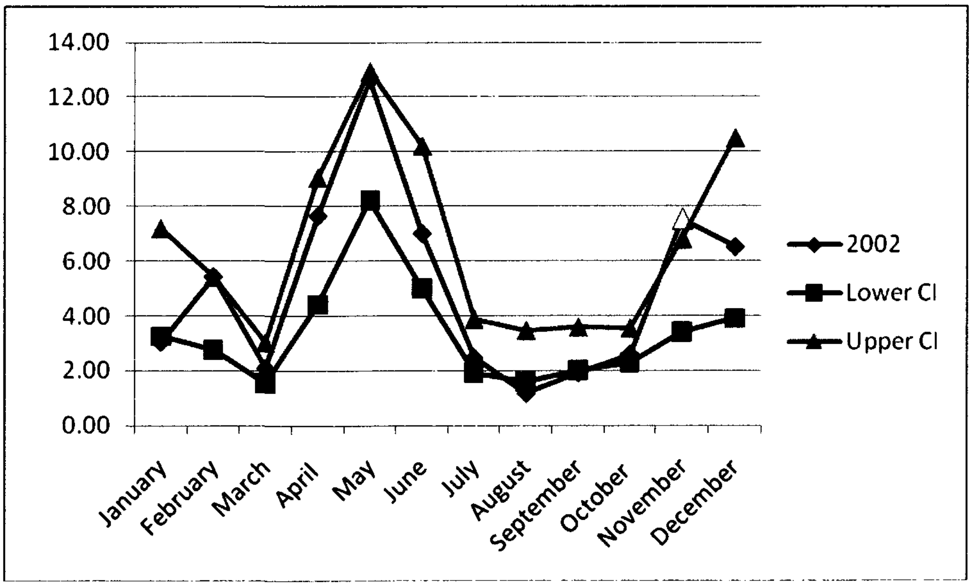


Figure 14: Rainfall for 2003 in Kenya with lower and upper 99% confidence intervals

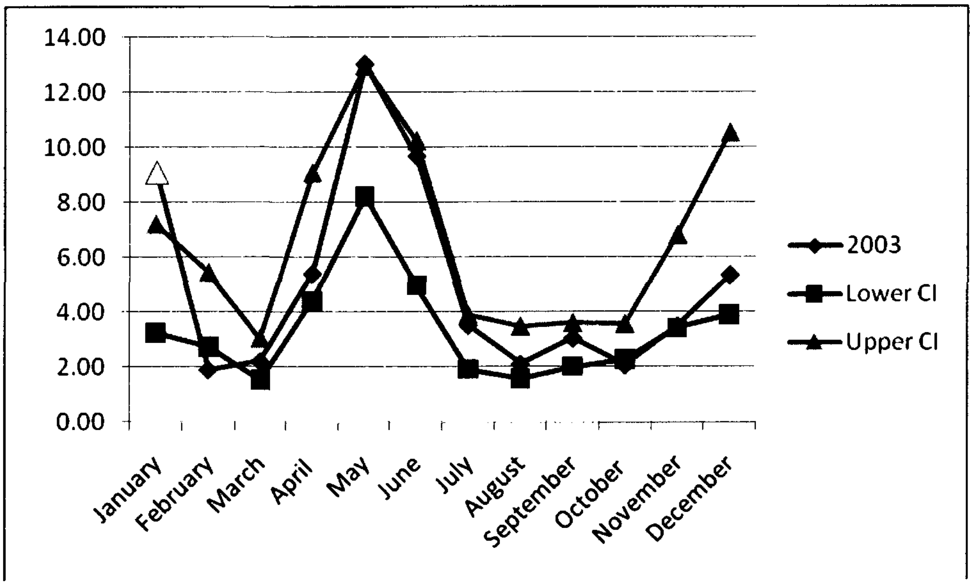


Figure 15: Rainfall for 2004 in Kenya with lower and upper 99% confidence intervals

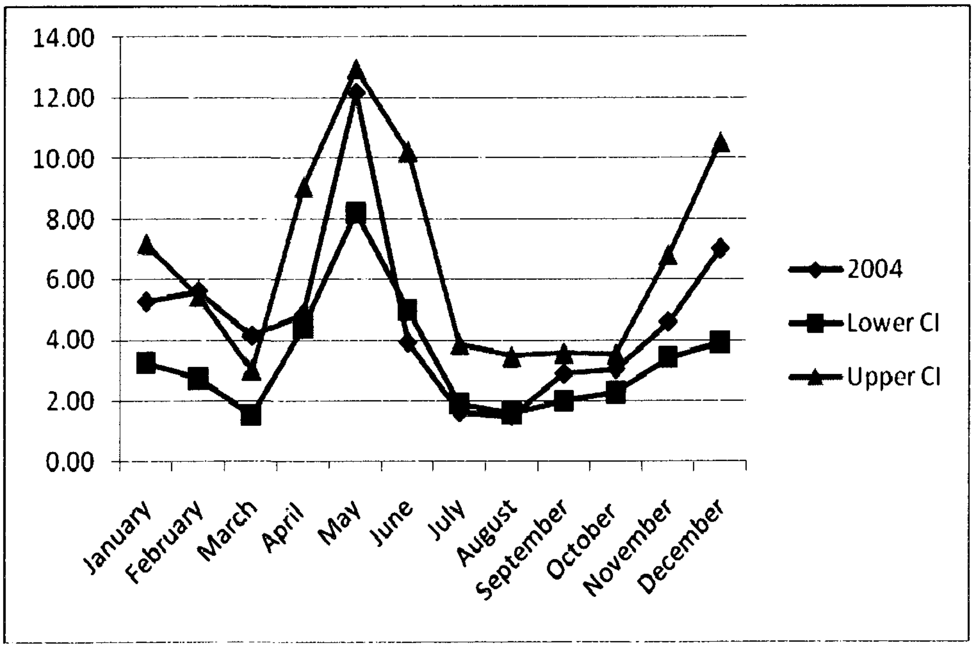
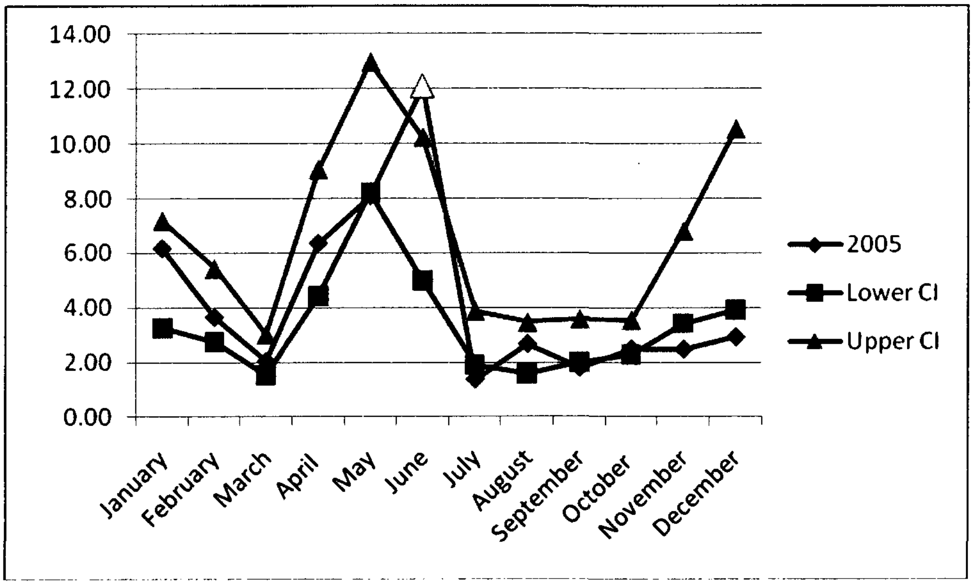


Figure 16: Rainfall for 2005 in Kenya with lower and upper 99% confidence intervals



Statistical analysis results signified higher than average rainfall amounts for January of 2003, April of 1999, June of 2005, November of 2002, and December of 1999, yet no Rift Valley fever activity was discovered during these times. In January 2003, the average maximum temperture in Kenya was 29°C and minimum temperature 22°C; in April of 1999, the average maximum temperature was 28°C and minimum temperature 22°C; in June of 2005, the average maximum temperature was 27°C and minimum temperature 22°C; in November of 2002, the average maximum temperature was 27°C and minimum temperature 22°C; and in December of 1999, the average maximum temperature was 28°C and minimum temperature 22°C. On average in January, the maximum temperature is 30°C and the minimum temperature 18°C; in April, the average maximum temperature is 28°C and the minimum temperature 20°C; in June, the average maximum temperature is 27°C and the minimum temperature 18°C; in November, the average maximum temperature is 27°C and the minimum temperature 19°C; in December, the average maximum temperature is 28°C and the minimum temperature 19°C according to average from the 1999-2005 dataset. Table 10 presents results for positive rainfall anomalies for 1999-2005 in Kenya. GIS maps for these months were analyzed and showed rainfall during these months as highly dispersed around the whole country of Kenya. GIS maps for January of 2003, April of 1999, June of 2005, November of 2002, and December of 1999 are presented in Figures 17-21.

Table 10: Positive rainfall anomalies 1999-2005 in Kenya during which no RVF activity was reported

Month	Year	Mean	$CI_{.99}$
January	2003	9.09	3.25-7.20
April	1999	12.10	4.42-9.06
June	2005	12.09	4.99-10.23
November	2002	7.54	3.42-6.81
December	1999	14.67	3.91-10.53

Figure 17: GIS map of above average rainfall in January of 2003 with no Rift Valley fever activity

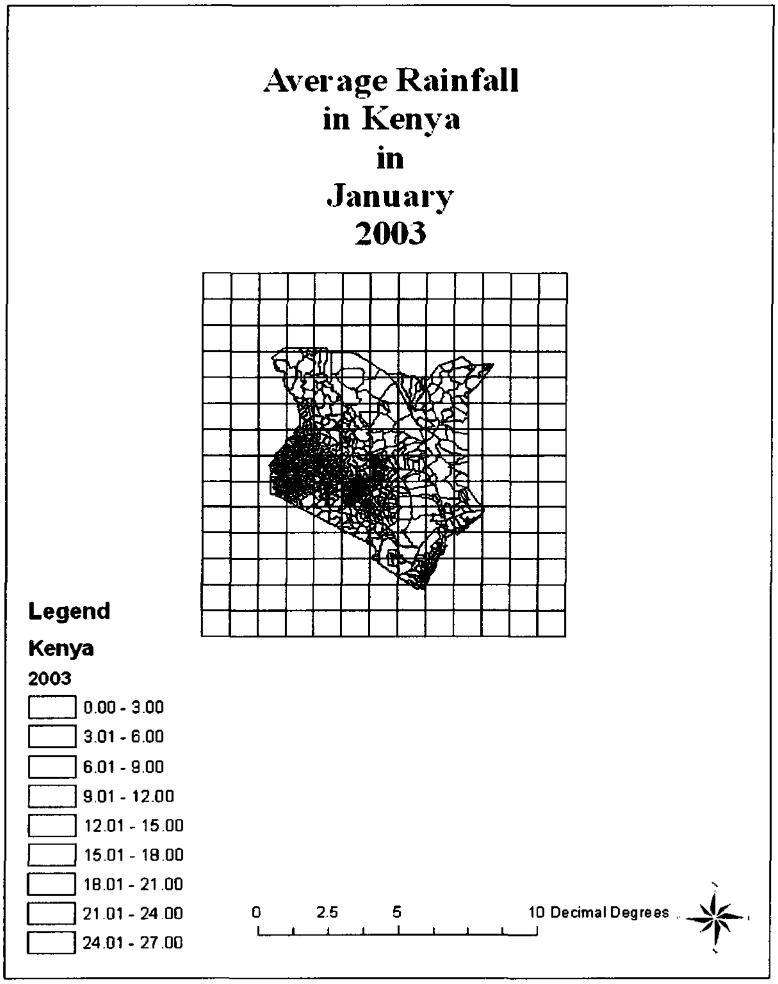


Figure 18: GIS map of above average rainfall in April of 1999 with no Rift Valley fever activity

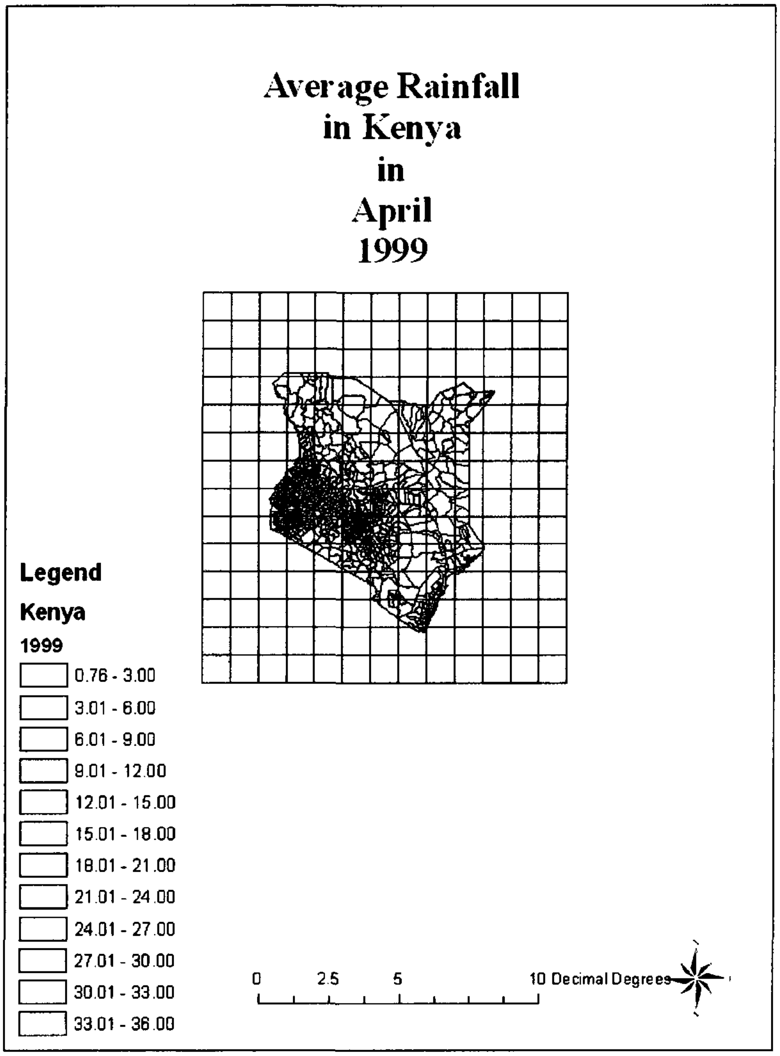


Figure 19: GIS map of above average rainfall in June of 2005 with no Rift Valley fever activity

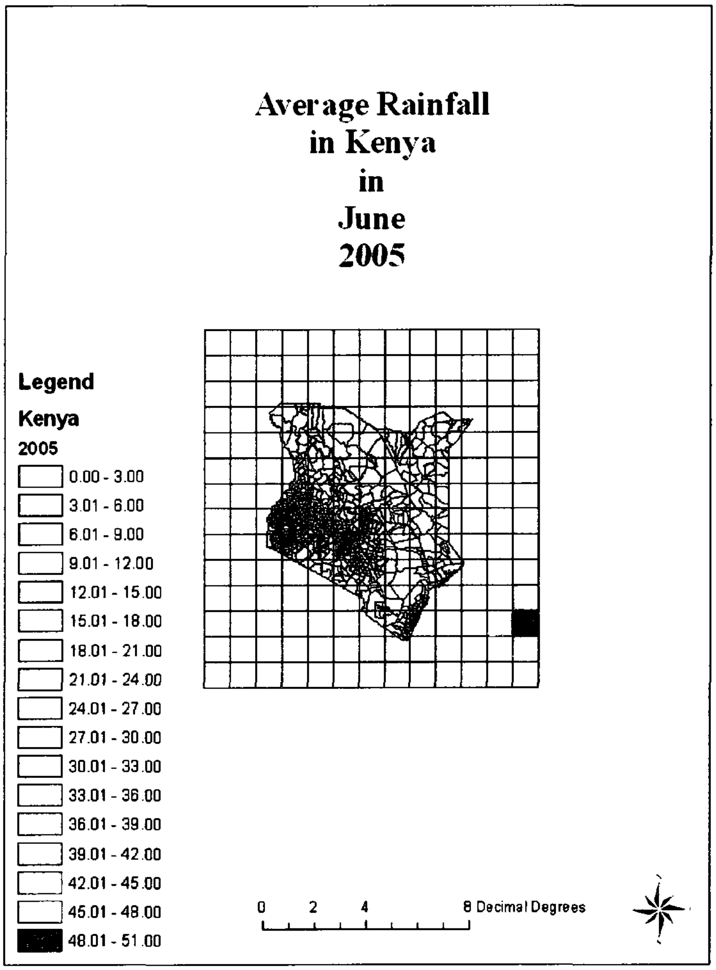


Figure 20: GIS map of above average rainfall in November of 2002 with no Rift Valley fever activity

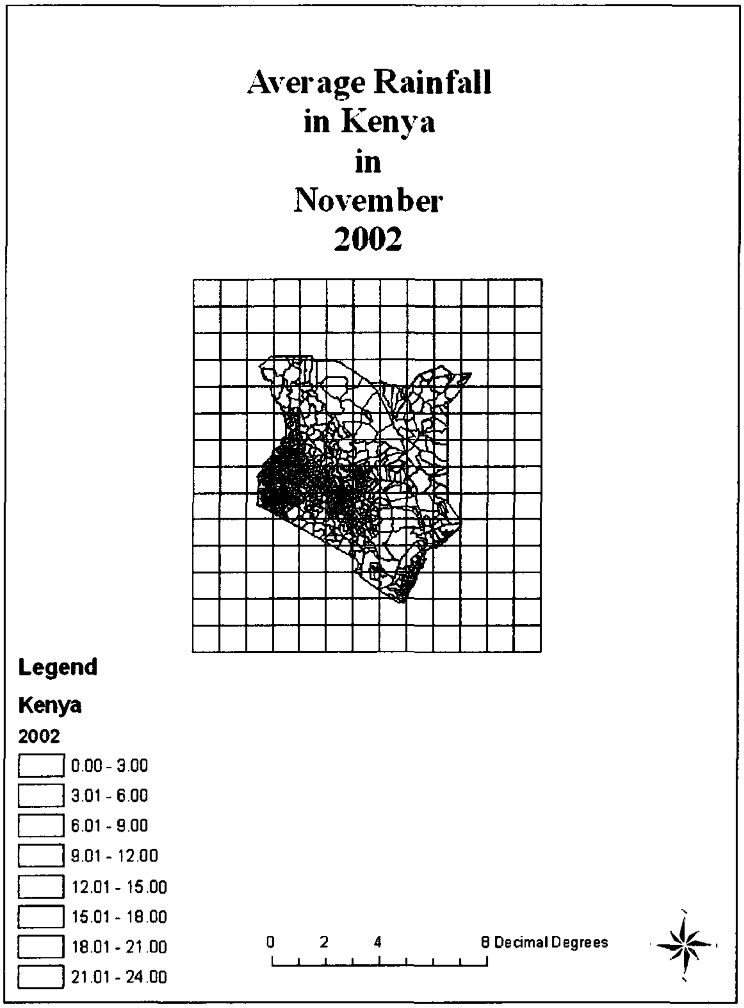
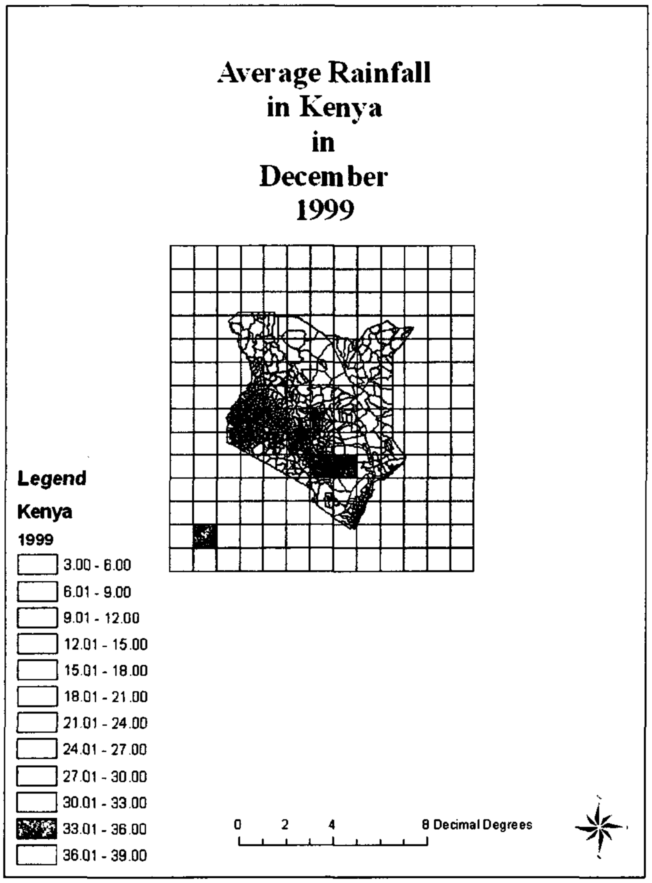


Figure 21: GIS map of above average rainfall in December of 1999 with no Rift Valley fever activity



Hot Spot Analysis

GiZScore above +2 standard deviations or below -2 standard deviations signified the presence of a hot spot. Kirinyaga, Thika, Nairobi, Embu and Machakos (Tara) in Kenya showed the presence of a hot spot in the beginning month of the RVF outbreak and no presence of a hot spot in the same month in the long term and short term dataset. Garissa, Hola, and Meru showed the opposite with hot spots found in the short term and long term dataset, but not found during the beginning month of the RVF outbreak in these areas. The areas of Kilifi, Kitui, Marakwet, Nyeri, Kiambu, Taveta, Maragua, Murang'a, Mandera, Malindi, Baringo, Mwingi, Machakos (Kibao), Lakipia, Ijara, Kwale, Makueni, Lamu, Mombasa, Mbeere, Wajir, Moyale, Samburu, and Nakuru found no presence of a hot spot in the beginning month of outbreak, nor in that same month in the long term and short term dataset. Hot spot analysis for Kenya was not useful in detecting RVF outbreak activity. Complete results for hot spot analysis are presented in Appendix B.

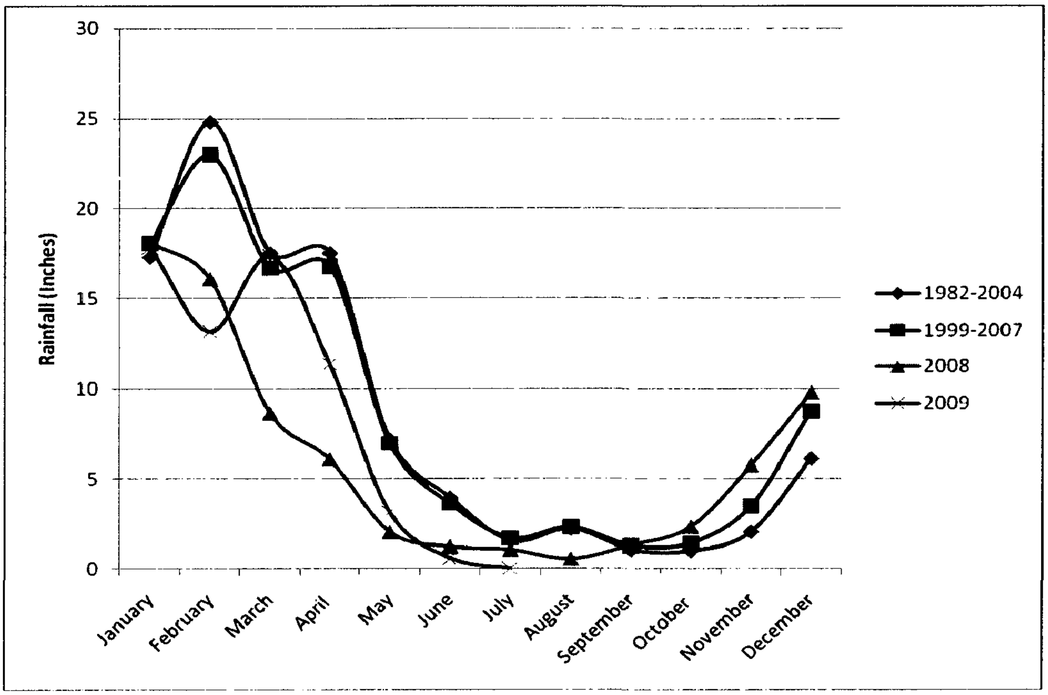
Research Question 2

Did positive rainfall anomalies occur prior to and during the 2008-2009 Rift Valley fever outbreaks in Madagascar?

Time series analysis

In the long term (1982-2004) and short term (1999-2007) dataset for Madagascar, rainfall was highest in the month of February ((x=24.799(long term); x=23.00(short term)) and lowest in the month of October ((x=1.0(long term); x=1.40(short term)). In 2008 and 2009, rainfall was highest in January ((x=18.16(2008); x=17.91(2009)). Although, this was not an unusual amount of rainfall for January as compared to the long term (January x=17.33) and short term (January x=18.10) dataset. March and April of 2008 reported a substantially lower amount of rainfall as well as for February of 2009. A mean of 8.64 was calculated in March of 2008, 6.07 in April of 2008, and 13.18 in February of 2009. A mean of 17.55 was calculated in March and April in the 1982-2004 dataset and 16.71 in March and 16.83 in April in the short term dataset. Figure 22 presents the time series results for the long term dataset (1982-2004), short term dataset (1999-2005) and for the years of the outbreak (2006, 2007) in Madagascar illustrating these points.

Figure 22: Monthly Rainfall in Madagascar for long term dataset (1982-2004), short term dataset (1999-2007) and the years of the Rift Valley fever animal outbreak (2008, 2009)



GIS Analysis

In Madagascar, nine of the ten Rift Valley fever outbreaks beginning in 2008 occurred in the Haute Matsiatra region of Madagascar. All of these outbreaks began in either November or December of 2008 and ended by January of 2009. For this region rainfall tended to be lowest in November and increased slightly in December with the highest amount of rainfall found in January of 2009. For outbreaks beginning in November and December of 2008 in the Haute Matsiatra region, rainfall was equal or slightly higher than normal when compared to the average amount of rainfall in the short term and long term dataset but only a significant amount of excess rainfall was discovered in the Ampasina area of the Haute Matsiatra region. An outbreak in

Antantananarivo, Madagascar began in February of 2008 and ended in October of 2008, and the amount of rainfall from February to September was either equal or less than the average amount of rainfall for this area during these months. For October of 2008 in the Antantananarivo region, the amount of rainfall was only slightly higher as compared to the short term and long term dataset. An outbreak in Vohitsaoka section of the Haute Matsiatra region of Madagascar began in March of 2009 and ended in May of 2009. In Vohitsaoka the amount of rainfall in March of 2009 was higher than the long term and short term dataset but in April and May of 2009, the amount of rainfall in the region was lower than normal. GIS analysis showed only one area of the eleven outbreak areas in 2008 and 2009 to have a higher than significant amount of rainfall. Although rainfall was present in each of the affected outbreak areas in Madagascar in November 2008 and December 2008 when most of the outbreaks occurred, widespread and heavy rainfall was not found. Appendix C presents rainfall data for each outbreak area in Madagascar comparing rainfall ranges from the long term dataset (1982-2004), the short term dataset (1999-2007), and the datasets during the outbreak months (2008, 2009).

Statistical analysis

GIS analysis showed no clear relationship between RVF activity and rainfall rates. Therefore, furthur statistical analysis was done on data from January 1999 through July of 2009 to discover when positive rainfall anomlies had occurred during the time period of RVF activity and during the time period without RVF activity. The standard deviation for the January 1999-2009 dataset in Madagascar was 5.79 resulting in a lower 99% confidence interval of 13.51 and an upper 99% confidence interval of 22.50. The standard deviation for the February 1999-2009 dataset in Madagascar was 6.06 resulting in a lower 99% confidence interval of 17.43 and an upper 99% confidence interval of 26.84. The standard deviation for the March 1999-2009 dataset in Madagascar was 5.28 resulting in a lower 99% confidence interval of 11.94 and an upper 99% confidence interval of 20.14. The standard deviation for the April 1999-2009 dataset in Madagascar was 4.71 resulting in a lower 99% confidence interval of 11.70 and an upper 99% confidence interval of 19.01. The standard deviation for the May 1999-2009 dataset in Madagascar was 3.01 resulting in a lower 99% confidence interval of 3.80 and a 99% upper confidence interval of 8.48. The standard deviation for the June 1999-2009 dataset in Madagascar was 2.01 resulting in a lower 99% confidence interval of 1.55 and an upper 99% confidence interval of 4.68. The standard deviation for the July 1999-2009 dataset in Madagascar was 1.63 resulting in a lower 99% confidence interval of .20 and an upper 99% confidence interval of 2.74. The standard deviation for the August 1999-2008 dataset in Madagascar was 2.92 resulting in a lower 99% confidence interval of .28 and an upper 99% confidence interval of 4.48. The standard deviation for the September 1999-2008 dataset in Madagascar was 1.05 resulting in a lower 99% confidence interval of .41 and an upper 99% confidence interval of 2.13. The standard deviation for the October 1999-2008 dataset in Madagascar was .65 resulting in a lower 99% confidence interval of .97 and an upper 99% confidence interval of 2.02. The standard deviation for the November 1999-2008 dataset in Madagascar was 2.90 resulting in a lower 99% confidence interval of 1.34 and an upper 99% confidence interval of 6.06. The standard deviation for the December 1999-2008 dataset in Madagascar was 5.52 resulting in a lower 99% confidence interval of 4.35 and an upper 99% confidence interval of 13.36. Using these confidence intervals, average amounts of rainfall for each year was graphed along with the upper and lower confidence intervals calculated for each month. Positive rainfall anomalies were those falling above the upper 99% confidence intervals. Figures 23 through 31 presents average rainfall for the years 1999 through 2007 during which no RVF activity was detected. Figures 32 and 33 presents rainfall for the years 2008 and 2009 during which RVF activity was detected. Data for August through December of 2009 was not available at the time of the analysis, therefore data for August through December was excluded.

Figure 23: Rainfall in 1999 in Madagascar with lower and upper 99% confidence intervals

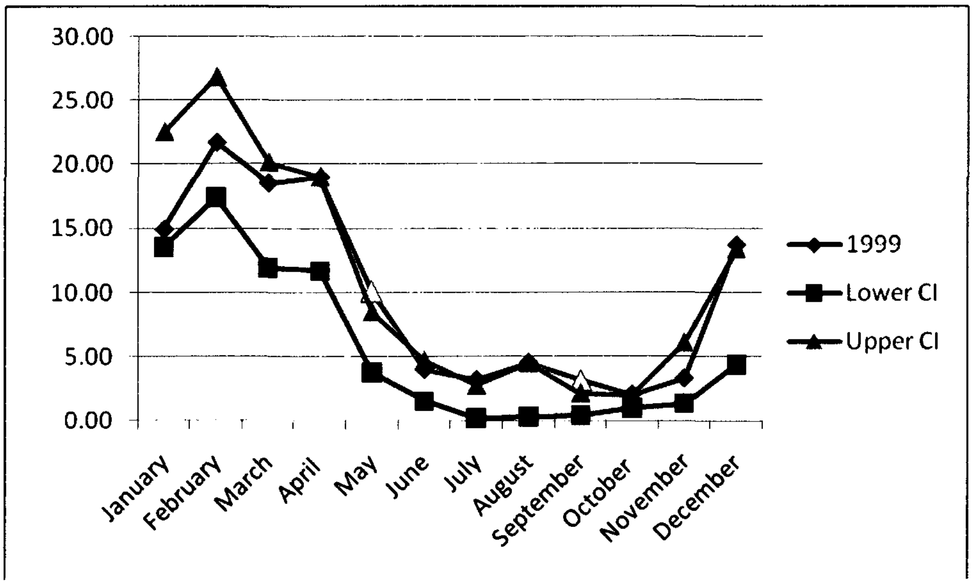


Figure 24: Rainfall in 2000 in Madagascar with lower and upper 99% confidence intervals

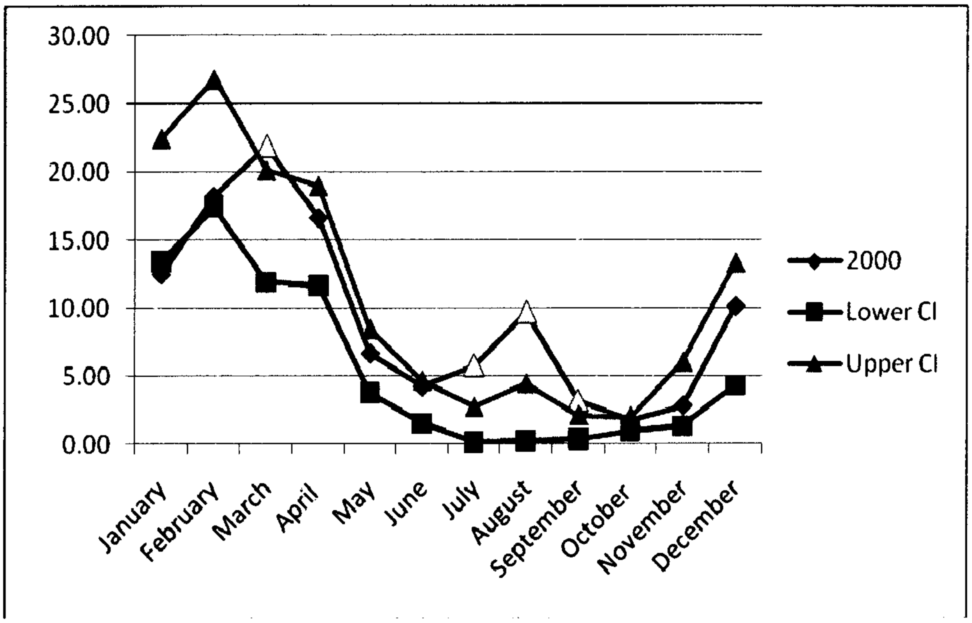


Figure 25: Rainfall in 2001 in Madagascar with lower and upper 99% confidence intervals

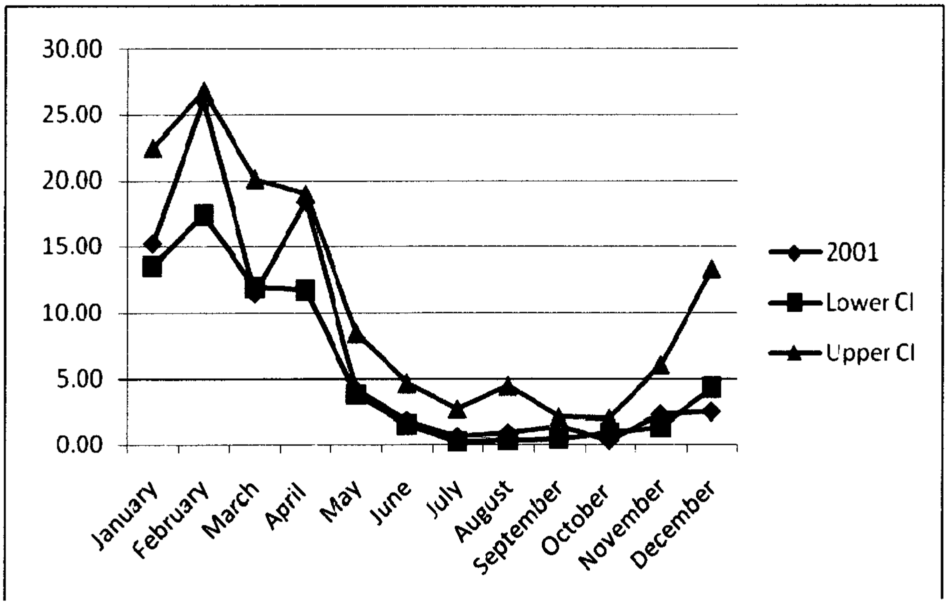


Figure 26: Rainfall in 2002 in Madagascar with lower and upper 99% confidence intervals

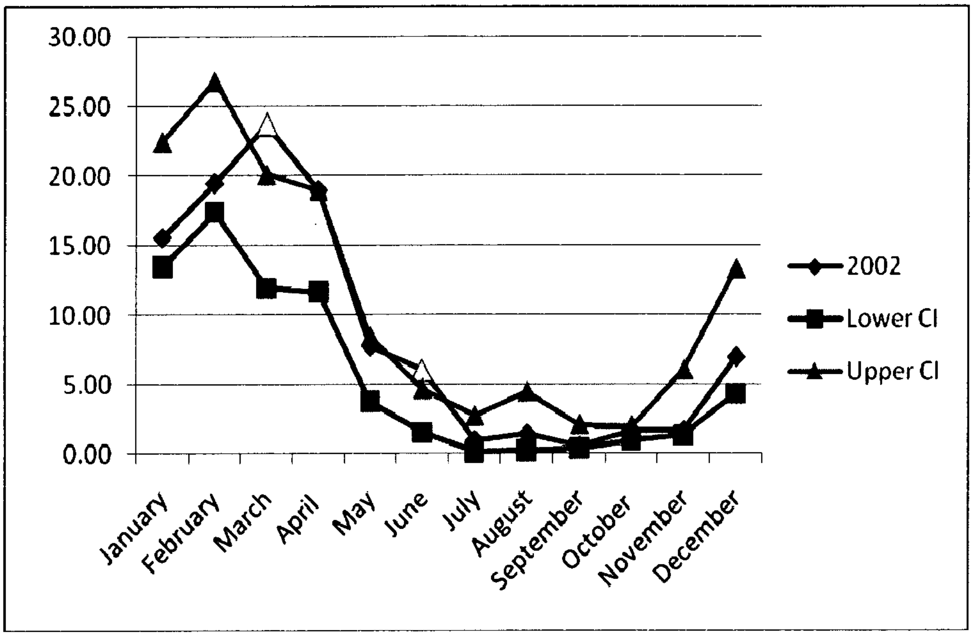


Figure 27: Rainfall in 2003 in Madagascar with lower and upper 99% confidence intervals

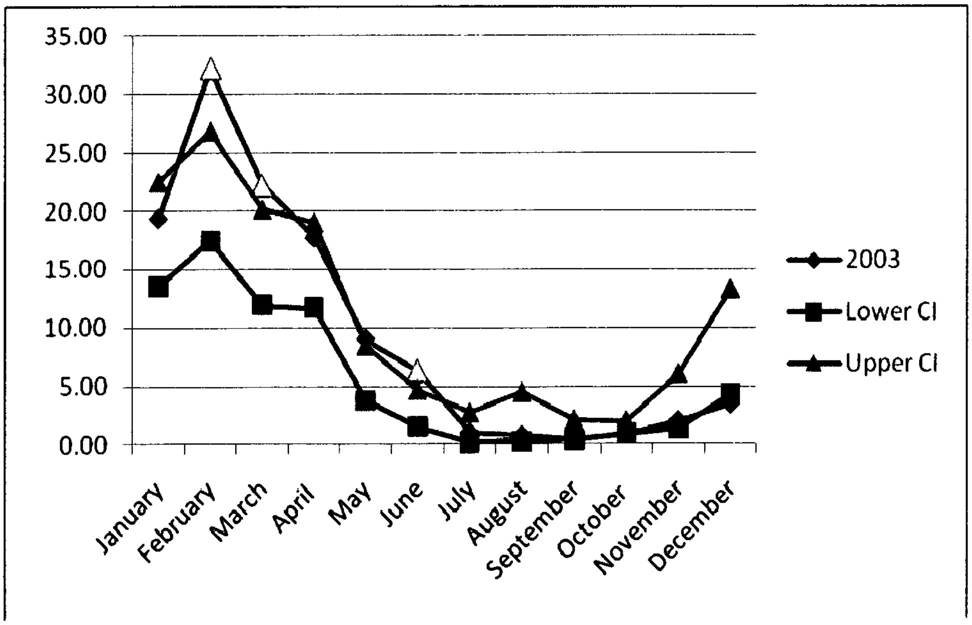


Figure 28: Rainfall in 2004 in Madagascar with lower and upper 99% confidence intervals

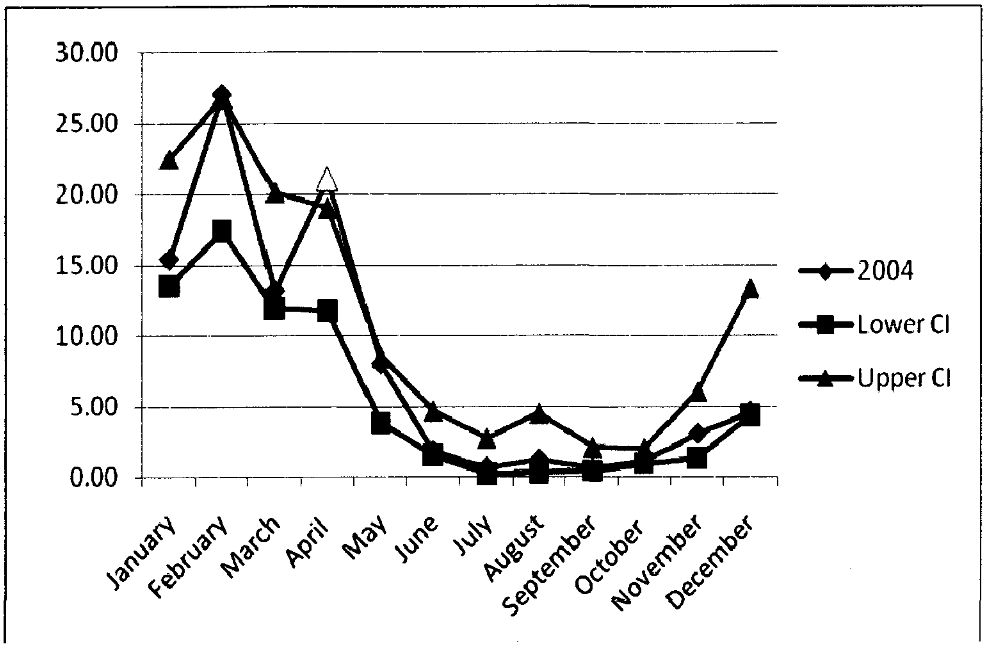


Figure 29: Rainfall in 2005 in Madagascar with lower and upper 99% confidence intervals

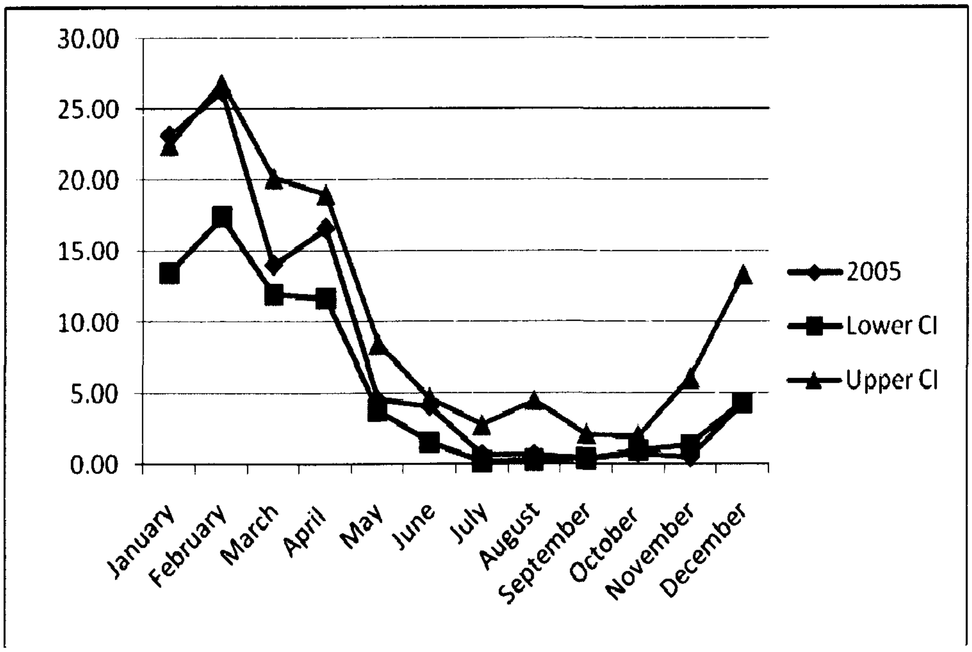


Figure 30: Rainfall in 2006 in Madagascar with lower and upper 99% confidence intervals

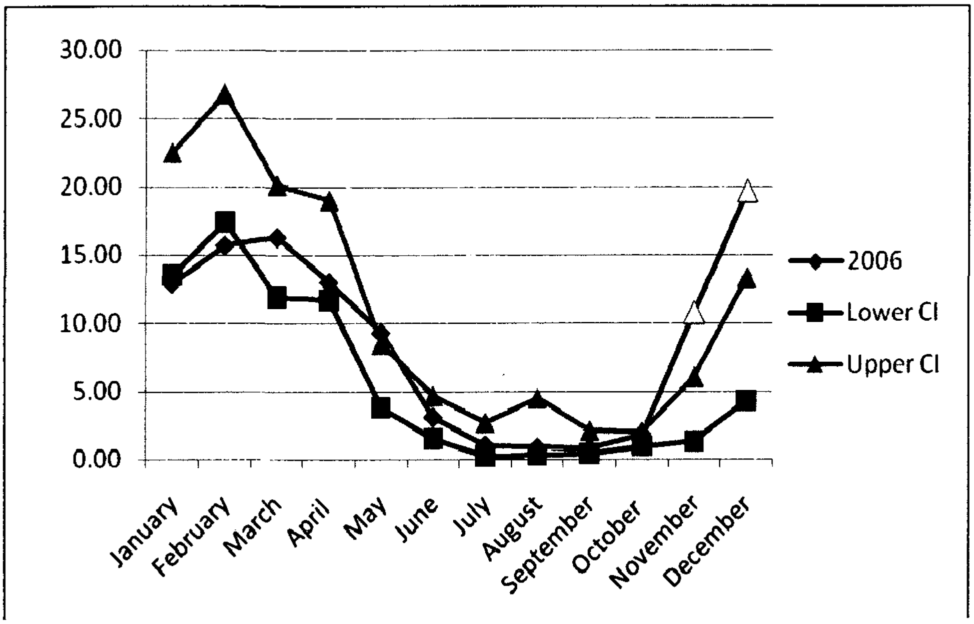


Figure 31: Rainfall in 2007 in Madagascar with lower and upper 99% confidence intervals

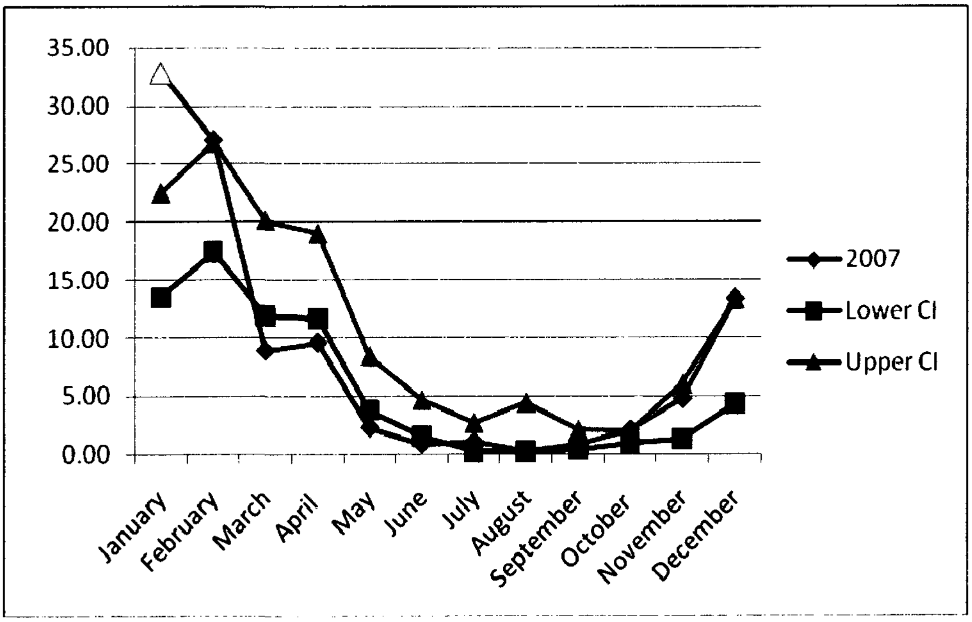


Figure 32: Rainfall in 2008 in Madagascar with lower and upper 99% confidence intervals

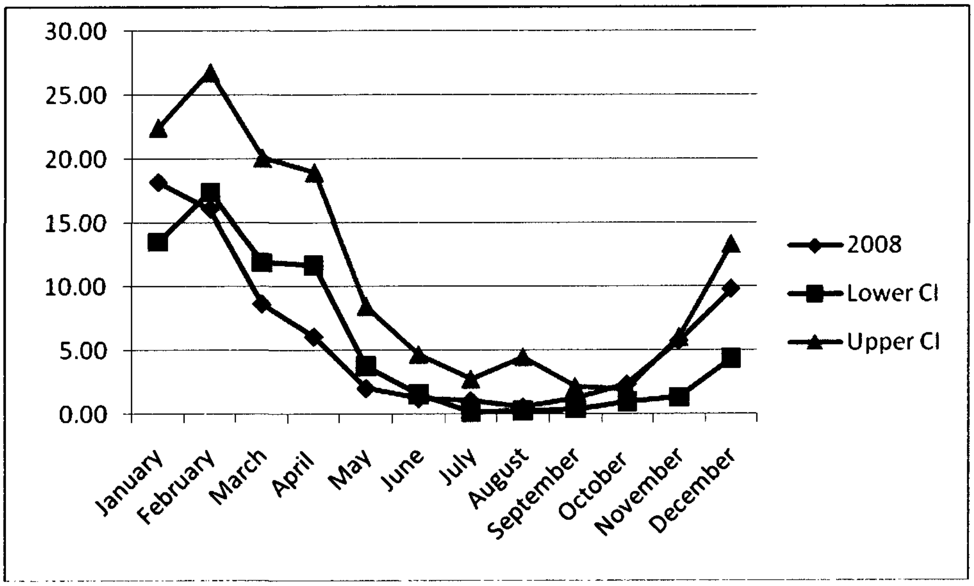
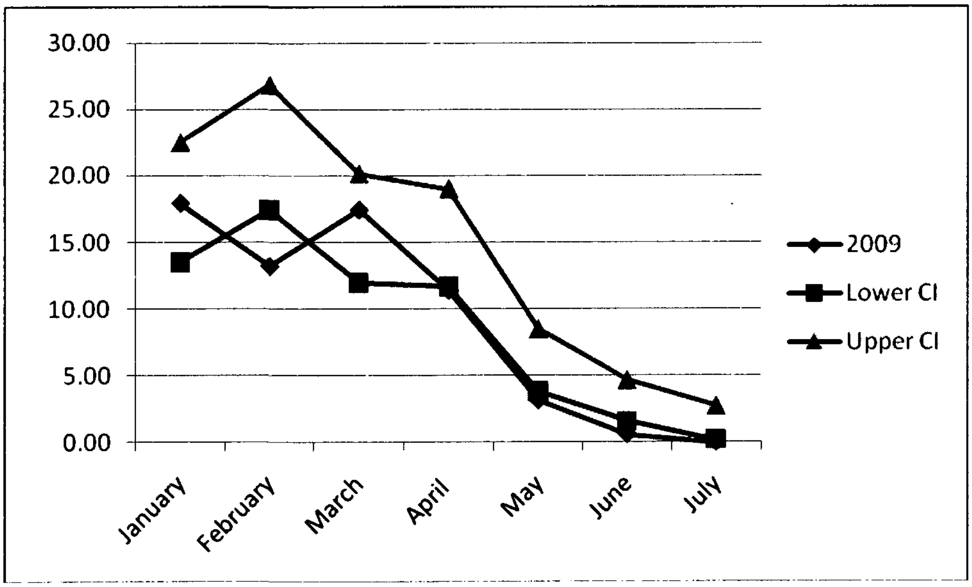


Figure 33: Rainfall in 2009 in Madagascar with lower and upper 99% confidence intervals



Positive rainfall anomalies occurred in 1999, 2000, 2002, 2003, 2003, 2006, and 2007. In 1999, positive rainfall anomalies were found in May and September. In 2000, positive rainfall anomalies were discovered in March, July, August, and September. In 2001, no positive rainfall anomalies were discovered. In 2002, March and June were found to have positive rainfall anomalies. In 2003, February, March, and June were found to have positve rainfall anomalies. April of 2004 also had a positive rainfall anomaly, while 2005 had none. November and December of 2006 and January of 2007 also had positive rainfall anomalies. No positive rainfall anomalies were discovered for 2008 and 2009 during which RVF activity was detected. In January 2007, the average maximum temperture in Madagascar was 25°C and minimum temperature 22°C. In February 2003, the average maximum temperature was 26°C and minimum temperature 24°C. In March of 2000, the average maximum temperature was 27°C and minimum temperature 24°C, and in March of 2002, the average maximum temperature was 28°C and minimum temperature 24°C. In March of 2003, the average maximum temperature was 28°C and minimum temperature 26°C. In April of 2004, the average maximum temperature was 28°C and minimum temperature 23°C. In May of 1999, the average maximum temperature was 25°C and minimum temperature 21°C. In June of 2002, the average maximum temperature was 24°C and minimum temperature 21°C, and in June of 2003, the average maximum temperature was 23°C and minimum temperature 20°C. In July of 2000, the average maximum temperature was 23°C and minimum temperature 19°C, and in August of 2000, the average maximum temperature was 25°C and minimum temperature 21°C. In September of 1999, the average maximum temperature was 24°C and minimum temperature 19°C, and in September of 2000, the average maximum temperature was 26°C and minimum temperature 21°C. In November of 2006, the average maximum temperature was 25°C and minimum temperature 20°C, and in December of 2006, the average maximum temperature was 26°C and minimum temperature 21°C. The monthly averages are as follows: January maximum temperature is 27°C and the minimum temperature 25°C; February maxiium temperature is 28°C and the minimum temperature 25°C; March maximum temperature is 28°C and the minimum temperature 25°C; April average maximum temperature is 27°C and the minimum temperature 24°C; May maximum temperature is 26°C and the minimum temperature 23°C; June average maximum temperature is 24°C and the minimum temperature 22°C; July average maximum temperature is 24°C and the minimum temperature 21°C; August maximum temperature is 24°C and the minimum temperature 21°C; September average maximum temperature is 25°C and the minimum temperature 21°C; November maximum temperature is 26°C and the minimum temperature 23°C; and December average maximum temperature is 27°C and the minimum temperature 25°C according to the 1999-2005 dataset. Table 11 presents results for positive rainfall anomalies in Madagascar.

Table 11: Statistical analysis results for positive rainfall anomalies 1999-2007 in Madgagascar during which no RVF activity was reported

Month	Year	Mean	$CI_{.99}$
January	2007	32.90	13.51-22.50
February	2003	32.22	17.43-26.84
March	2000	21.94	11.94-20.14
March	2002	23.72	11.94-20.14
March	2003	22.22	11.94-20.14
April	2004	21.07	11.70-19.01
May	1999	10.06	3.80-8.48
June	2002	6.07	1.55-4.68
June	2003	6.34	1.55-4.68

July	2000	5.80	.20-2.74
August	2000	9.69	.28-4.48
September	2000	3.19	.41-2.13
September	1999	3.16	.41-2.13
November	2006	10.77	1.34-6.06
December	2006	19.67	4.35-13.36

Hot Spot Analysis

GiZScore above +2 or below -2 were found in the beginning months of the RVF outbreak in Antady, Nasandratrony, Ambanimaso, Imandry, Tsaramandroso, Ambonifehidrano, and Marodinta as well as in the same month in the long term and short term dataset. In Antananarivo, hot spots were found in the year 2008 at the beginning of their RVF outbreak, but no hot spots were found in the corresponding month for the short term and long term outbreak. In Antanifotsy and Ampasina, hot spots were found in the year 2008 at the beginning of their RVF outbreak as well as the short term dataset, but not in the long term dataset. In Antady, Nasandratrony, Ambanimaso, Imandry, Tsaramandroso, and Marodinta, hot spots were found for all months in which the RVF outbreak occurred. Vohitsaoka reported zero outbreaks in the outbreak year and none in the long term or short term dataset. Hot spot analysis was not useful in Madagascar in detecting above average amounts of rainfall. Hot spot analysis results for all areas of Madagascar reporting RVF outbreak activity in 2008 and 2009 is presented in Appendix D.

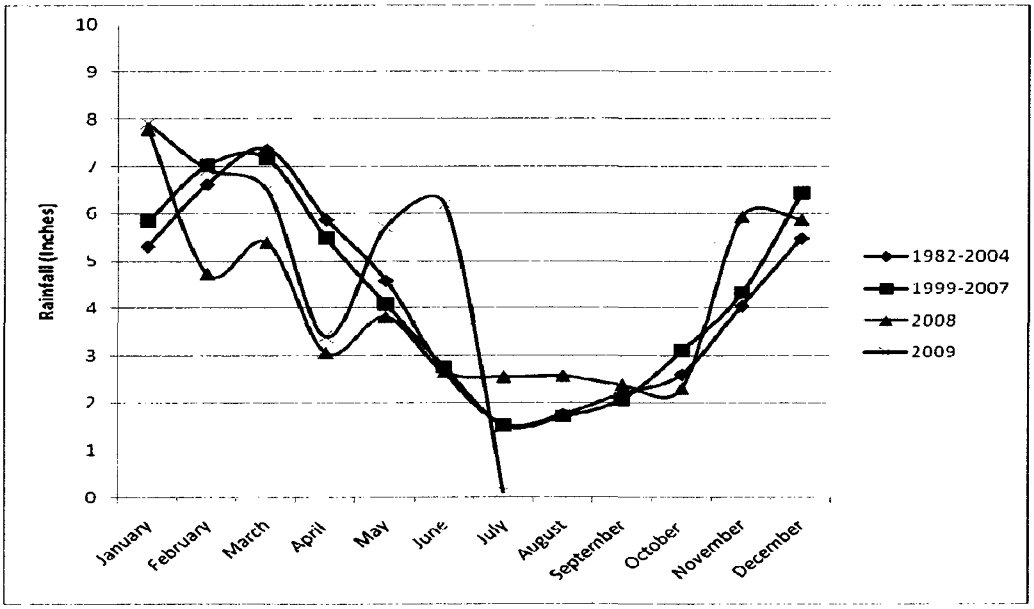
Research Question 3

Did positive rainfall anomalies occur prior to and during the 2008-2009 Rift Valley fever outbreaks in South Africa?

Time series analysis

In the long term (1982-2004) and short term (1999-2007) datasets, the highest amount of rainfall was in March ((x=7.36(long term); x=7.17(short term)). While in 2008 and 2009 the highest amount of rainfall was found to be in the month of January ((x=7.78(2008); x=7.91(2009)). July was found to have the lowest amount of rainfall in the long term (July x=1.54) and short term (July x=1.52) datasets and October was found to have the lowest amount of rainfall in 2008 (x=2.31). No month in 2008 was found to have an unusually high or unusually low amount of rainfall when compared to the short term and long term datasets. June of 2009 reported a high amount of rainfall while July of 2009 reported a lower than normal amount of rainfall. A time series rainfall graph for South Africa for the long term dataset (1982-2004), short term dataset, and the years 2008-2009 during which an RVF animal outbreak occurred is presented in Figure 34.

Figure 34: Monthly Rainfall in South Africa for long term dataset (1982-2004), short term dataset (1999-2007) and the years of the Rift Valley fever animal outbreak (2008, 2009)



GIS Analysis

All outbreaks in South Africa occurring in 2008 ended by June with most beginning in January, February, March, or April of 2008 and one outbreak beginning in January of 2008. An outbreak in Kwazulu-Natal began in February of 2009 and ended in May of 2009. In Mpumalanga, Ba-Phalaborwa, Leeuwkraal, Witpoort, Madibeng, and Potchefstroom in the beginning month of the outbreak, lower than average amounts of rainfall were found as compared to average amounts of rainfall in the short term and long term datasets. Bela-Bela and Leeuwkraal reported the same average amount of rainfall in the beginning month of the outbreak as compared to the long term and short term average. Only Doornkloof reported a higher than average amount of rainfall in the beginning month of the RVF outbreak. Kwazulu-Natal reported a higher than average amount of rainfall in the beginning month of the RVF outbreak than the short term dataset, but the same amount as the long term dataset. In all outbreak regions in South Africa, rainfall ranged from 0-15 inches in 2008 and 0-18 inches in the Kwazulu-Natal region in 2009. For the long term and short term datasets, rainfall ranged from 0-18 inches. Appendix E presents average amount of rainfall for RVF outbreak areas in South Africa.

Statistical analysis

Since GIS analysis showed that no relationship exists between rainfall and Rift Valley fever outbreaks, rainfall data for the years 1999-2009 was further analyzed to discover when positive and negative rainfall anomalies may have occurred. Since data was not available for August through December of 2009 at the time of the analysis data was analyzed from January 1999 through July 2009. The standard deviation for the

January 1999-2009 dataset in South Africa was 1.77 resulting in a lower 99% confidence interval of 4.79 and an upper 99% confidence interval of 7.54. The standard deviation for the February 1999-2009 dataset in South Africa was 2.44 resulting in a lower 99% confidence interval of 4.60 and an upper 99% confidence interval of 8.39. The standard deviation for the March 1999-2009 dataset in South Africa was 3.10 resulting in a lower 99% confidence interval of 4.54 and an upper 99% confidence interval of 9.36. The standard deviation for the April 1999-2009 dataset in South Africa was 2.30 resulting in a lower 99% confidence interval of 3.29 and an upper 99% confidence interval of 6.86. The standard deviation for the May 1999-2009 dataset in South Africa was 1.44 resulting in a lower 99% confidence interval of 3.10 and a 99% upper confidence interval of 5.33. The standard deviation for the June 1999-2009 dataset in South Africa was 1.37 resulting in a lower 99% confidence interval of 1.99 and an upper 99% confidence interval of 4.12. The standard deviation for the July 1999-2009 dataset in South Africa was .64 resulting in a lower 99% confidence interval of .99 and an upper 99% confidence interval of 1.99. The standard deviation for the August 1999-2008 dataset in South Africa was .87 resulting in a lower 99% confidence interval of 1.09 and an upper 99% confidence interval of 2.50. The standard deviation for the September 1999-2008 dataset in South Africa was .83 resulting in a lower 99% confidence interval of 1.44 and an upper 99% confidence interval of 2.79. The standard deviation for the October 1999-2008 dataset in South Africa was .93 resulting in a lower 99% confidence interval of 2.26 and an upper 99% confidence interval of 3.77. The standard deviation for the November 1999-2008 dataset in South Africa was 1.11 resulting in a lower 99% confidence interval of 3.59 and an upper 99% confidence interval of 5.40. The standard deviation for the December

1999-2008 dataset in South Africa was 2.50 resulting in a lower 99% confidence interval of 4.34 and an upper 99% confidence interval of 8.42. Using these confidence intervals, average amounts of rainfall for each year was graphed along with the upper and lower confidence intervals calculated for each month. Positive rainfall anomalies were those falling above the upper 99% confidence intervals. Figures 35 through 43 presents average rainfall for the years 1999 through 2007 during which no RVF activity was detected while figures 44 and 45 presents rainfall for the years 2008 and 2009 during which RVF activity was detected.

Figure 35: Rainfall in 1999 in South Africa with lower and upper 99% confidence intervals

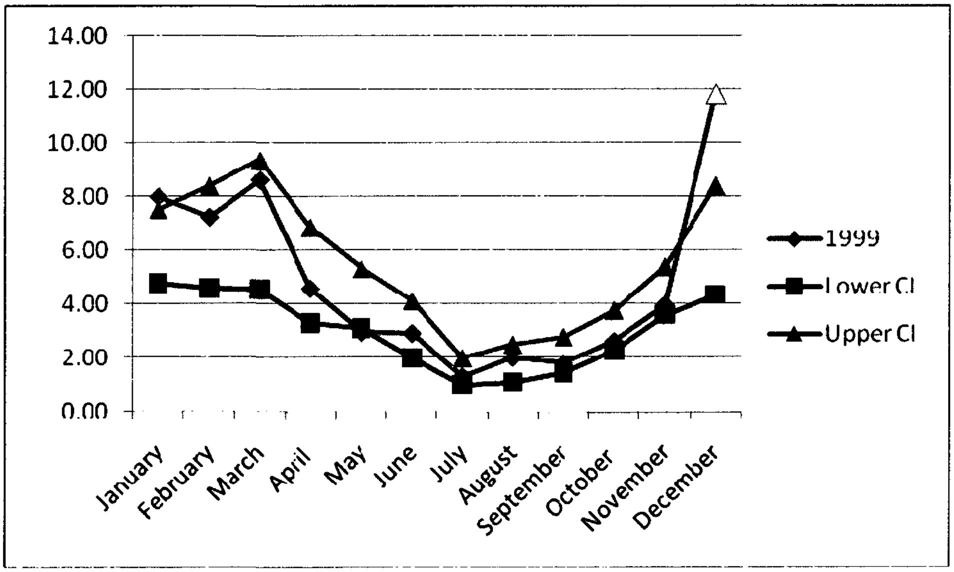


Figure 36: Rainfall in 2000 in South Africa with lower and upper 99% confidence intervals

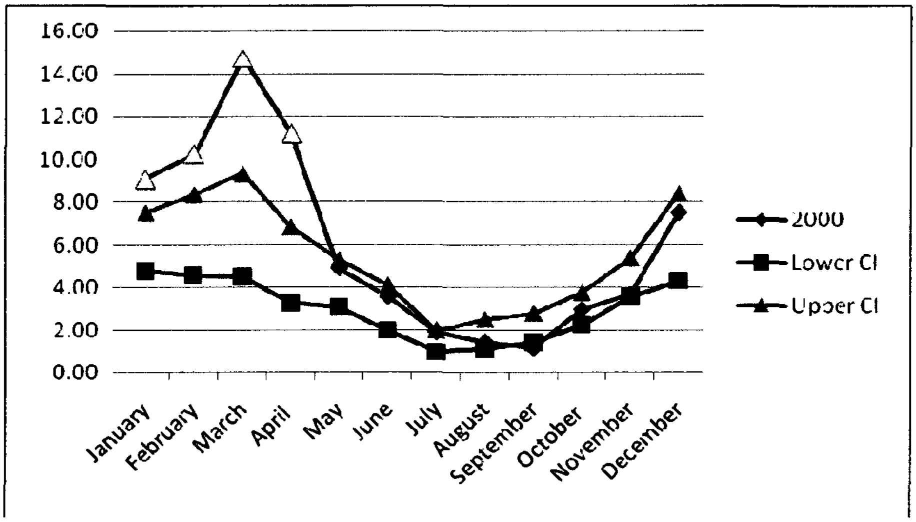


Figure 37: Rainfall in 2001 in South Africa with lower and upper 99% confidence intervals

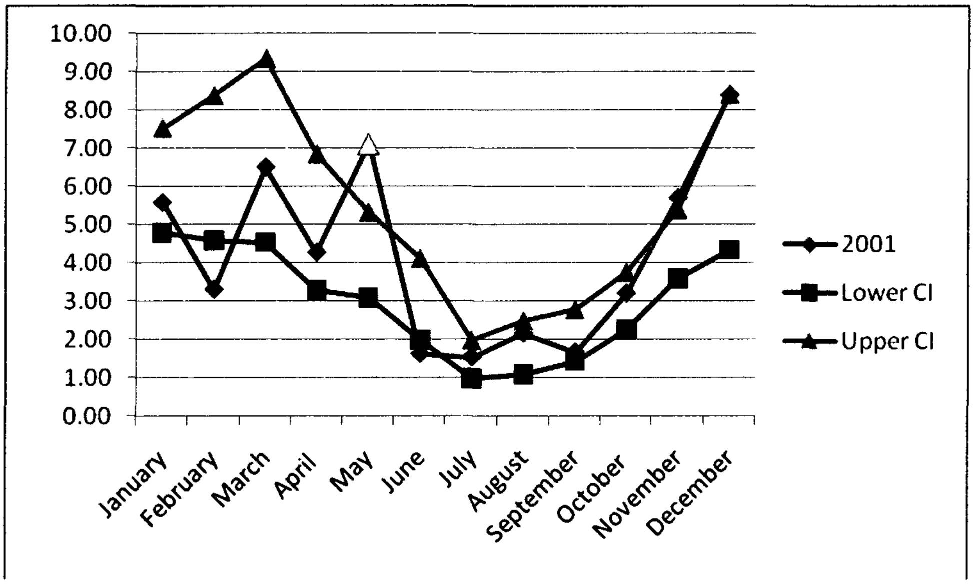


Figure 38: Rainfall in 2002 in South Africa with lower and upper 99% confidence intervals

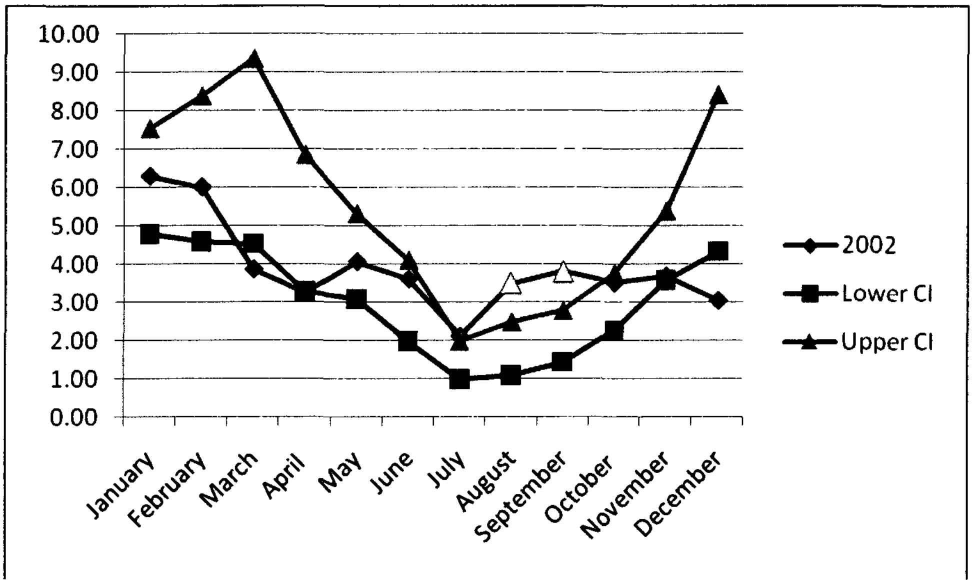


Figure 39: Rainfall in 2003 in South Africa with lower and upper 99% confidence intervals

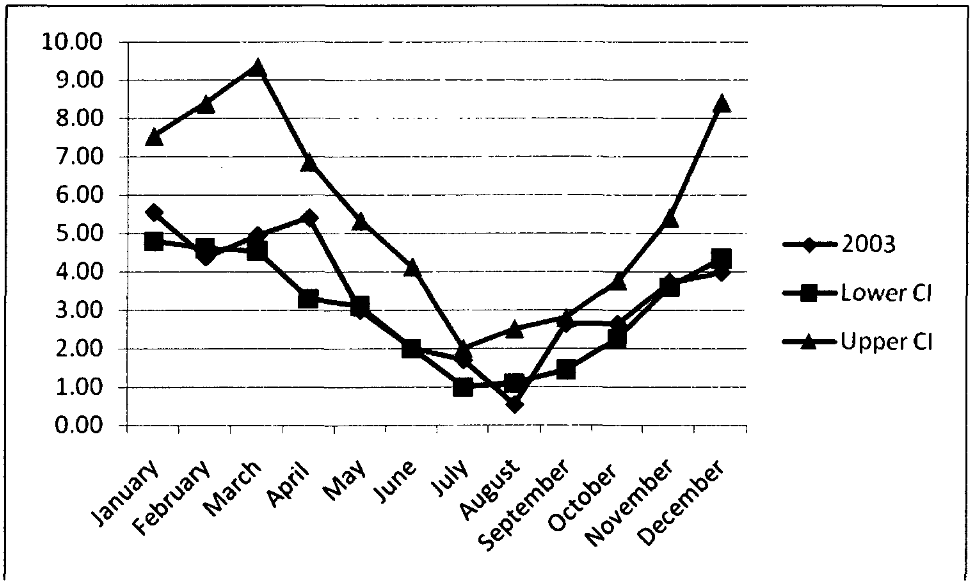


Figure 40: Rainfall in 2004 in South Africa with lower and upper 99% confidence intervals

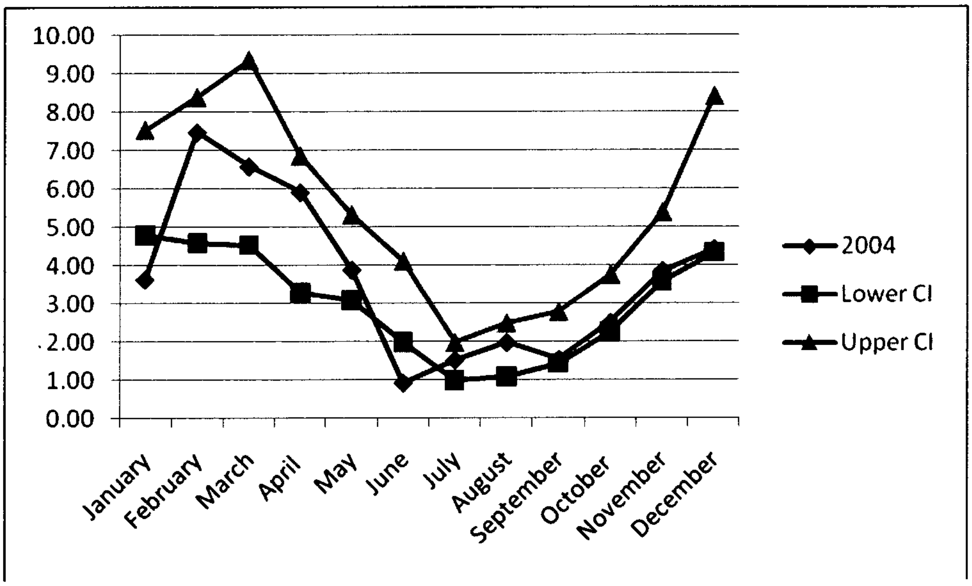


Figure 41: Rainfall in 2005 in South Africa with lower and upper 99% confidence intervals

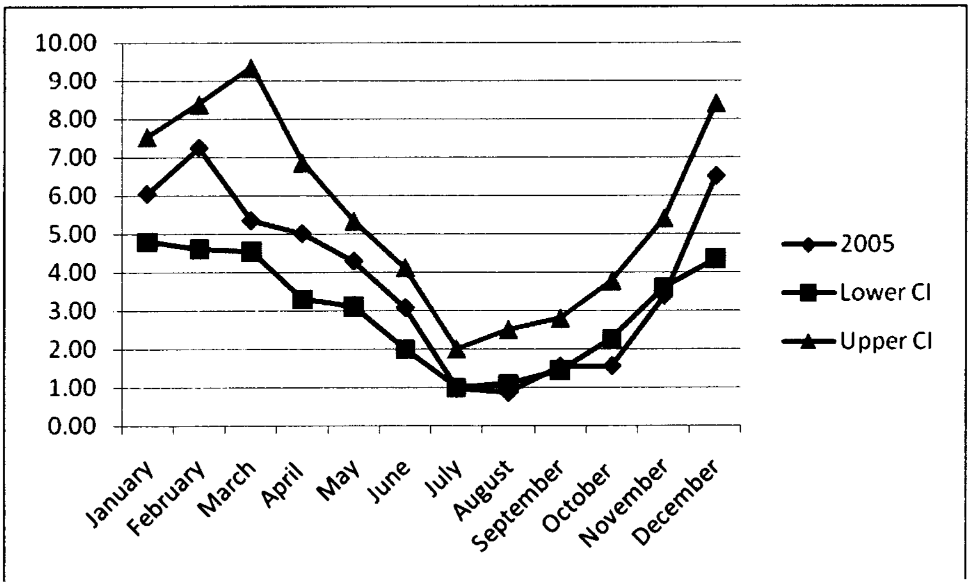


Figure 42: Rainfall 2006 in South Africa with lower and upper 99% confidence intervals

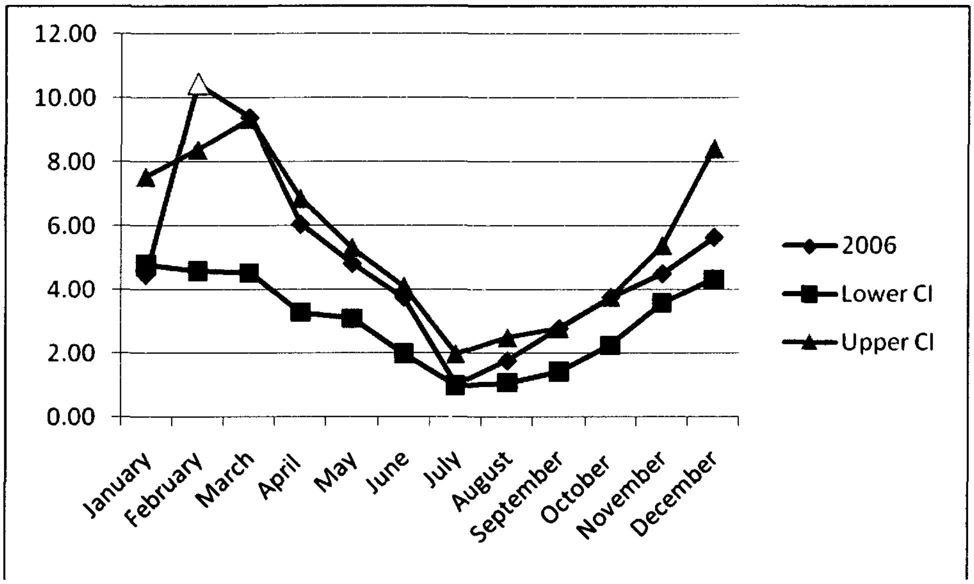


Figure 43: Rainfall in 2007 in South Africa with lower and upper 99% confidence intervals

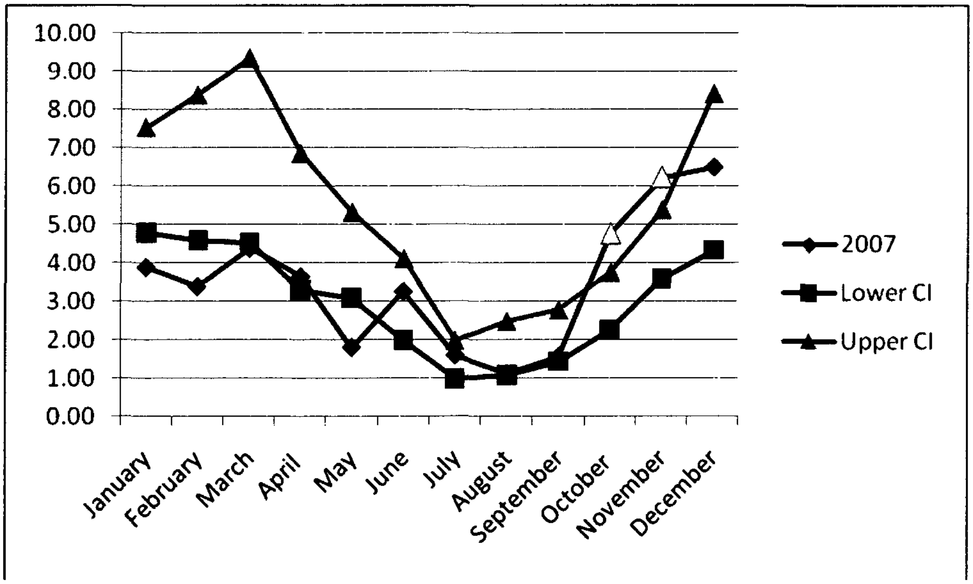


Figure 44: Rainfall in 2008 in South Africa with lower and upper 99% confidence intervals

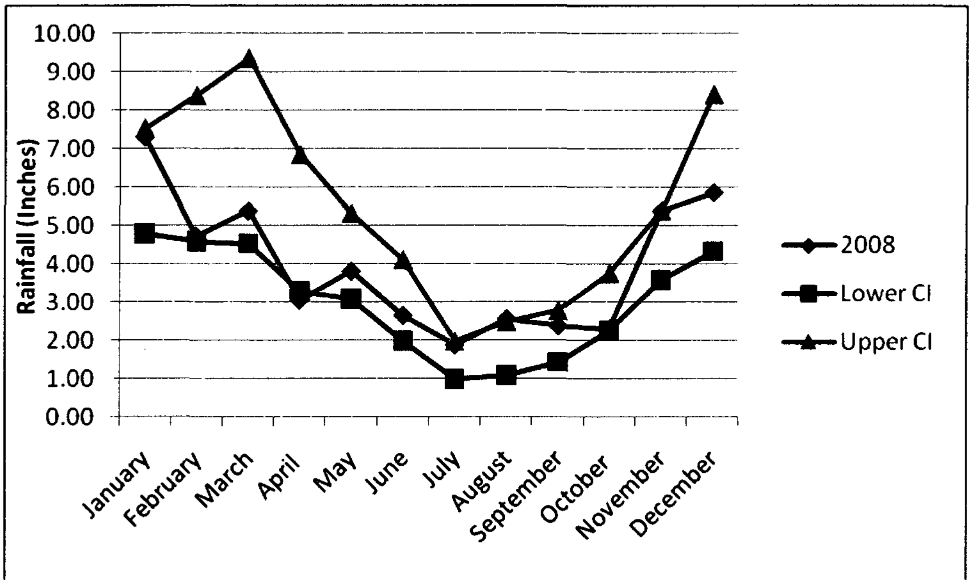
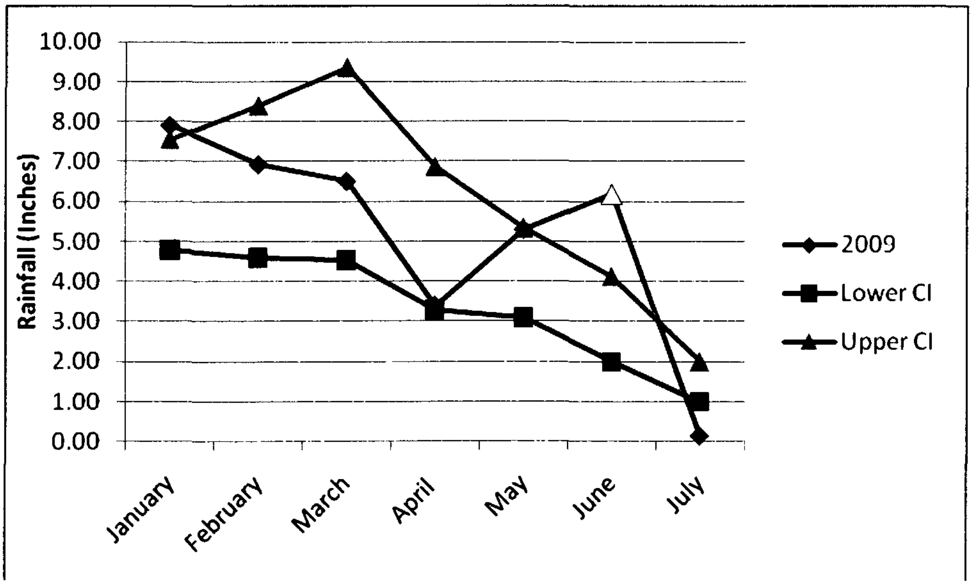


Figure 45: Rainfall in 2009 in South Africa with lower and upper 99% confidence intervals



Results concluded that positive rainfall anomalies had occurred in 1999, 2000, 2001, 2002, 2006,2007, and 2009. In 1999, December was found to have a positive rainfall anomaly. In 2000, January, February, March, and April were found to have positive rainfall anomalies. In 2001, May displayed a positive rainfall anomaly. In 2002, August and September were found to have positive rainfall anomliess. In 2006, February was found to have positive rainfall anomalies, and in 2007, October and November were discovered to have positive rainfall anomalies. No Rift Valley fever was reported during these times. In 2008 during Rift Valley fever activity, no months were found to have elevated amounts of rainfall, and for 2009, only June was found to have elevated amounts of rainfall. In January 2000, the average maximum temperture in South Africa was 25°C and minimum temperature 16°C; February 2000 average maximum temperature was 27°C and minimum temperature 17°C; February of 2006 average maximum temperature was 28°C and minimum temperature 19°C; March of 2000 average maximum temperature was 26°C and minimum temperature 18°C; April of 2000 average maximum temperature was 23°C and minimum temperature 15°C;May of 2001 average maximum temperature was 20°C and minimum temperature 13°C; August of 2002 average maximum temperature was 18°C and minimum temperature 11°C; September of 2002 average maximum temperature was 24°C and minimum temperature 12°C; October of 2007 average maximum temperature was 23°C and minimum temperature 14°C; November of 2007 average maximum temperature was 24°C and minimum temperature 14°C; December of 1999 average maximum temperature was 25°C and minimum temperature 17°C; and June of 2009 average maximum temperature was 18°C and minimum temperature 10°C. On average in January, the maximum temperature is 27°C and the minimum temperature 18°C; February maximum temperature is 27°C and the minimum temperature 19°C; March the maximum temperature is 26°C and the minimum temperature 18°C; April average maximum temperature is 24°C and the minimum temperature 16°C; May maximum temperature is 22°C and the minimum temperature 13°C; June maximum temperature is 20°C and the minimum temperature 11°C; August maxiium temperature is 21°C and the minimum temperature 11°C; September average maximum temperature is 23°C and the minimum temperature 13°C; October average maximum temperature is 25°C and the minimum temperature 15°C; November maximum temperature is 23°C and the minimum temperature 16°C; and December average maximum temperature is 26°C and the minimum temperature 17°C according to averages from the 1999-2005 dataset. Table 12 presents the positive rainfall anomalies during which no RVF activity was detected, and Table 13 presents results for positive rainfall anomalies in South Africa during which RVF activity was detected.

Table 12: Positive rainfall anomalies 1999-2007 in South Africa during which no RVF activity was reported

Month	**Year**	**Mean**	**$CI_{.99}$**
January	2000	9.09	4.79-7.54
February	2000	10.24	4.6-8.39
February	2006	10.45	4.6-8.39
March	2000	14.75	4.54-9.36
April	2000	11.22	3.29-6.86
May	2001	7.11	3.10-5.33
August	2002	3.51	1.09-2.5
September	2002	3.81	1.44-2.79
October	2007	4.77	2.26-3.77
November	2007	6.23	3.59-5.40
December	1999	11.83	4.34-8.42

Table 13: Positive rainfall anomalies during the RVF outbreak in South Africa 2008-2009

Month	Year	Mean	$CI_{.99}$
June	2009	6.19	1.99-4.12

Hot Spot Analysis

GiZScore above +2 or below -2 indicating a hot spot were found in Bela-Bela, Leeuwkraal (Cullinan), and Doornkloof in the beginning month of the RVF outbreak, yet not in the corresponding month in the short term and long term datasets. In Ba-Phalaborwa and Kwazulu-Natal, a hot spot was identified in the beginning month of the RVF outbreak as well as in the short term and long term datasets. In Leeuwkraal (Moretele), Witpoort, Madibeng, Mpumalanga (Mbombela, Moroka), and Krokodildrift, no hot spots were found in the beginning month of the RVF outbreak, nor in the corresponding month in the short term and long term datasets. In Mpumalanga (Ngwenya, Grootboom, Marlothi, One Tree Hill, Ten Bosch, Vyeboom, Richtersnek), although hot spots were in the corresponding month of outbreak start in the long term and short term datasets, no hot spots were found in the month of RVF outbreak start. Hot spots were not found in the final month of the RVF outbreak in the outbreak year nor short term or long term datasets. Fully detailed results for hotspot analysis results for South Africa are presented in Appendix F.

Research Question 4

Were the temperature ranges during the 2006-2007 Rift Valley fever outbreaks in Kenya different than historical temperature ranges for Kenya?

Time series analysis

In the long term (1982-2004) dataset for Kenya, the lowest mean maximum temperature (tmax) was in November (x=26.72) and highest mean maximum temperature in February (x=31.15). The lowest range of the maximum temperature in the long term dataset was found in April (R=14.31) and the highest in January (R=16.85). In the short term (1999-2005) dataset for Kenya, the lowest mean maximum temperature was in July (x=26.63) and highest mean maximum temperature in February (x=31.09). The lowest range of maximum temperature in the short term dataset was found in November (R=14.58) and the highest was found in September (R=19.52). In 2006, the lowest mean maximum temperature was found in July (x=26.31) and lowest range in May (R= 17.87), while the highest mean maximum temperature in February (x=30.94) and highest range was also in February (R=21.93). In 2007, the lowest mean maximum temperature was found in July (x=26.77), lowest range in June (R= 18.70), the highest mean maximum temperature in February (x=30.64), and highest range was in September (R=22.08). Mean maximum temperature for all four datasets seemed to follow the same trend with only May, October, November, and December of 2007 reporting higher mean results than the other three datasets. Maximum temperature tends to be highest in February and declines sharply with lowest maximum temperature being reported in July and increasing through September. Maximum temperature rates declined in October and November and increased in December. Figure 46 and 47 present the average mean and range of maximum temperatures for the long term dataset, short term dataset, and the 2006 and 2007 dataset for Kenya.

Figure 46: Monthly tmax in Kenya for the long term dataset (1982-2004), short term dataset (1999-2005) and the years of the Rift Valley fever animal outbreak (2006, 2007)

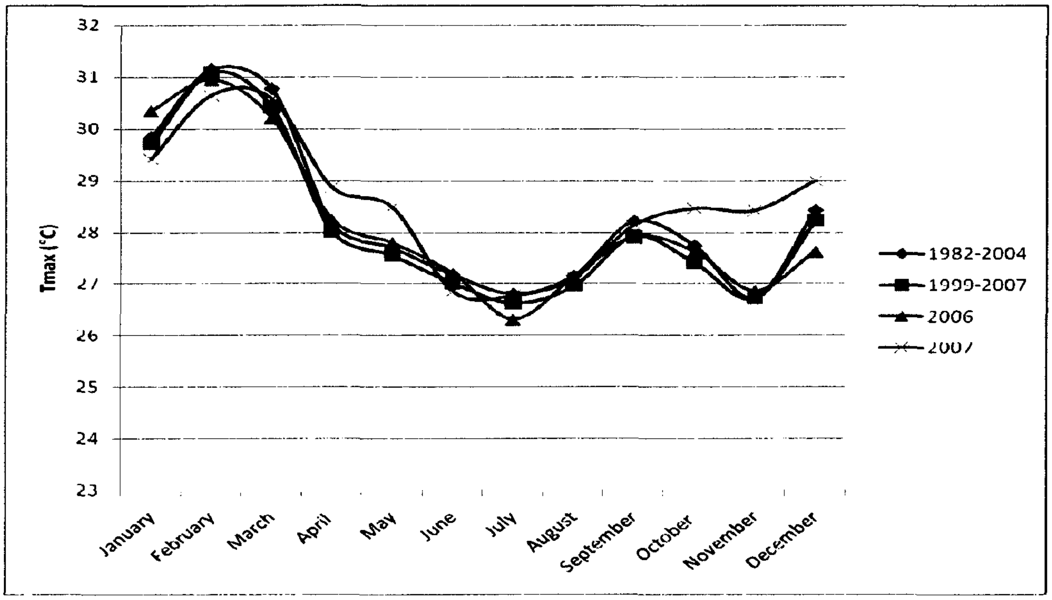
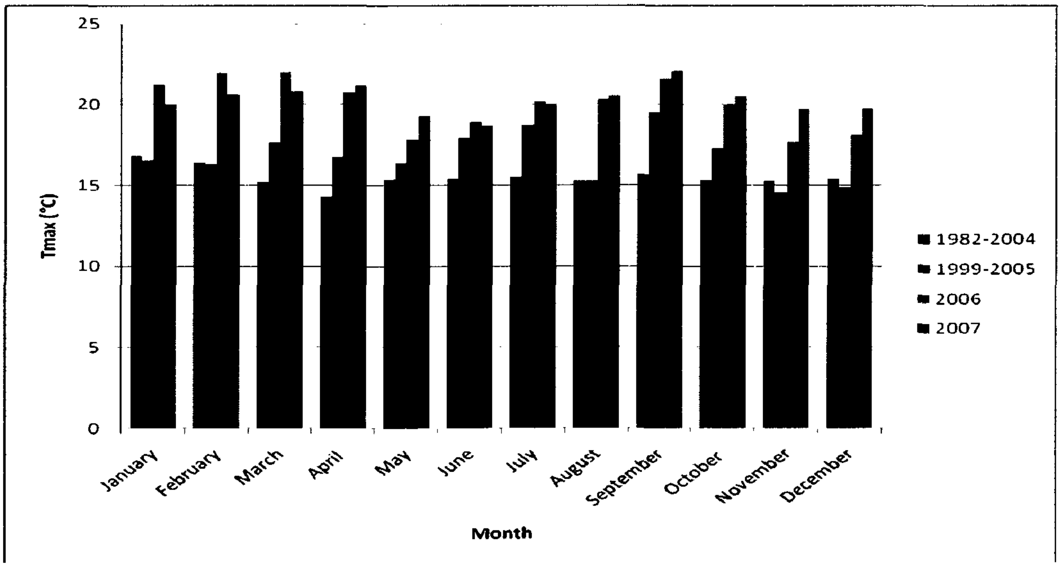


Figure 47: Range of tmax in Kenya for the long term dataset (1982-2004), short term dataset (1999-2005) and the years of the Rift Valley fever animal outbreak (2006, 2007)



In the long term (1982-2004) dataset for Kenya, the lowest mean minimum temperature (tmin) was in July (x=17.83) and highest mean minimum temperature in April (x=19.80). The lowest range of the minimum temperature in the long term dataset was found in September (R=15.12) and the highest in February (R=18.92). In the short term (1999-2005) dataset for Kenya, the lowest mean minimum temperature was in July (x=17.91) and highest mean minimum temperature in April (x=19.87). The lowest range of minimum temperature in the short term dataset was found in August (R=15.28) and the highest was found in February (R=22.77). In 2006, the lowest mean minimum temperature was found in July (x=19.10), lowest range in August (R= 16.38), the highest mean minimum temperature in March (x=21.32), and highest range in November (R=21.58). In 2007, the lowest mean minimum temperature was found in July (x=18.76), lowest range in August (R= 16.74), the highest mean minimum temperature in March (x=21.13), and highest range in December (R=23.55). Mean minimum temperature for all the short term and long term datasets seemed to follow the same trend, and the 2006 and 2007 dataset seemed to follow the same trend as well. Minimum temperature is highest in March and decreases sharply with lowest minimum temperature reported in July and decrease levels in October. The mean minimum temperature was slightly higher than usual in December of 2006. Figure 48 and 49 presents the average mean and range of minimum temperature's for the long term, short term, 2006, and 2007 datasets.

Figure 48: Monthly tmin in Kenya for the long term dataset (1982-2004), short term dataset (1999-2005) and the years of the Rift Valley fever animal outbreak (2006, 2007)

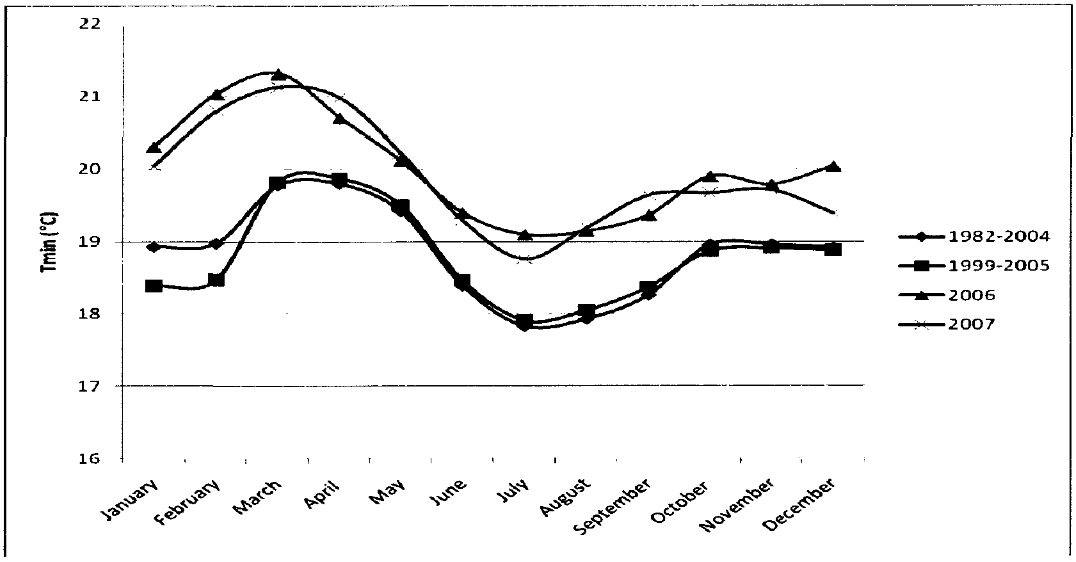
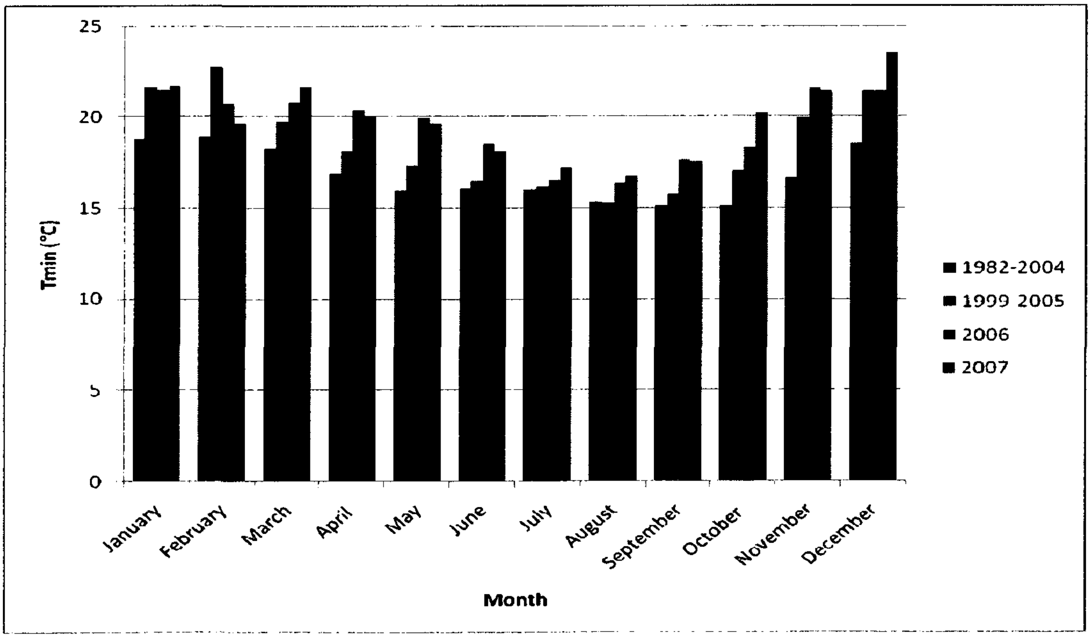


Figure 49: Range of tmin in Kenya for the long term dataset (1982-2004), short term dataset (1999-2005) and the years of the Rift Valley fever animal outbreak (2006, 2007)



GIS Analysis

Analysis of maximum and minimum temperature in the areas where RVF outbreaks occurred found no truly significant differences in tmax and tmin. For the beginning month of RVF, outbreaks in most areas tmax and tmin were the same or slightly less or elevated as compared to the long term and short term datasets for Kenya. For the preceding months and during the RVF outbreak, temperature ranges were the same or slightly less or elevated as compared to the long term and short term datasets. Overall between 2006 and 2007, 36 areas of Kenya experienced Rift Valley fever outbreaks. Within those 36 areas, 7 of the areas were within the Coast region, 5 in the North-Eastern region, 12 in the Eastern region, 5 in the Rift Valley region, 6 in the Central region, and 1 in the Nairobi region. Within the Coast region, the maximum temperature ranged between 24°C and 39°C, and the minimum temperature ranged between 15°C and 27°C. Within the North-Eastern region the maximum temperature ranged between 30°C and 39°C, and the minimum temperature was between 18°C and 24°C. Within the Eastern region, the maximum temperature ranged between 18°C and 36°C, and the minimum temperature ranged between 9°C and 21°C. Within the Rift Valley region, the maximum temperature ranged between 18°C and 33°C, and the minimum temperature ranged between 9°C and 21°C. Within the Central region, the maximum temperature ranged between 18°C and 27°C, and the minimum temperature was between 9°C and15°C. Within the Nairobi region, maximum temperature ranged between 21°C and 27°C, and the minimum temperature ranged between 9°C and 12°C. These temperature ranges were for all months during which an RVF outbreak occurred for the short term, long term and outbreak datasets. The Coast region of Kenya has the warmest temperature, and the Central region the coolest temperatures. For all outbreak areas, tmax ranged between 18°C and 39°C, and tmin ranged between 9°C and 27°C. Table 14 presents the average maximum and minimum temperatures for all regions of Kenya which experienced RVF outbreaks for the long term, short term, and outbreak datasets. A fully detailed comparison of all 36 outbreak areas in Kenya for all datasets is presented in Appendix G.

Table 14: Tmax and tmin temperature ranges for regions of Kenya during Kenyan Rift Valley fever animal outbreaks 2006-2007

Region	**Average Temperature (Long term, short term, and outbreak datasets)**	
COAST (7)	Tmax	24-27, 27-30, 30-33, 36-39
	Tmin	15-18,18-21, 21-24, 24-27
NORTH-EASTERN (5)	Tmax	30-33, 33-36, 36-39
	Tmin	18-21,21-24
EASTERN (12)	Tmax	18-21, 21-24, 24-27, 27-30,33-36
	Tmin	9-12,12-15, 15-18, 18-21
RIFT VALLEY(5)	Tmax	18-21,21-24, 24-27, 27-30, 30-33
	Tmin	9-12, 12-15,18-21
CENTRAL (6)	Tmax	18-21,21-24,24-27
	Tmin	9-12,12-15
NAIROBI AREA (1)	Tmax	21-24,24-27
	Tmin	9-12

Research Question 5

Were the temperature ranges during the 2008-2009 Rift Valley fever outbreaks in Madagascar different than historical temperature ranges for Madagascar?

Time series analysis

In the long term (1982-2004) dataset for Madagascar, the lowest mean maximum temperature (tmax) was in July (x=23.62) and highest mean maximum temperature in March (x=27.56). The lowest range of the maximum temperature in the long term dataset was found in January (R=11.02) and the highest in August (R=13.95). In the short term (1999-2007) dataset for Madagascar, the lowest mean maximum temperature was in July (x=23.72) and highest mean maximum temperature in March (x=27.58). The lowest range of maximum temperature in the short term dataset was found in January (R=10.24) and the highest was found in August (R=13.95). In 2008, the lowest mean maximum temperature was found in July (x=23.39), lowest range in March (R= 10.42), highest mean maximum temperature in January (x=27.09), and highest range in July (R=14.94). Data in 2009 was only available until July as analysis of data began in August of 2009, but the lowest mean maximum temperature up until July was in May (x=22.99) and the highest mean maximum temperature in January (x=27.87). For 2009, the lowest range up until July was in March (R=10.68) and highest range in May (R=18.87). Mean maximum temperature for all four datasets seemed to follow the same trend with only May of 2009 reporting a lower than average mean than the other three datasets. On average, maximum temperature tends to be highest January through April with a small decline May through August. Then, temperature increases in September through December. Figure 50 and 51 present the average mean and range of maximum temperatures for the long term, short term, 2008, and 2009 datasets for Madagascar.

Figure 50: Mean tmax in Madagascar for the long term dataset (1982-2004), short term dataset (1999-2007), and the years of the Rift Valley fever animal outbreak (2008, 2009)

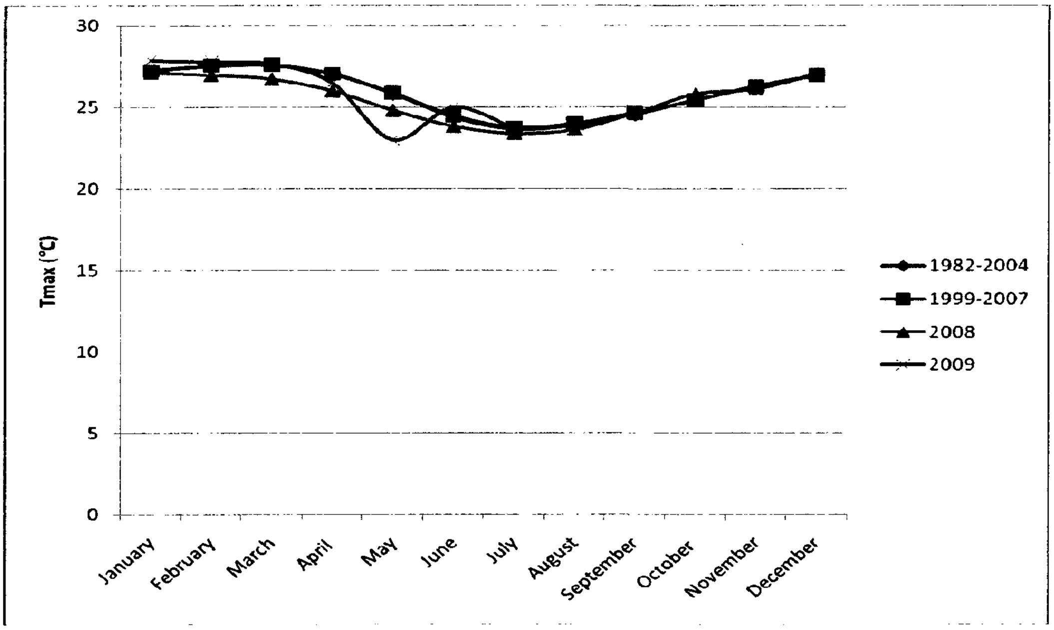
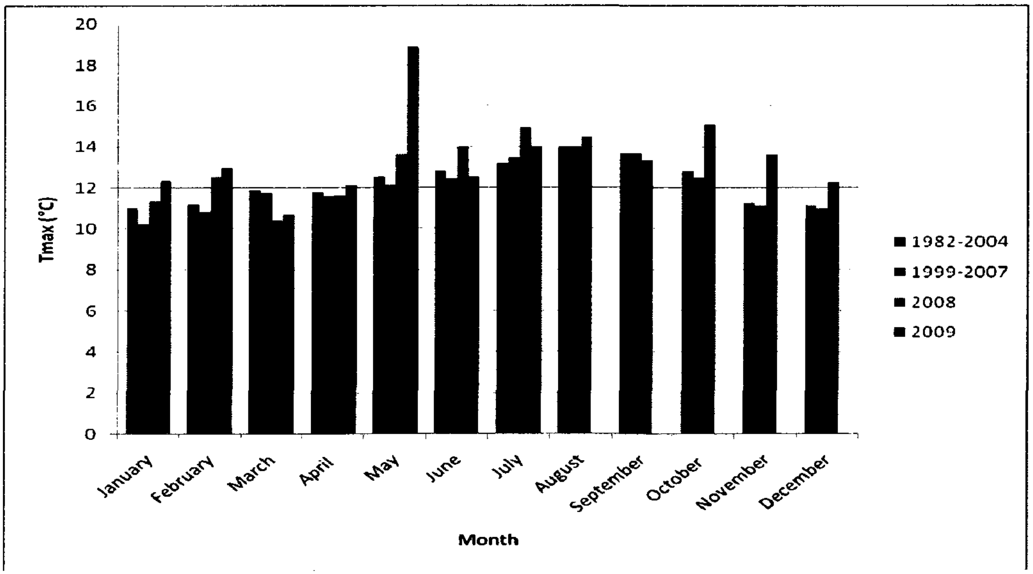


Figure 51: Range of tmax in Madagascar for the long term dataset (1982-2004), short term dataset (1999-2007), and the years of the Rift Valley fever animal outbreak (2008, 2009)



In the long term (1982-2004) dataset for Madagascar, the lowest mean minimum temperature (tmin) was in July (x=20.79) and highest mean minimum temperature in March (x=25.32). The lowest range of the minimum temperature in the long term dataset was found in January (R=13.38) and the highest in June (R=17.44). In the short term (1999-2007) dataset for Madagascar, the lowest mean minimum temperature was in August (x=20.72) and highest mean minimum temperature in March (x=25.19). The lowest range of minimum temperature in the short term dataset was found in January (R=10.24) and the highest was found in June (R=17.93). In 2008, the lowest mean minimum temperature was found in July (x=20.78), lowest range in November (R= 13.67), highest mean minimum temperature in December (x=25.85), and highest range in June (R=18.93). In 2009, although data was only available through July, the lowest mean minimum temperature was in July (x=20.93), lowest range in March (R= 10.68), highest mean minimum temperature in January (x=25.76), and highest range in May (R=18.87). Mean minimum temperature seemed to follow the same trend with highest temperature in January through March and a steep decline with lowest mean temperatures in July and August and an increase in mean temperature with high temperatures again in December. Figures 52 and 53 present the average mean and range of minimum temperature's for the long term dataset, short term dataset, the 2008, and 2009 dataset for Madagascar.

Figure 52: Monthly tmin in Madagascar for the long term dataset (1982-2004), short term dataset (1999-2007), and the years of the Rift Valley fever animal outbreak (2008, 2009)

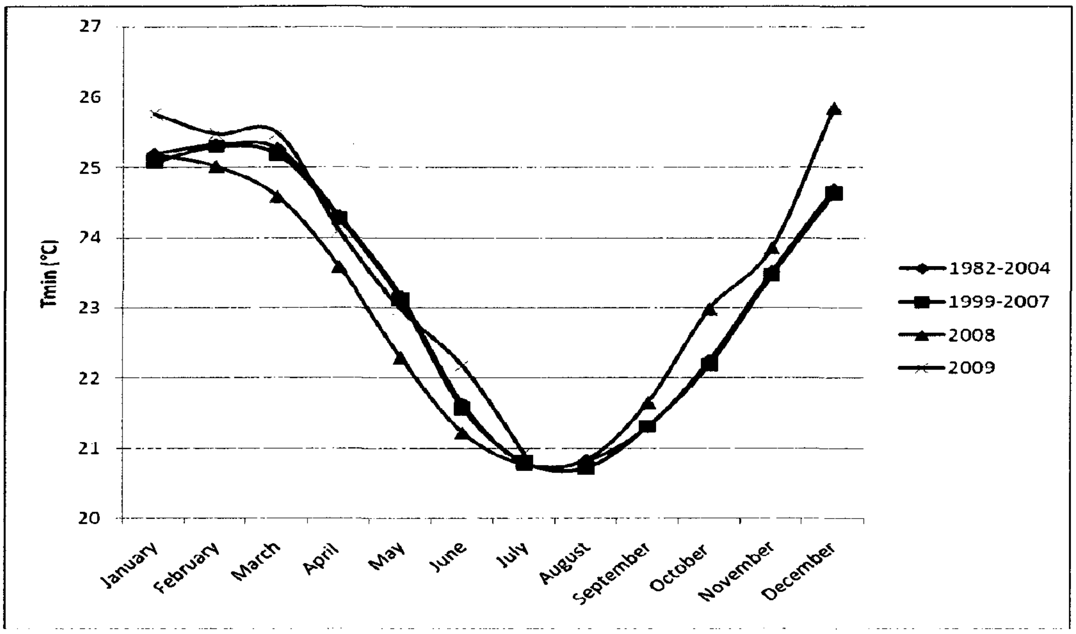
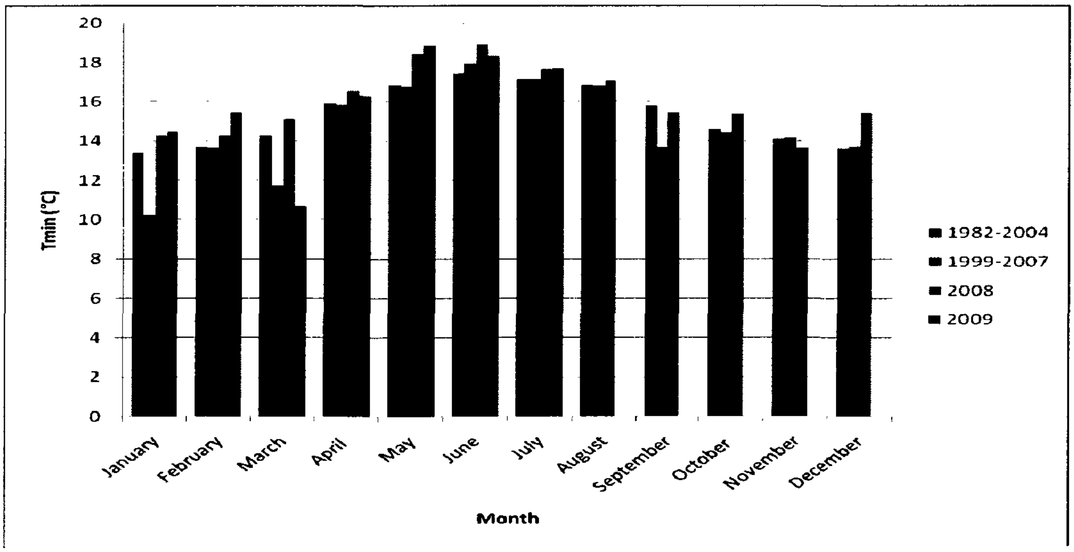


Figure 53: Range of tmin in Madagascar for the long term dataset (1982-2004), short term dataset (1999-2007), and the years of the Rift Valley fever animal outbreak (2008, 2009)



GIS Analysis

Analysis of maximum and minimum temperature in the areas where RVF outbreaks occurred found no truly significant differences in tmax and tmin. For the beginning month of RVF outbreaks in most areas, tmax and tmin were the same or slightly less or elevated as compared to the long term and short term dataset for Madagascar. For the preceding months as well during the RVF outbreak, temperature ranges were the same or slightly less or elevated as compared to the long term and short term datasets. Overall between 2008 and 2009, 11 areas of Kenya experienced Rift Valley fever outbreaks. Within those 11 areas, 10 of the areas were within the Haute Matsiatra region, and the other area was within the Antananarivo region. The Haute Matsiatra region consists of the towns of Antady, Nasandratrony, Ambanimaso, Imandry, Tsaramandroso, Antanifotsy, Ampasina, Ambonifehidrano, Marodinta, and Vohitsaoka. Within the Haute Matsiatra region, the maximum temperature ranged between 21°C and 33°C, and the minimum temperature ranged between 12°C and 27°C. Within the Antananarivo region, the maximum temperature ranged between 18°C and 24°C and the minimum temperature between 9°C and 18°C. These temperature ranges were for all months during which an RVF outbreak occurred for the short term, long term and outbreak datasets. On average within the Haute Matsiatra region, the maximum temperature was within the range of 21°C and 24°C and the minimum temperature between 15°C and 18°C. Table 15 presents the average maximum and minimum temperatures for the two regions of Madagascar which experienced RVF outbreaks for the long term, short term, and outbreak datasets. A fully detailed comparison of all 11 outbreak areas in Kenya for all datasets is presented in Appendix H.

Table 15: Tmax and tmin temperature ranges for regions of Madagascar during Rift Valley fever animal outbreaks 2008-2009

Region	Average Temperature (Long term, short term, and outbreak datasets)	
HAUTE MATSIATRA(10)	Tmax	21-24, 24-27,27-30,30-33
	Tmin	12-15,15-18,18-21,21-24,24-27
ANTANANARIVO (1)	Tmax	18-21,21-24
	Tmin	9-12,12-15,15-18

Research Question 6

Were the temperature ranges during the 2008-2009 Rift Valley fever outbreaks in South Africa different than historical temperature ranges for South Africa?

Time series analysis

In the long term (1982-2004) dataset for South Africa, the lowest mean maximum temperature (tmax) was in July (x=19.62) and highest mean maximum temperature in October (x=26.75). The lowest range of the maximum temperature in the long term dataset was found in April (R=15.69) and the highest in October (R=18.98). In the short term (1999-2007) dataset for South Africa, the lowest mean maximum temperature was in August (x=19.77) and highest mean maximum temperature in February (x=26.68). The lowest range of maximum temperature in the short term dataset was found in March (R=15.62), and the highest was found in October (R=19.25). In 2008, the lowest mean maximum temperature was in July (x=23.39), lowest range in July (R= 17.52), highest mean maximum temperature in January (x=27.09), and highest range was in October (R=24.26). Data in 2009 was only available until July as analysis of data began in August of 2009, but the lowest mean maximum temperature was in July (x=18.60) and the highest mean maximum temperature in January (x=26.69). For 2009, the lowest range up until July was in February (R=17.32) and highest range in July (R=20.07).

Mean maximum temperature for all four datasets seemed to follow the same trend with only July of 2009 reporting a slightly lower than average mean than the other three datasets. On average, maximum temperature tends to be highest January through March with a slight decline March through August followed by increasing temperature in September through December. Figure 54 and 55 present the average mean and range of maximum temperatures for the long term dataset, short term dataset, 2008, and 2009 datasets for South Africa.

Figure 54: Monthly tmax in South Africa for the long term dataset (1982-2004), short term dataset (1999-2007) and the years of the Rift Valley fever animal outbreak (2008, 2009)

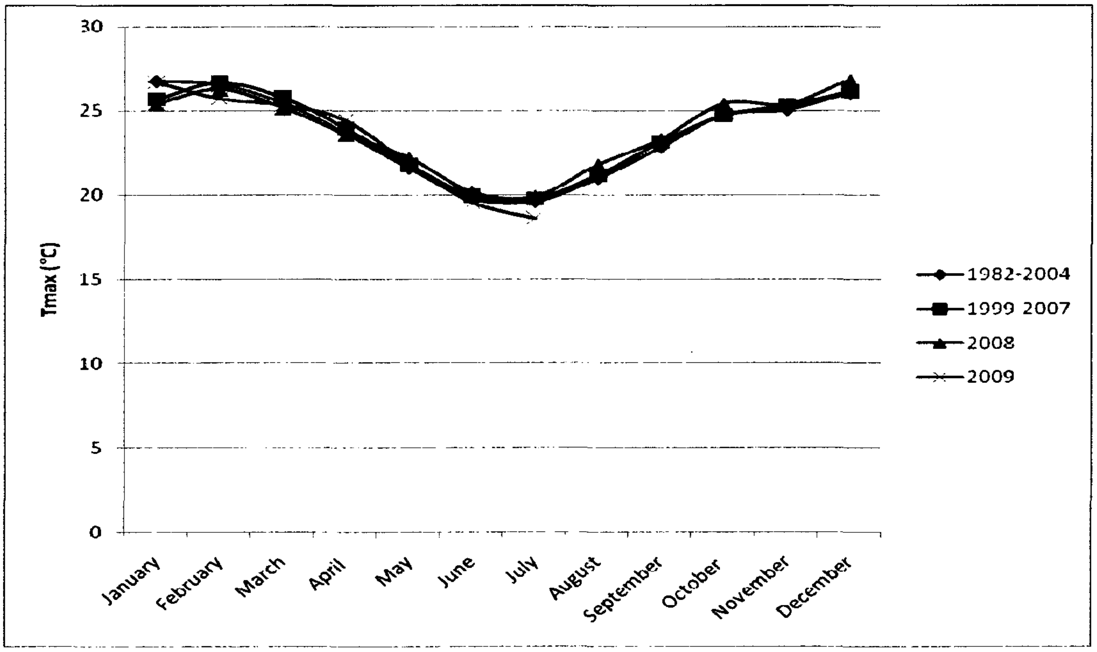
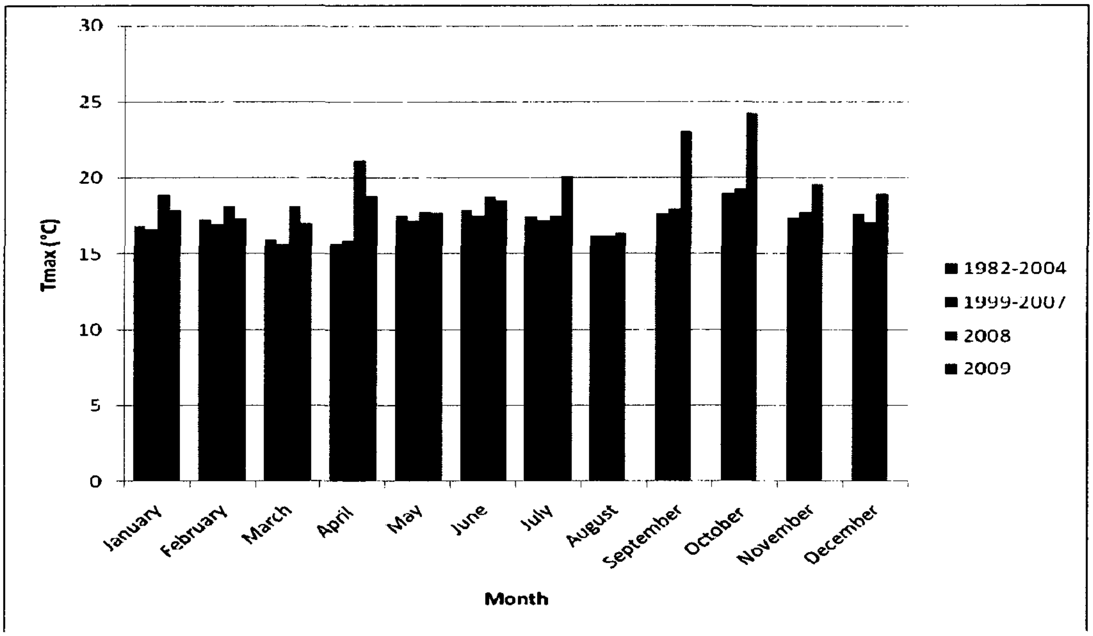


Figure 55: Range of tmax in South Africa for the long term dataset (1982-2004), short term dataset (1999-2007) and the years of the Rift Valley fever animal outbreak (2008, 2009)



In the long term (1982-2004) dataset for South Africa, the lowest mean minimum temperature (tmin) was in July (x=10.56) and highest mean minimum temperature in February (x=18.59). The lowest range of the minimum temperature in the long term dataset was found in December (R=16.48) and the highest in June (R=23.28). In the short term (1999-2007) dataset for South Africa, the lowest mean minimum temperature was in July (x=10.54) and highest mean minimum temperature in February (x=18.54). The lowest range of minimum temperature in the short term dataset was found in August (R=16.17) and the highest was found in June (R=23.50). In 2008, the lowest mean minimum temperature was in July (x=11.20), lowest range in October (R= 16.65), highest mean minimum temperature in February (x=19.07), and highest range in July (R=22.06). In 2009, although data was only available through July, the lowest mean minimum temperature was in July (x=10.96), lowest range in January (R= 16.97), highest mean minimum temperature in February (x=19.35), and highest range was also in July (R=23.21). Mean minimum temperature seemed to follow the same trend with highest temperature in January through March and a steep decline with lowest mean temperatures in July and August followed by an increase in mean temperature with high temperatures again in December. Figure 56 presents the average mean, and Figure 57 presents the range of minimum temperatures for the long term dataset, short term dataset, the 2008, and 2009 datasets for South Africa.

Figure 56: Monthly tmin in South Africa for the long term dataset (1982-2004), short term dataset (1999-2007) and the years of the Rift Valley fever animal outbreak (2008, 2009)

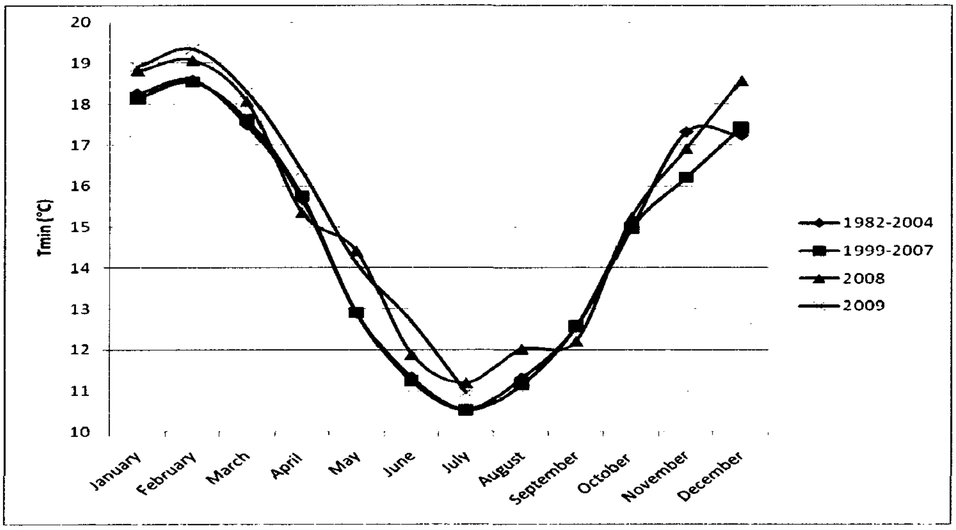
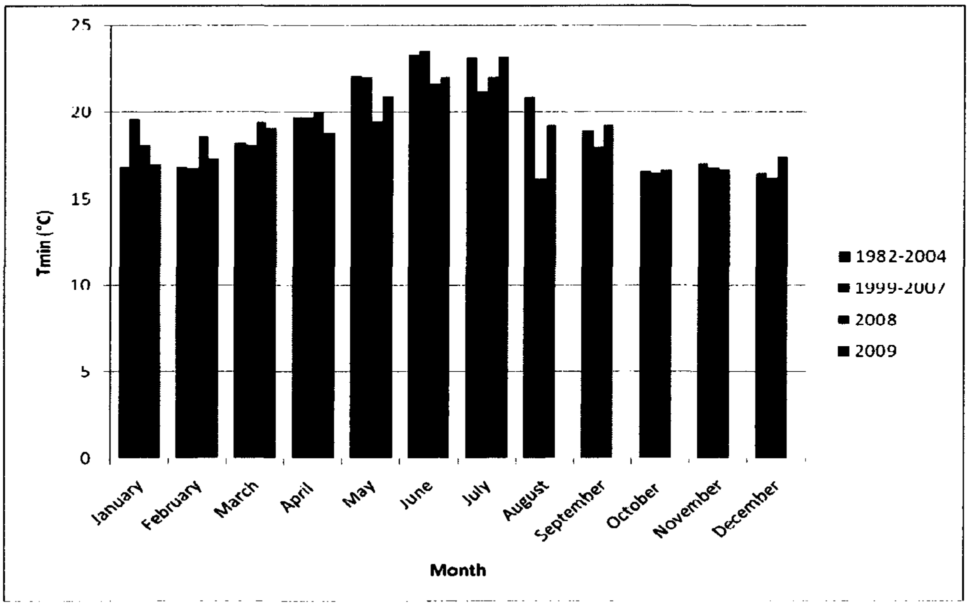


Figure 57: Range of tmin in South Africa for the long term dataset (1982-2004), short term dataset (1999-2007) and the years of the Rift Valley fever animal outbreak (2008, 2009)



GIS Analysis

Analysis of maximum and minimum temperature in the areas where RVF outbreaks occurred found no truly significant differences in tmax and tmin for South Africa. For the beginning month of RVF outbreaks in most areas, tmax and tmin were the same or slightly less or elevated as compared to the long term and short term datasets for Kenya. For the preceding months as well during the RVF outbreak, temperature ranges were the same or slightly less or elevated as compared to the long term and short term datasets. Overall between 2008 and 2009, 38 townships in South Africa experienced Rift Valley fever outbreaks. Within those 38 townships, 12 resided in the Mpumalanga region, 5 in the Limpopo region, 4 in the Gauteng region, 3 in the North West region and 14 in the Kwazulu-Natal region. Within the Mpumalanga region, the maximum temperature ranged between 2°C and 30°C, and the minimum temperature ranged between 12°C and 21°C. Within the Limpopo region, the maximum temperature ranged between 21°C and 30°C and the minimum temperature between 6°C and 21°C. Within the Gauteng region the maximum temperature ranged between 15°C and 27°C, and the minimum temperature ranged between 3°C and 15°C. Within the North West region the maximum temperature ranged between 18°C and 30°C, and the minimum temperature ranged between 6°C and 15°C. Within the Kwazulu-Natal region maximum temperature ranged between 15°C and 24°C, and the minimum temperature ranged between 6°C and 15°C. These temperature ranges were for all months during which an RVF outbreak occurred for the short term, long term, and outbreak datasets. For all outbreak areas, tmax ranged between 15°C and 30°C, and tmin ranged between 3°C and 21°C. Temperature ranges for all outbreak regions were similar, and this may be due to the fact that all outbreak regions are located within the North Western area of South Africa. Table 16 presents the average maximum and minimum temperatures ranges for all regions of South Africa which experienced RVF outbreaks for the long term, short term, and outbreak datasets. A fully detailed comparison of all 38 outbreak areas in South Africa for all datasets is presented in Appendix I.

Table 16: Tmax and tmin temperature ranges for regions of South Africa during Rift Valley fever animal outbreaks 2008-2009 in South Africa

Region	**Average Temperature (Long term, short term, and outbreak datasets)**	
MPUMALANGA (12)	Tmax	21-24,24-27,27-30
	Tmin	12-15,15-18,18-21
LIMPOPO (5)	Tmax	21-24, 24-27,27-30
	Tmin	6-9,9-12, 12-15,15-18,18-21
GAUTENG (4)	Tmax	15-18,18-21,21-24,24-27
	Tmin	3-6,6-9,9-12,12-15
NORTH WEST PROVINCE (3)	Tmax	18-21,21-24,24-27,27-30

KWAZULU-NATAL (14)	Tmin	6-9,9-12,12-15,
	Tmax	15-18,18-21,21-24
	Tmin	6-9,9-12,12-15

Summary of Results

In Kenya, two rainy seasons occur: one in April through June and another at the end of the year in November and December. Although rainfall is typically high in December, an excess amount of rainfall occurred in December of 2006 showing a relationship may exist with higher than average amounts of rainfall and Rift Valley fever outbreaks in Kenya. Upon further analysis in Kenya, positive rainfall anomalies may occur without any Rift Valley fever activity. Thus, showing rainfall may be only one variable needed in Kenya for an RVF outbreak to occur. In Madagascar and South Africa, excess rainfall did not seem to have a relationship with Rift Valley fever activity; showing that only rainfall needs to exist, but no positive rainfall anomaly needs to occur in order to have an RVF outbreak. Hot spot analysis for all three countries for rainfall showed that some outbreak areas had hot spots, while others did not. Hot spot analysis does not seem to predict, nor correlate with Rift Valley fever activity or excess rainfall amounts. In Kenya, Madagascar, and South Africa, a wide range of temperature values were found in outbreak areas showing that many various mosquito vectors with a wide range of environmental temperature competencies are responsible for the spread of Rift Valley fever.

CHAPTER V

Discussion

The purpose of this study is to determine if a relationship exist between temperature, rainfall, and Rift Valley fever outbreaks having occurred in Kenya, Madagascar, and South Africa. This study involved the analysis of data from the National Oceanic & Atmospheric Administration (NOAA) Climate Prediction Center Famine Early Warning System Rainfall Estimate archives and the NOAA Global Data Assimilation System Temperature archive to address the following six research questions:

1. Did positive rainfall anomalies occur prior to and during the 2006-2007 Rift Valley fever outbreaks in Kenya?
2. Did positive rainfall anomalies occur prior to and during the 2008-2009 Rift Valley fever outbreaks in Madagascar?
3. Did positive rainfall anomalies occur prior to and during the 2008-2009 Rift Valley fever outbreaks in South Africa?
4. Were the temperature ranges during the 2006-2007 Rift Valley fever outbreaks in Kenya different than historical temperature ranges for Kenya?
5. Were the temperature ranges during the 2008-2009 Rift Valley fever outbreaks in Madagascar different than historical temperature ranges for Madagascar?
6. Were the temperature ranges during the 2006-2009 Rift Valley fever outbreaks in South Africa different than historical temperature ranges for South Africa?

Importance of Environmental Variables

Rainfall

Excess rainfall anomalies occurred in many sections of Kenya during the 1990s and have been associated with increased mosquito abundance and documented periods of significantly increased malaria and filaria transmission (John 2000, Bogh 1998). This study shows a possible relationship exists with positive rainfall anomalies in Kenya and Rift Valley fever outbreaks. In Kenya, *Aedes cumminsii*, *Aedes furcifer*, *Aedes mcintoshi*, *Culex zombaensis,* and *Mansonia africana* have been linked to Rift Valley fever outbreaks. In previous studies in Kenya, it has been indicated that widespread and prolonged rainfall raises the water tables flooding grassland depressions known as dambos (Linthicum et al, 1983). It is believed that many of the *Aedes* mosquito vectors linked to RVF in Kenya colonize the dambos in the grasslands, and within 20 days following the flooding of dambo habitat, the eggs hatch *Aedes* mosquitoes which transmit the RVF virus. It has also been speculated the second wave of transmission is by the *Culex* species which are dominant 30 to 40 days after flooding.

In this study, heavy and widespread rainfall occurred in December of 2006 at the beginning of the Rift Valley fever outbreak in Kenya in most areas. An outbreak did occur in Kiambu, Kenya, beginning in February of 2006 and ending in April of 2007. In December of 2006, a higher than normal amount of rainfall was found in Kiambu, Kenya. Upon further analysis, rainfall was found to be widespread and heavy during November of 2006. Figure 58 presents a GIS map showing this widespread and heavy rainfall in November of 2006 in Kenya. Figure 59 presents a GIS map showing average amount of rainfall in the long term dataset in Kenya, and Figure 60 presents a GIS map showing average amount of rainfall in the short term dataset in Kenya.

Figure 58: GIS map of average amount of rainfall in November 2006

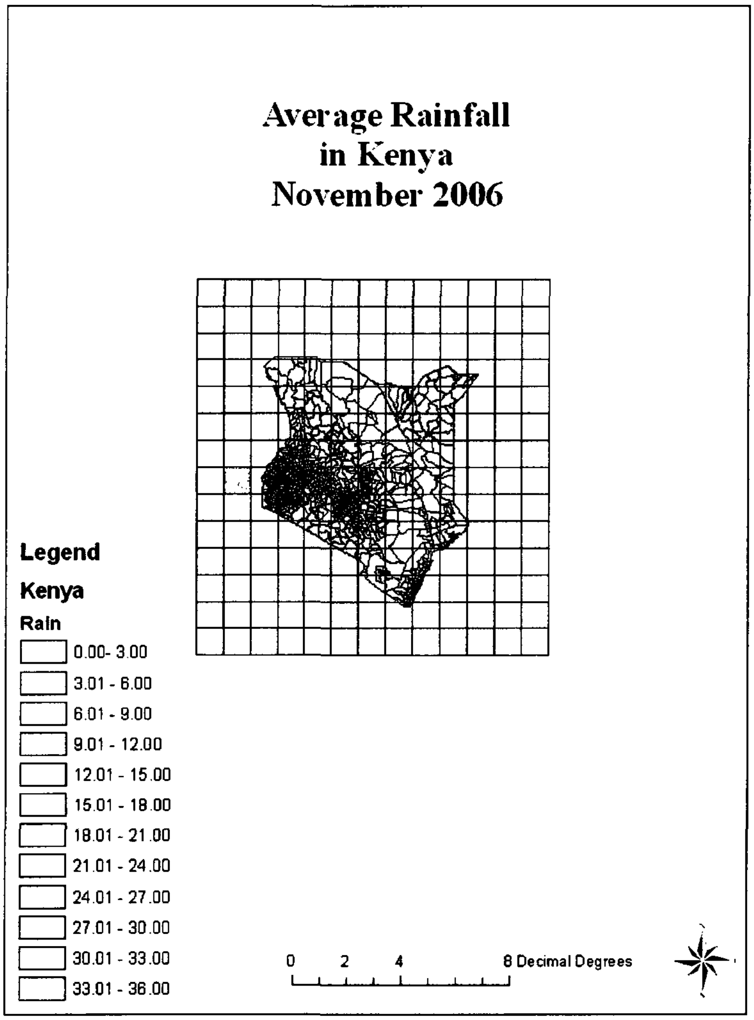


Figure 59: GIS maps of average amount of rainfall in November 1982-2004

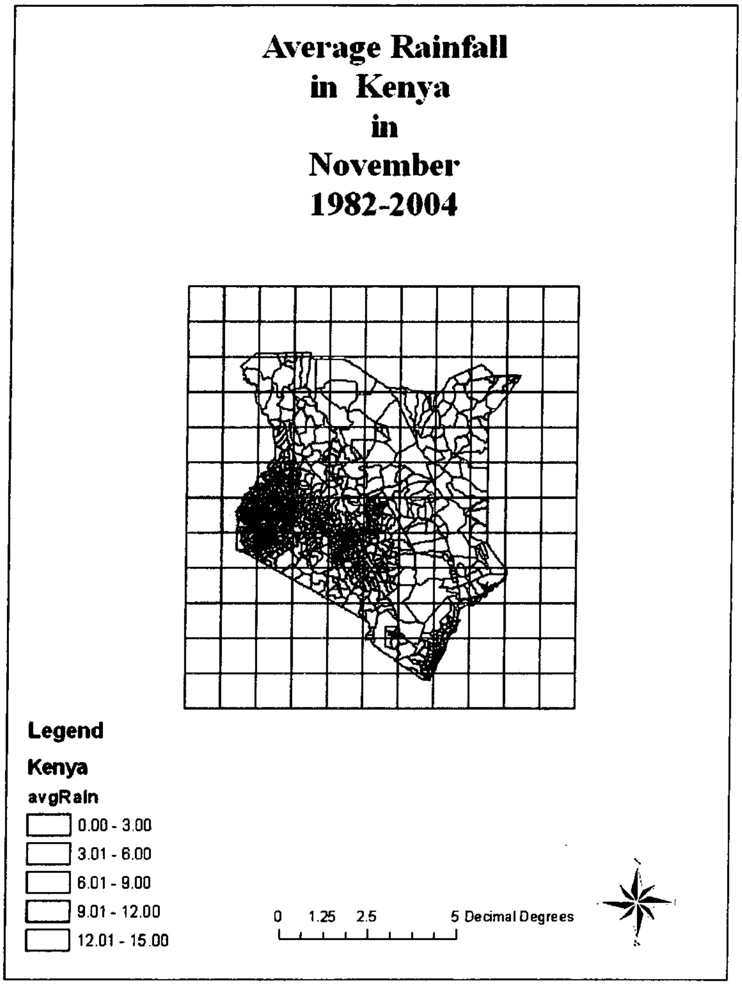
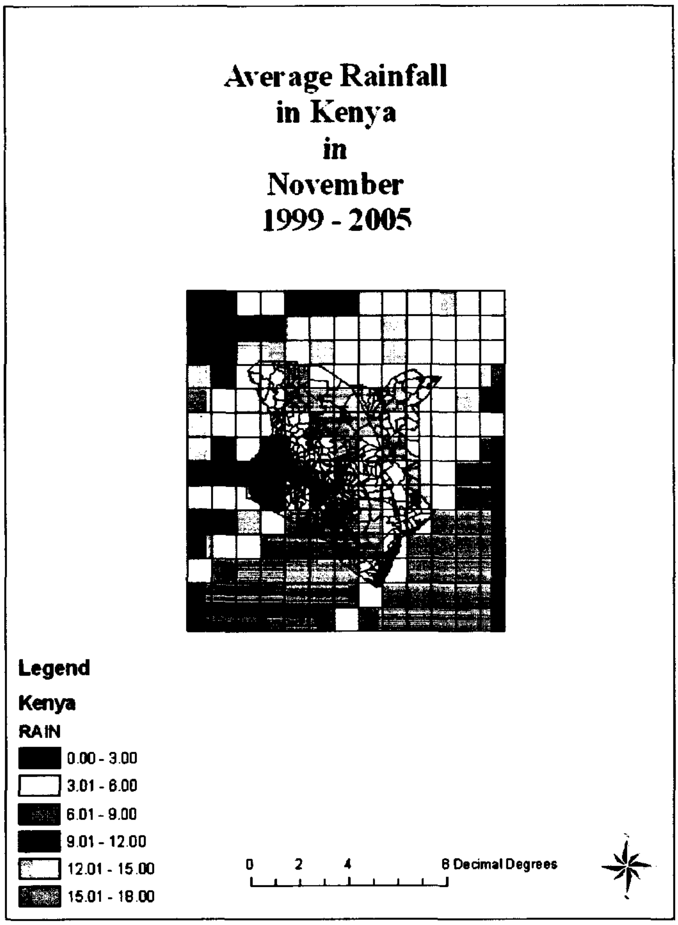


Figure 60: GIS maps of average amount of rainfall in November 1999-2005



Most of the Rift Valley fever outbreaks in Kenya had ended by April of 2007, and average amounts of rainfall were found for most outbreak areas January through April of 2007. This study confirms that a possible relationship exist between excess rainfall anomalies in Kenya and Rift Valley fever outbreaks as has been found in previous studies. This study seems to confirm the previous findings that excess rainfall causes *Aedes* floodwater mosquitoes to hatch in dambos and the second wave of transmission being carried out by *Culex* species mosquitoes which require little to no water. Further analysis in Kenya showed that positive rainfall anomalies may occur in Kenya with no Rift Valley fever activity detected. This finding demonstrates that rainfall is only one of the critical variables needed for a Rift Valley fever outbreak to occur in Kenya.

No significant positive rainfall anomalies occurred at the beginning of the RVF outbreaks in Madagascar and South Africa. In South Africa *Aedes unidentatus*, *Aedes dentatus*, *Aedes circumluteolus,* and *Culex zombaensis* have been linked to RVF outbreaks and as of December of 2009 the species of mosquito responsible for the spread of Rift Valley fever in Madagascar has not been identified. It is therefore unclear if floodwater *Aedes* species mosquitoes began a wave of transmission of RVF activity and the second wave of transmission is completed by *Culex* species of mosquitoes as with Kenya. In most of the outbreak areas in Madagascar and South Africa, some rainfall was present during the outbreak, but not significantly above the average amount of rainfall for that area and in many areas less than average amounts of rainfall were found. This may signify that only a small amount of rainfall or standing water is needed for the mosquito vectors responsible for the spread of RVF in Madagascar and South Africa. This may also signify that rainfall is not one of the critical variables playing a role in Rift Valley fever outbreaks in Madagascar and South Africa. This may be due to the fact that the mosquito species responsible for RVF spread in Madagascar and South Africa may not depend on rainfall but rather breed in wet areas such as large rivers or dams. The differences seen in role of rainfall between Kenya, Madagascar, and South Africa may also be because of terrain differences, cultural differences (i.e., differences in livestock practices, farming practices, agricultural practices), as well as climatic variables. These differences need to be further investigated in order to understand the key variables that may initiate an RVF outbreak in these countries.

For all months where positive rainfall anomalies were found the maximum and minimum temperature were also presented as well. Although this study approaches temperature and rainfall separately average temperature was given for months with positive rainfall anomalies to discover if any possible relationship between temperature rainfall and RVF activity may be possible which would merit further analysis. For Kenya, Madagascar and South Africa no relationship between temperature and rainfall seemed to be present. For all three countries when positive rainfall anomalies were found the average temperature did not differ aside from 1 to 2 degrees from the average maximum and minimum temperature calculated from the short term datasets.

Cluster hot spot analysis for rainfall was not useful in determining excess rainfall values for a specific area. While for some areas a hot spots was found other areas did not have hotspots and the results varied between the long term, short term and outbreak datasets. No clear spatial patterns were seen nor the identity of the locations, magnitudes, and shapes of statistically significant pattern described. Getis and Ord cluster hot spot analysis using Arc Map 9.3 does not seem to be a valid method for determining spatial cluster patterns for rainfall values. The failure of cluster analysis may be due to the fact that cluster analysis techniques are heuristic in nature and are given to different solutions depending upon the particular technique. Perhaps other spatial cluster analysis techniques may produce significant results in future studies. The times series analysis, statistical analysis, and GIS analysis seemed to be valid and reliable methods for examining rainfall data

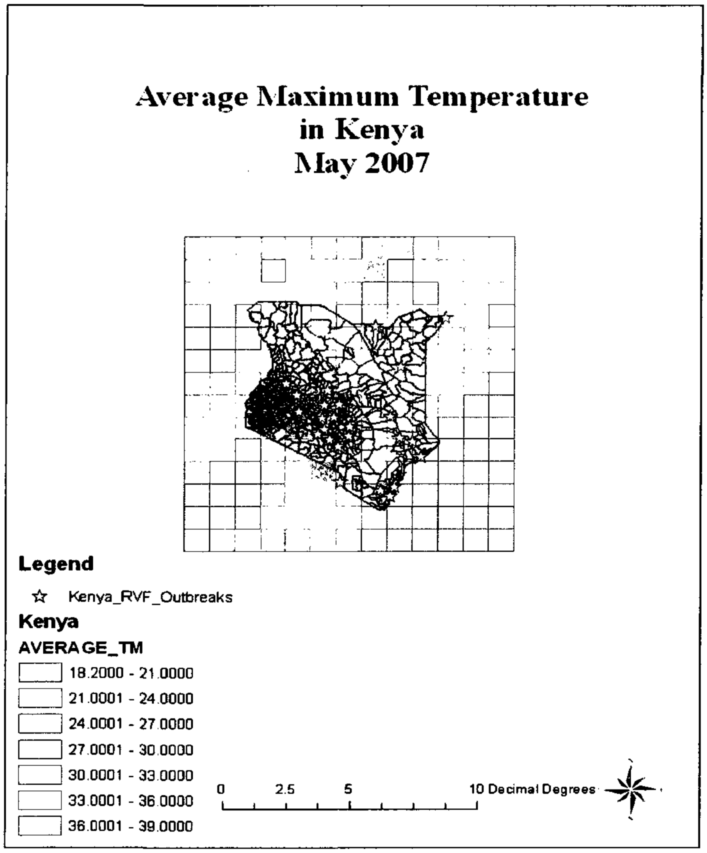
Temperature

In Turell (1989), it was noted that the environmental temperature significantly affected the vectorial capacity of species being studied, *Aedes fowleri* for RVF virus. It was found that transmission occurring earlier and at a higher rate in mosquitoes held at higher temperatures significantly affected the vectorial capacity for RVF virus. In Githecko (2000), the effect of climate change on transmission was most often observed at the extremes of the range of temperatures at which transmission occurs, 14 -18 degrees Celsius at the lower end and 35-40 degrees Celsius at the upper end. Warmer temperatures have been found to speed the development of the parasites in mosquitoes raising the odds of disease transmission while cooler temperatures slow reproduction rates and disease replication with extreme cold weather killing adult mosquitoes and over-wintering eggs and larvae (Epstein, 2000). A threshold temperature above which death is inevitable and the minimum temperature below which the mosquito cannot become active vary among mosquito species.

According to time series analysis results in the study it was noted that May, October, November, and December of 2007 had higher than average temperatures in Kenya but it was only during May of 2007 that Rift Valley fever activity was reported. GIS analysis as seen below in Figure 61 shows areas that experienced an RVF outbreak during 2006-2007 did not experience an above average maximum temperature. No RVF activity was reported past June of 2007, thus showing warmer than average temperatures are not needed in Kenya for an RVF outbreak to occur. In Madagascar no significantly above average maximum temperatures were found during time series analysis and only May of 2009 was found to have a below average maximum temperature and January of

2009 an above average minimum temperature. No significantly different maximum or minimum temperature results were found for South Africa during time series or GIS analysis.

Figure 61: GIS map of maximum temperature (tmax) in May 2007



In this study it was found that the maximum temperature in Kenya ranged between 21 °C and 33°C, and the minimum temperature ranged between 9°C and 24°C. It therefore must be noted that the mosquito species responsible for the spread of Rift Valley fever in Kenya function between 9°C and 33°C with different mosquito species possibly being responsible for the outbreaks within different outbreak areas. Also, it does not seem that the mosquito species responsible for the spread of RVF in Kenya function at the extremes of ranges of temperature due to no extreme temperature values were found. In Madagascar, the maximum temperature ranged between 21°C and 33°C and the minimum temperature ranged between 9°C and 27°C. It must therefore be noted that the mosquito species responsible for the spread of Rift Valley fever in Madagascar function between the temperature ranges of 9°C and 33°C. In Madagascar as well, no extremes temperature ranges were found. In South Africa, the maximum temperature ranged between 15°C and 30°C, and minimum temperature ranged between 3°C and 18°C. Therefore, in South Africa, it must be noted that the mosquito species responsible for the spread of Rift Valley function between the temperatures ranges 3°C and 30°C. Mosquitoes responsible for the spread of RVF in South Africa seem to function well in cooler temperatures as the temperature in outbreak areas could be as low as 3°C, and the high for temperature in South Africa during an outbreak was found to be 30°C. This signifies that extreme warmer temperatures are not needed in order for RVF outbreaks to occur as has been suggested in the literature. The temperature range tables created in the results section of this dissertation may serve as a guide in determining the temperature ranges in those areas during the outbreak and assist in identifying the possible mosquito species responsible for the spread of RVF in these outbreak areas.

Limitations

Rift Valley fever outbreaks cannot occur without a competent vector and host, and RVF will not occur in the United States unless competent vectors are within range of competent host. This study is limited in its assumptions as well as its inability to include all variables related to RVF activity. The original purpose of the study was to evaluate the effect of temperature and rainfall directly related to the mosquito species linked to Rift Valley fever in Kenya, Madagascar, and South Africa. The present analyses were constrained by limitations in the data. It was primarily limited by the lack of information on the mosquito species linked to Rift Valley fever in these countries. The original research plan aimed to look at the life cycle, feeding habits, flight habits, and length of life and 'ideal' temperature ranges for *Aedes cumminsii*, *Aedes furcifer*, *Aedes mcintoshi*, *Aedes unidentatus*, and *Aedes circumluteolus* to determine the role of floodwater *Aedes* mosquitoes in the outbreak in Kenya and South Africa. Although currently studies are being conducted in Madagascar, it is not known exactly which mosquito species in Madagascar are responsible for transmitting Rift Valley fever. Also, no research in the literature exists in regards to the behavior of the mosquito species linked to the Rift Valley fever outbreaks in Kenya and South Africa. By not being able to link the environmental variables, temperature, and rainfall directly to the mosquito species responsible for the spread of RVF in that area limits this research, as each mosquito species varies in how environmental variables influence mosquito community dynamics. This study does not try to correlate rainfall and temperature with Rift Valley fever outbreaks but only serves as an investigative study into the possible relationship between rainfall and temperature during outbreaks of Rift Valley fever. Further studies should incorporate mosquito community dynamics information as this information becomes available.

Policy Implications

Rift Valley fever research has become increasingly important as it has proven itself to be a virus able to invade ecologically diverse areas. The results of this study will be used to develop and refine predictive algorithms for RVFV transmission with the ultimate goal of providing improved early prediction of RVFV outbreaks. This study will allow for the removal of the rainfall variable from RVFV predictive algorithms unless *Aedes* rainfall mosquitoes are believed to possibly have an involvement in the RVF disease transmission cycle. In the United States, the Southwest would probably be the only region in which the rainfall variable would have to be included in any RVFV predictive algorithms as *Aedes* rainfall mosquitoes are known to play a role in disease transmission related to other vector borne diseases such as West Nile Virus in this area. Early prediction of Rift Valley fever outbreaks will allow for better control measures during Rift Valley fever outbreaks as well as better preventative measures. As the United States has listed Rift Valley fever as a Category A agent, much attention has been turned into further understanding this disease and its possible spread to the United States. This study will help not only to be used in RVFV transmission algorithms to predict where outbreaks may occur elsewhere, but also will allow for discovering conducive environments in the United States and predicting where an outbreak may occur in the U.S.

The results of this study have two policy implications. First, understanding how weather conditions influence mosquito community dynamics and ultimately how Rift Valley fever activity is critical for effective disease transmission models and surveillance and control programs. Second, disease transmission models can be useful in predicting future outbreaks of disease, and appropriate control strategies can be initiated to try to prevent devastating epidemics, but only with known parameters values such as environmental conditions. These models of disease transmission will also be useful for differentiating between a naturally occurring outbreak of disease and an act of terrorism using biological weapons in the United States. This study will not only assist entomologists and other scientists in understanding what role temperature and rainfall have played in Rift Valley fever outbreaks but also serve as a reminder of the necessary research that needs to be done in order to understand the mosquito vectors involved in RVF.

This study also brings focus to the One Health Initiative, a movement to forge co-equal, all inclusive collaborations between physicians, veterinarians, and other scientific-health related disciplines. It recognizes the fact that human and animal health and mental health (via the human-animal bond phenomenon) are inextricably linked. Rift Valley fever is a disease that its effect on humans is intrinsically linked to its animal host and vectors. Studies such as this which focus on the variables that plays a role on animal host and vectors but can be linked to human outbreak activity highlight the importance of taking a "One Health" perspective when studying zoonoses.

Future Research

The findings from this study underscore the many questions that remain unanswered and opportunities for research regarding the variables that play a role in the transmission of Rift Valley fever. There are three main areas that future research should address.

1. identify the mosquito vectors responsible for the spread of Rift Valley fever; and
2. variables affecting competence and transmission in mosquito vectors; and
3. types of hosts that are capable of becoming viremic.

Once mosquito vectors have been identified that have played a role in historical Rift Valley fever outbreaks, the variables affecting each vector must be studied. The effect of environmental variable such as temperature and rainfall vary from species to species of mosquito. Some mosquito vectors need little to no rainfall while others need an excess amount of rainfall in order to complete their life cycle. Temperature has various variables on a mosquito such as the interval between an infectious blood meal and when a mosquito is capable of transmitting RVF virus by bite. While this study has identified that rainfall and temperature have various relationships depending on location, it is not known whether this is due to differences in mosquito species responsible for the spread of RVF in different locations.

This study does implicate that non-floodwater mosquito species may be responsible for the spread of RVF in locations outside of East Africa. It is believed that floodwater *Aedes* mosquitoes are responsible for the beginning RVF outbreaks in Kenya which has been previously stated in the literature, but this does not seem to be the case with Madagascar and South Africa. As this is the first study to examine the relationship between rainfall and RVF activity outside of East Africa, this study highlights the need to examine non-floodwater mosquitoes in RVF outbreak. The implications of correlating non rainfall mosquitoes to RVF activity are vital to RVF transmission models for the United States as rainfall is not abundant in many areas of the US, and many non-floodwater mosquito species can be found in most areas in the US.

Many variables affect the ability of a given mosquito species to transmit a particular arbovirus including intrinsic variables such as susceptibility to oral infection, the ability of the virus to disseminate from the midgut to the hemacoel and infect the salivary glands, and finally for the virus to be secreted in the saliva. Mosquito density, vertebrate host density and immune status, viremia levels produced in vertebrates, feeding preference of the mosquito, and longevity of the mosquito also affect whether a mosquito species would be a potential vector of RVF virus. All of these various mosquito species variables should be the focus of future studies.

The effect of standing water versus rainfall anomalies should also be further investigated as standing water can be attributed to agricultural practices and not rainfall. Also, once all mosquito vectors responsible for the spread of Rift Valley fever have been identified, the life cycle of these mosquitoes as well as behavior can be further investigated. Behavior of mosquito varies from species to species with variables such as feeding behavior, flight habits, and host preferences being very different. Feeding behavior is important in determining the efficiency of a mosquito vector for transmission of RVF. For example, some mosquitoes prefer to feed on cattle and thus might be important in amplifying and maintaining RVF, but would be relatively unimportant in transmitting the virus to humans. It is extremely important to identify the mosquito vectors and variables affecting the competence and transmission of these mosquito vectors as mosquito control is dependent upon knowing these things. Mosquito control practices currently are different for each mosquito species and by not knowing this information these practices may be ineffective.

Future research should also focus on identifying the type of host capable of becoming viremic as this may play a major role in the vector-host life cycle. For example, if in the United States it is found that ungulates are capable of becoming viremic, this will play an important role in Rift Valley fever activity if it were to enter the United States, since some mosquitoes are known to change their feeding preference based upon season or host availability. Mosquitoes are opportunistic feeders and may be important bridge vectors in that they may feed on a viremic ungulate and later pass the virus on to a susceptible mammalian host (Turell, 2005). Once the mosquito species are further investigated and the host identified, the risk of the disease transmission model for RVF can be strengthened, and the risk of mosquito species transmitting RVF to humans can be calculated. Control efforts can then be focused on one or a few specific species, thereby reducing detrimental effects on non-target species and improving the effectiveness of control measures. Evaluating the combination of all variables that may influence mosquito populations will aid in strengthening models of mosquito community dynamics.

Conclusions

With the concern surrounding climate changes and biological attacks vector-borne diseases, such as Rift Valley fever have been in the spotlight. The goal of this study was to better understand the relationship between the environmental variables of temperature, rainfall and Rift Valley fever outbreaks in three geographically different countries that have had RVF outbreaks within the last ten years. Rainfall has been used in order to predict RVF activity in Kenya, but this study has shown that rainfall would not be useful in predicting RVF activity in countries such as Madagascar and South Africa. This study has also negated the idea that extreme warm temperature values are needed in order for RVF outbreaks to occur. Future research should look at investigating the mosquito species responsible for the spread of RVF in RVF-affected countries and understanding these mosquito species. This study has allowed us to understand two of the important variables that have been identified to possibly play a major role in RVF outbreaks. By further understanding these variables and the role they play in RVF activity, it will allow for better refinement of RVF disease transmission models which can be used to predict future outbreaks and initiate control campaigns to prevent the further spread of the disease.

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APPENDIX A

A comparison of rainfall data for Kenya prior to and during Kenyan Rift Valley fever animal outbreaks 2006-2007

Region	Start Date	End Date	Rainfall Data					
Galmagara, Garissa, NORTH-EASTERN	12/4/06	6/24/07	**Years**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**
			1982-2004	9-12	3-6	0-3	0-3	0-3
			1999-2005	9-12	3-6	0-3	0-3	0-3
			2006	12-15				3-6
			2007		0-3	0-3	0-3	
Galmagara, Garissa, NORTH-EASTERN	12/4/06	6/24/07	**Years**	**MAY**	**JUN**			
			1982-2004	6-9	6-9			
			1999-2005	6-9	3-6			
			2007	0-3	0-3			
Region	**Start Date**	**End Date**	**Rainfall Data**					
Hola, Tan River, COAST	12/4/06	4/5/07	**Years**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**
			1982-2004	9-12	6-9	0-3	0-3	3-6
			1999-2005	9-12	3-6	0-3	0-3	0-3
			2006	12-15				
			2007		0-3	0-3	0-3	3-6
Region	**Start Date**	**End Date**	**Rainfall Data**					
Kilifi, Kilifi, COAST	1/21/07	4/18/07	**Years**	**JAN**	**FEB**	**MAR**	**APR**	
			1982-2004	6-9	3-6	0-3	6-9	
			1999-2005	0-3	3-6	3-6	6-9	
			2007	0-3	0-3	6-9	6-9	
Region	**Start Date**	**End Date**	**Rainfall Data**					
Ikanga, Ndetani, Maliku, Kyoani, Ngungi, Kituti, Kitui, EASTERN	1/21/07	4/18/07	**Years**	**JAN**	**FEB**	**MAR**	**APR**	
			1982-2004	6-9	0-3	0-3	3-6	
			1999-2005	3-6	0-3	0-3	3-6	
			2007	3-6	0-3	0-3	9-12	
Region	**Start Date**	**End Date**	**Rainfall Data**					
Olot, Marakwet, RIFT VALLEY	1/21/07	4/18/07	**Years**	**JAN**	**FEB**	**MAR**	**APR**	
			1982-2004	3-6	3-6	3-6	6-9	
			1999-2005	3-6	0-3	0-3	3-6	
			2007	9-12	9-12	3-6	15-18	
Region	**Start Date**	**End Date**	**Rainfall Data**					
Baibariu, Meru North, EASTERN	12/4/06	2/22/07	**Years**	**DEC**	**JAN**	**FEB**		
			1982-2004	3-6	6-9	0-3		
			1999-2005	3-6	6-9	0-3		
			2006	18-21				
			2007		3-6	0-3		
Region	**Start Date**	**End Date**	**Rainfall Data**					
Ngare Ndare Meru Central, EASTERN	12/4/06	5/4/07	**Years**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**
			1982-2004	3-6	6-9	0-3	0-3	3-6
			1999-2005	3-6	6-9	0-3	0-3	3-6
			2006	18-21				
			2007		3-6	0-3	3-6	12-15
Ngare Ndare Meru Central, EASTERN	12/4/06	5/4/07	**Years**	**MAY**				
			1982-2004	15-18				
			1999-2005	15-18				

			2007	9-12				
Region	**Start Date**	**End Date**	**Rainfall Data**					
Giathugu, Nyeri, CENTRAL	12/4/06	4/5/07	**Years**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**
			1982-2004	9-12	3-6	0-3	0-3	3-6
			1999-2005	6-9	3-6	0-3	0-3	3-6
			2006	15-18				
			2007		3-6	0-3	3-6	12-15
Region	**Start Date**	**End Date**	**Rainfall Data**					
Gatandu, Gikambura, Kiambu, CENTRAL	2/6/06	4/16/07	**Years**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**
			1982-2004	3-6	0-3	6-9	12-15	9-12
			1999-2005	3-6	0-3	6-9	15-18	6-9
			2006	0-3	3-6	6-9	15-18	6-9
			2007	0-3	0-3	9-12		
Gatandu, Gikambura, Kiambu, CENTRAL	2/6/06	4/16/07	**Years**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**
			1982-2004	0-3	0-3	0-3	0-3	3-6
			1999-2005	0-3	0-3	0-3	0-3	3-6
			2006	0-3	0-3	0-3	3-6	18-21
Gatandu, Gikambura, Kiambu, CENTRAL	2/6/06	4/16/07	**Years**	**DEC**	**JAN**			
			1982-2004	9-12	6-9			
			1999-2005	9-12	3-6			
			2006	18-21				
			2007		6-9			
Region	**Start Date**	**End Date**	**Rainfall Data**					
Mwatate Sisal, Lualenyi Ranch, Taveta, Tiata Taveta, COAST	12/4/06	1/16/07	**Years**	**DEC**	**JAN**			
			1982-2004	6-9	6-9			
			1999-2005	9-12	6-9			
			2006	18-21				
			2007		0-3			
Region	**Start Date**	**End Date**	**Rainfall Data**					
Kenol, Maragua, CENTRAL	1/22/07	6/16/07	**Years**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**
			1982-2004	3-6	3-6	0-3	6-9	12-15
			1999-2005	3-6	3-6	0-3	6-9	12-15
			2007	3-6	3-6	0-3	12-15	9-12
Kenol, Maragua, CENTRAL	1/22/07	6/16/07	**Years**	**JUN**				
			1982-2004	9-12				
			1999-2005	9-12				
			2007	6-9				
Region	**Start Date**	**End Date**	**Rainfall Data**					
Njoguini, Rurii, Murang'a, CENTRAL	12/4/06	6/24/07	**Years**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**
			1982-2004	9-12	6-9	3-6	0-3	6-9
			1999-2005	9-12	3-6	3-6	0-3	6-9
			2006	18-21				
			2007		3-6	0-3	0-3	6-9
Njoguini, Rurii, Murang'a, CENTRAL	12/4/06	6/24/07	**Years**	**MAY**	**JUN**			
			1982-2004	12-15	9-12			
			1999-2005	15-18	6-9			
			2007	9-12	6-9			
Region	**Start Date**	**End Date**	**Rainfall Data**					
Dantu, Kutulo, Gari, Didkuro, Mandera, NORTH-EASTERN	12/4/06	3/3/07	**Years**	**DEC**	**JAN**	**FEB**	**MAR**	
			1982-2004	3-6	0-3	0-3	0-3	
			1999-2005	3-6	0-3	0-3	0-3	
			2006	6-9				
			2007		0-3	0-3	0-3	
Region	**Start Date**	**End Date**	**Rainfall Data**					
Lango Baya, Viriku, Malindi, COAST	1/8/07	4/10/07	**Years**	**JAN**	**FEB**	**MAR**	**APR**	
			1982-2004	3-6	0-3	0-3	3-6	
			1999-2005	3-6	0-3	0-3	3-6	
			2007	0-3	0-3	0-3	3-6	
Region	**Start Date**	**End Date**	**Rainfall Data**					
Karia, Meru Central, EASTERN	12/4/06	5/4/07	**Years**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**
			1982-2004	3-6	6-9	0-3	0-3	3-6
			1999-2005	3-6	6-9	0-3	0-3	3-6
			2006	18-21				

			2007		3-6	0-3	3-6	15-18
Karia, Meru Central, EASTERN	12/4/06	5/4/07	**Years**	**MAY**				
			1982-2004	15-18				
			1999-2005	15-18				
			2007	9-12				
Region	**Start Date**	**End Date**	**Rainfall Data**					
Tebere, Kirinyaga, CENTRAL	12/4/06	5/4/07	**Years**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**
			1982-2004	9-12	3-6	0-3	0-3	3-6
			1999-2005	9-12	3-6	0-3	0-3	3-6
			2006	18-21				
			2007		3-6	0-3	3-6	6-9
Tebere, Kirinyaga, CENTRAL	12/4/06	5/4/07	**Years**	**MAY**				
			1982-2004	12-15				
			1999-2005	9-12				
			2007	3-6				
Region	**Start Date**	**End Date**	**Rainfall Data**					
Longewan, Sindani, Kiserian, Maji Ndege, Baringo, RIFT VALLEY	2/2/07	5/4/07	**Years**	**FEB**	**MAR**	**APR**	**MAY**	
			1982-2004	0-3	0-3	3-6	12-15	
			1999-2005	0-3	0-3	3-6	9-12	
			2007	3-6	0-3	12-15	9-12	
Region	**Start Date**	**End Date**	**Rainfall Data**					
Dadaab, Galmagara, Bura, Shantabak, Mbalambala, Danyiri, Garissa, NORTH-EASTERN	12/4/06	1/19/07	**Years**	**DEC**	**JAN**			
			1982-2004	9-12	3-6			
			1999-2005	6-9	3-6			
			2006	12-15				
			2007		0-3			
Region	**Start Date**	**End Date**	**Rainfall Data**					
Kavuti, Ikime, Malawa, Mwingi, EASTERN	1/22/07	4/12/07	**Years**	**JAN**	**FEB**	**MAR**	**APR**	
			1982-2004	6-9	0-3	0-3	3-6	
			1999-2005	6-9	0-3	0-3	3-6	
			2007	3-6	0-3	0-3	9-12	
Region	**Start Date**	**End Date**	**Rainfall Data**					
Kibao, Machakos, EASTERN	2/12/07	2/26/07	**Years**	**FEB**				
			1982-2004	3-6				
			1999-2005	3-6				
			2007	3-6				
Region	**Start Date**	**End Date**	**Rainfall Data**					
Nanyuki, Laikipia, RIFT VALLEY	1/25/07	2/25/07	**Years**	**JAN**	**FEB**			
			1982-2004	3-6	0-3			
			1999-2005	3-6	0-3			
			2007	3-6	0-3			
Region	**Start Date**	**End Date**	**Rainfall Data**					
Masalani, Ijara, NORTH-EASTERN	12/4/06	3/3/07	**Years**	**DEC**	**JAN**	**FEB**	**MAR**	
			1982-2004	9-12	3-6	0-3	0-3	
			1999-2005	9-12	3-6	0-3	0-3	
			2006	12-15				
			2007		3-6	0-3	0-3	
Region	**Start Date**	**End Date**	**Rainfall Data**					
Kinango, Musiu, Lunga Lunga, Kidzumbani, Kwale, COAST	12/4/06	4/16/07	**Years**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**
			1982-2004	6-9	6-9	3-6	0-3	6-9
			1999-2005	9-12	6-9	3-6	3-6	6-9
			2006	9-12				
			2007		0-3	0-3	6-9	6-9
Region	**Start Date**	**End Date**	**Rainfall Data**					
Kasuvi, Kathyaka, Ntahnge, Makueni, EASTERN	1/23/07	5/14/07	**Years**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**
			1982-2004	9-12	3-6	0-3	3-6	6-9
			1999-2005	6-9	3-6	0-3	6-9	6-9
			2007	3-6	0-3	6-9	3-6	3-6
Region	**Start Date**	**End Date**	**Rainfall Data**					
Township, Meru South, EASTERN	1/31/07	4/7/07	**Years**	**JAN**	**FEB**	**MAR**	**APR**	
			1982-2004	6-9	0-3	0-3	3-6	
			1999-2005	6-9	0-3	0-3	3-6	
			2007	3-6	0-3	3-6	12-15	
Region	**Start Date**	**End Date**	**Rainfall Data**					

Ruiru, Thika, CENTRAL	12/4/06	6/22/07	**Years**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**
			1982-2004	9-12	6-9	3-6	0-3	6-9
			1999-2005	9-12	3-6	3-6	0-3	6-9
			2006	18-21				
			2007		6-9	0-3	0-3	6-9
Ruiru, Thika, CENTRAL	12/4/06	6/22/07	**Years**	**MAY**	**JUN**			
			1982-2004	12-15	9-12			
			1999-2005	15-18	6-9			
			2007	6-9	6-9			
Region	**Start Date**	**End Date**	**Rainfall Data**					
Kasarani, Nairobi, NAIROBI AREA	12/4/06	4/5/07	**Years**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**
			1982-2004	9-12	6-9	3-6	0-3	6-9
			1999-2005	9-12	3-6	3-6	0-3	6-9
			2006	18-21				
			2007		3-6	0-3	3-6	9-12
Region	**Start Date**	**End Date**	**Rainfall Data**					
Lamu, Lamu, COAST	12/4/06	2/23/07	**Years**	**DEC**	**JAN**	**FEB**		
			1982-2004	6-9	3-6	0-3		
			1999-2005	6-9	3-6	0-3		
			2006	9-12				
			2007		0-3	0-3		
Region	**Start Date**	**End Date**	**Rainfall Data**					
Mombasa, Mombasa, COAST	1/4/07	2/3/07	**Years**	**JAN**	**FEB**			
			1982-2004	3-6	0-3			
			1999-2005	3-6	0-3			
			2007	0-3	0-3			
Region	**Start Date**	**End Date**	**Rainfall Data**					
Evurore, Karaba, Waschoro, Mutito, Mbeere, EASTERN	12/4/06	5/10/07	**Years**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**
			1982-2004	9-12	3-6	0-3	0-3	3-6
			1999-2005	9-12	3-6	0-3	0-3	3-6
			2006	18-21				
			2007		0-3	0-3	0-3	3-6
Evurore, Karaba, Waschoro, Mutito, Mbeere, EASTERN	12/4/06	5/10/07	**Years**	**MAY**				
			1982-2004	15-18				
			1999-2005	12-15				
			2007	9-12				
Region	**Start Date**	**End Date**	**Rainfall Data**					
Karurumo, Embu, EASTERN	12/4/06	3/3/07	**Years**	**DEC**	**JAN**	**FEB**	**MAR**	
			1982-2004	3-6	6-9	0-3	0-3	
			1999-2005	3-6	6-9	0-3	0-3	
			2006	18-21				
			2007		3-6	0-3	0-3	
Region	**Start Date**	**End Date**	**Rainfall Data**					
Adadi Jole, Wajir, NORTH-EASTERN	12/27/06	1/29/07	**Years**	**DEC**	**JAN**			
			1982-2004	6-9	3-6			
			1999-2005	6-9	0-3			
			2006	6-9				
			2007		0-3			
Region	**Start Date**	**End Date**	**Rainfall Data**					
Godoma, Moyale, EASTERN	1/29/07	3/30/07	**Years**	**JAN**	**FEB**	**MAR**		
			1982-2004	3-6	0-3	0-3		
			1999-2005	3-6	0-3	0-3		
			2007	0-3	0-3	0-3		
Region	**Start Date**	**End Date**	**Rainfall Data**					
Tara, Machakos, EASTERN	12/4/06	1/26/07	**Years**	**DEC**	**JAN**			
			1982-2004	9-12	6-9			
			1999-2005	9-12	3-6			
			2006	18-21				
			2007		3-6			
Region	**Start Date**	**End Date**	**Rainfall Data**					
Nodnyo, Laresoro, Lerata, Sereolipi, Samburu, RIFT VALLEY	2/5/07	4/1/07	**Years**	**FEB**	**MAR**	**APR**		
			1982-2004	3-6	0-3	6-9		
			1999-2005	3-6	3-6	6-9		
			2007	0-3	6-9	3-6		
Region	**Start Date**	**End Date**	**Rainfall Data**					

Marula, Nakuru, RIFT VALLEY	12/4/06	3/8/07	**Years**	**DEC**	**JAN**			
			1982-2004	6-9	3-6	6-9	0-3	
			1999-2005	6-9	3-6	3-6	0-3	
			2006	12-15				
			2007		3-6	6-9	0-3	

APPENDIX B

Hot spot results for areas of Rift Valley fever animal outbreaks in Kenya 2006-2007

Region	Start Date	End Date	Hot Spots					
Galmagara, Garissa, NORTH-EASTERN	12/4/06	6/24/07	Year/ Month	DEC	JAN	FEB	MAR	APR
			1982-2004	Y	N	N	N	N
			1999-2005	Y	N	N	N	N
			2006	N				
			2007		N	N	N	Y
Galmagara, Garissa, NORTH-EASTERN	12/4/06	6/24/07	Year/ Month	MAY	JUN			
			1982-2004	N	Y			
			1999-2005	N	Y			
			2007	Y	N			
Region	**Start Date**	**End Date**	**Hot Spots**					
Hola, Tan River, COAST	12/4/06	4/5/07	Year	DEC	JAN	FEB	MAR	APR
			1982-2004	Y	N	N	N	N
			1999-2005	Y	N	N	N	N
			2006	N				
			2007		N	N	N	Y
Region	**Start Date**	**End Date**	**Hot Spots**					
Kilifi, Kilifi, COAST	1/21/07	4/18/07	Year	JAN	FEB	MAR	APR	
			1982-2004	N	N	N	N	
			1999-2005	N	N	N	N	
			2007	N	N	N	N	
Region	**Start Date**	**End Date**	**Hot Spots**					
Ikanga, Ndetani, Maliku, Kyoani, Ngungi, Kituti, Kitui, EASTERN	1/21/07	4/18/07	Year	JAN	FEB	MAR	APR	
			1982-2004	N	N	N	N	
			1999-2005	N	N	N	N	
			2007	N	N	N	N	
Region	**Start Date**	**End Date**	**Hot Spots**					
Olot, Marakwet, RIFT VALLEY	1/21/07	4/18/07	Year	JAN	FEB	MAR	APR	
			1982-2004	N	N	N	N	
			1999-2005	N	N	N	N	
			2007	N	N	N	N	
Region	**Start Date**	**End Date**	**Hot Spots**					
Baibariu, Meru North, EASTERN	12/4/06	2/22/07	Year	DEC	JAN	FEB		
			1982-2004	Y	N	N		
			1999-2005	Y	N	N		
			2006	N				
			2007		N	N		
Region	**Start Date**	**End Date**	**Hot Spots**					
Ngare Ndare Meru Central, EASTERN	12/4/06	5/4/07	Year	DEC	JAN	FEB	MAR	APR
			1982-2004	Y	N	N	N	N
			1999-2005	Y	N	N	N	N
			2006	N				
			2007		N	N	N	N
Ngare Ndare Meru Central, EASTERN	12/4/06	5/4/07	Year	MAY				
			1982-2004	N				
			1999-2005	N				
			2007	N				
Region	**Start Date**	**End Date**	**Hot Spots**					
Giathugu, Nyeri, CENTRAL	12/4/06	4/5/07	Year	DEC	JAN	FEB	MAR	APR
			1982-2004	N	N	N	N	N
			1999-2005	N	N	N	N	N
			2006	N				

			2007		N	N	N	N
Region	**Start Date**	**End Date**	**Hot Spots**					
Gatandu, Gikambura, Kiambu, CENTRAL	2/6/06	4/16/07	**Year**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**
			1982-2004	N	N	N	N	N
			1999-2005	N	N	N	N	N
			2006	N	N	N	N	N
			2007	N	N	N		
Gatandu, Gikambura, Kiambu, CENTRAL	2/6/06	4/16/07	**Year**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**
			1982-2004	N	N	N	N	N
			1999-2005	N	N	N	N	N
			2006	N	N	N	N	N
Gatandu, Gikambura, Kiambu, CENTRAL	2/6/06	4/16/07	**Year**	**DEC**	**JAN**			
			1982-2004	N	N			
			1999-2005	N	N			
			2006	Y				
			2007		N			
Region	**Start Date**	**End Date**	**Hot Spots**					
Mwatate Sisal, Lualenyi Ranch, Taveta, Tiata Taveta, COAST	12/4/06	1/16/07	**Year**	**DEC**	**JAN**			
			1982-2004	N	N			
			1999-2005	N	N			
			2006	N				
			2007		N			
Region	**Start Date**	**End Date**	**Hot Spots**					
Kenol, Maragua, CENTRAL	1/22/07	6/16/07	**Year**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**
			1982-2004	N	N	N	N	N
			1999-2005	N	N	N	N	N
			2007	N	N	N	N	N
Kenol, Maragua, CENTRAL	1/22/07	6/16/07	**Year**	**JUN**				
			1982-2004	N				
			1999-2005	N				
			2007	N				
Region	**Start Date**	**End Date**	**Hot Spots**					
Njoguini, Rurii, Murang'a, CENTRAL	12/4/06	6/24/07	**Year**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**
			1982-2004	N	N	N	N	N
			1999-2005	N	N	N	N	N
			2006	N				
			2007		N	N	N	N
Njoguini, Rurii, Murang'a, CENTRAL	12/4/06	6/24/07	**Year**	**MAY**	**JUN**			
			1982-2004	N	N			
			1999-2005	N	N			
			2007	N	N			
Region	**Start Date**	**End Date**	**Hot Spots**					
Dantu, Kutulo, Gari, Didkuro, Mandera, NORTH-EASTERN	12/4/06	3/3/07	**Year**	**DEC**	**JAN**	**FEB**	**MAR**	
			1982-2004	N	N	N	N	
			1999-2005	N	N	N	N	
			2006	N				
			2007		N	N	N	
Region	**Start Date**	**End Date**	**Hot Spots**					
Lango Baya, Viriku, Malindi, COAST	1/8/07	4/10/07	**Year**	**JAN**	**FEB**	**MAR**	**APR**	
			1982-2004	N	N	N	N	
			1999-2005	N	N	N	N	
			2007	N	N	N	Y	
Region	**Start Date**	**End Date**	**Hot Spots**					
Karia, Meru Central, EASTERN	12/4/06	5/4/07	**Year**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**
			1982-2004	Y	N	N	N	N
			1999-2005	Y	N	N	N	N
			2006	N				
			2007		N	N	N	N
Karia, Meru	12/4/06	5/4/07	**Year**	**MAY**				

Central, EASTERN			1982-2004	N				
			1999-2005	N				
			2007	N				
Region	**Start Date**	**End Date**	**Hot Spots**					
Tebere, Kirinyaga, CENTRAL	12/4/06	5/4/07	**Year**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**
			1982-2004	N	N	N	N	N
			1999-2005	N	N	N	N	N
			2006	Y				
			2007		N	N	N	N
Tebere, Kirinyaga, CENTRAL	12/4/06	5/4/07	**Year**	**MAY**				
			1982-2004	N				
			1999-2005	N				
			2007	N				
Region	**Start Date**	**End Date**	**Hot Spots**					
Longewan, Sindani, Kiserian, Maji Ndege, Baringo, RIFT VALLEY	2/2/07	5/4/07	**Year**	**FEB**	**MAR**	**APR**	**MAY**	
			1982-2004	N	N	N	N	
			1999-2005	N	N	N	N	
			2007	N	N	N	N	
Region	**Start Date**	**End Date**	**Hot Spots**					
Dadaab, Galmagara, Bura, Shantabak, Mbalambala, Danyiri, Garissa, NORTH-EASTERN	12/4/06	1/19/07	**Year**	**DEC**	**JAN**			
			1982-2004	Y	N			
			1999-2005	Y	N			
			2006	N				
			2007		N			
Region	**Start Date**	**End Date**	**Hot Spots**					
Kavuti, Ikime, Malawa, Mwingi, EASTERN	1/22/07	4/12/07	**Year**	**JAN**	**FEB**	**MAR**	**APR**	
			1982-2004	N	N	N	N	
			1999-2005	N	N	N	N	
			2007	N	N	N	N	
Region	**Start Date**	**End Date**	**Hot Spots**					
Kibao, Machakos, EASTERN	2/12/07	2/26/07	**Year**	**FEB**				
			1982-2004	N				
			1999-2005	N				
			2007	N				
Region	**Start Date**	**End Date**	**Hot Spots**					
Nanyuki, Laikipia, RIFT VALLEY	1/25/07	2/25/07	**Year**	**JAN**	**FEB**			
			1982-2004	N	N			
			1999-2005	N	N			
			2007	N	N			
Region	**Start Date**	**End Date**	**Hot Spots**					
Masalani, Ijara, NORTH-EASTERN	12/4/06	3/3/07	**Year**	**DEC**	**JAN**	**FEB**	**MAR**	
			1982-2004	N	N	N	N	
			1999-2005	N	N	N	N	
			2006	N				
			2007		N	N	N	
Region	**Start Date**	**End Date**	**Hot Spots**					
Kinango, Musiu, Lunga Lunga, Kidzumbani, Kwale, COAST	12/4/06	4/16/07	**Year**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**
			1982-2004	N	N	N	N	N
			1999-2005	N	N	N	N	N
			2006	N				
			2007		N	N	N	N
Region	**Start Date**	**End Date**	**Hot Spots**					
Kasuvi, Kathyaka, Ntahnge, Makueni, EASTERN	1/23/07	5/14/07	**Year**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**
			1982-2004	N	N	N	N	N
			1999-2005	N	N	N	N	N
			2007	N	N	N	N	N

Region	Start Date	End Date	Hot Spots					
Township, Meru South, EASTERN	1/31/07	4/7/07	Year	JAN	FEB	MAR	APR	
			1982-2004	N	N	N	N	
			1999-2005	N	N	N	N	
			2007	N	N	N	N	
Region	**Start Date**	**End Date**	**Hot Spots**					
Ruiru, Thika, CENTRAL	12/4/06	6/22/07	Year	DEC	JAN	FEB	MAR	APR
			1982-2004	N	N	N	N	N
			1999-2005	N	N	N	N	N
			2006	Y				
			2007		N	N	N	N
Ruiru, Thika, CENTRAL	12/4/06	6/22/07	Year	MAY	JUN			
			1982-2004	N	N			
			1999-2005	N	N			
			2007	N	N			
Region	**Start Date**	**End Date**	**Hot Spots**					
Kasarani, Nairobi, NAIROBI AREA	12/4/06	4/5/07	Year	DEC	JAN	FEB	MAR	APR
			1982-2004	N	N	N	N	N
			1999-2005	N	N	N	N	N
			2006	Y				
			2007		N	N	N	N
Region	**Start Date**	**End Date**	**Hot Spots**					
Lamu, Lamu, COAST	12/4/06	2/23/07	Year	DEC	JAN	FEB		
			1982-2004	N	N	N		
			1999-2005	N	N	N		
			2006	N				
			2007		N	N		
Region	**Start Date**	**End Date**	**Hot Spots**					
Mombasa, Mombasa, COAST	1/4/07	2/3/07	Year	JAN	FEB			
			1982-2004	N	N			
			1999-2005	N	N			
			2007	N	N			
Region	**Start Date**	**End Date**	**Hot Spots**					
Evurore, Karaba, Waschoro, Mutito, Mbeere, EASTERN	12/4/06	5/10/07	Year	DEC	JAN	FEB	MAR	APR
			1982-2004	N	N	N	N	N
			1999-2005	N	N	N	N	
			2006	N				
			2007		N	N	N	N
Evurore, Karaba, Waschoro, Mutito, Mbeere, EASTERN	12/4/06	5/10/07	Year	MAY				
			1982-2004	N				
			1999-2005	N				
			2007	N				
Region	**Start Date**	**End Date**	**Hot Spots**					
Karurumo, Embu, EASTERN	12/4/06	3/3/07	Year	DEC	JAN	FEB	MAR	
			1982-2004	N	N	N	N	
			1999-2005	N	N	N	N	
			2006	Y				
			2007		N	N	N	
Region	**Start Date**	**End Date**	**Hot Spots**					
Adadi Jole, Wajir, NORTH-EASTERN	12/27/06	1/29/07	Year	DEC	JAN			
			1982-2004	N	N			
			1999-2005	N	N			
			2006	N				
			2007		N			
Region	**Start Date**	**End Date**	**Hot Spots**					
Godoma, Moyale, EASTERN	1/29/07	3/30/07	Year	JAN	FEB	MAR		
			1982-2004	N	N	N		
			1999-2005	N	N	N		
			2007	N	N	N		

Region	Start Date	End Date	Hot Spots					
Tara, Machakos, EASTERN	12/4/06	1/26/07	Year	DEC	JAN			
			1982-2004	N	N			
			1999-2005	N	N			
			2006	Y				
			2007		N			

Region	Start Date	End Date	Hot Spots					
Nodnyo, Laresoro, Lerata, Sereolipi, Samburu, RIFT VALLEY	2/5/07	4/1/07	Year	FEB	MAR	APR		
			1982-2004	N	N	N		
			1999-2005	N	N	N		
			2007	N	N	N		

Region	Start Date	End Date	Hot Spots					
Marula, Nakuru, RIFT VALLEY	12/4/06	3/8/07	Year	DEC	JAN			
			1982-2004	N	N			
			1999-2005	N	N			
			2006	N				
			2007		N			

APPENDIX C

A comparison of rainfall data for Madagascar prior to and during Rift Valley fever animal outbreaks 2008-2009

Region	**Start Date**	**End Date**	**Rainfall Data**					
Antady, Fianarantsoa, Fianarantsoa I, HAUTE MATSIATRA	11/16/08	1/31/09	**Year**	**NOV**	**DEC**	**JAN**		
			1982-2004	3-6	12-15	24-27		
			1999-2007	9-12	15-18	21-24		
			2008	12-15	18-21			
			2009			36-39		
Region	**Start Date**	**End Date**	**Rainfall Data**					
Nasandratrony, Isandra, HAUTE MATSIATRA	11/16/08	1/31/09	**Year**	**NOV**	**DEC**	**JAN**		
			1982-2004	3-6	12-15	24-27		
			1999-2007	9-12	15-18	21-24		
			2008	12-15	18-21			
			2009			15-18		
Region	**Start Date**	**End Date**	**Rainfall Data**					
Ambanimaso, Fianarantsoa, Fianarantsoa I, HAUTE MATSIATRA	11/22/08	1/31/09	**Year**	**NOV**	**DEC**	**JAN**		
			1982-2004	3-6	12-15	33-36		
			1999-2007	9-12	18-21	36-39		
			2008	12-15	18-21			
			2009			39-42		
Region	**Start Date**	**End Date**	**Rainfall Data**					
Imandry, Fianarantsoa, Fianarantsoa I, HAUTE MATSIATRA	11/24/08	1/31/09	**Year**	**NOV**	**DEC**	**JAN**		
			1982-2004	3-6	12-15	24-27		
			1999-2007	9-12	12-15	21-24		
			2008	12-15	18-21			
			2009			36-39		
Region	**Start Date**	**End Date**	**Rainfall Data**					
Tsaramandroso, Fianarantsoa, Fianarantsoa I, HAUTE MATSIATRA	11/29/08	1/31/09	**Year**	**NOV**	**DEC**	**JAN**		
			1982-2004	3-6	12-15	33-36		
			1999-2007	9-12	9-12	36-39		
			2008	12-15	15-18			
			2009			21-24		
Region	**Start Date**	**End Date**	**Rainfall Data**					
Antanifotsy, Fianarantsoa, Fianarantsoa I, HAUTE MATSIATRA	12/10/08	1/31/09	**Year**	**DEC**	**JAN**			
			1982-2004	3-6	18-21			
			1999-2007	9-12	12-15			
			2008	9-12				
			2009		12-15			
Region	**Start Date**	**End Date**	**Rainfall Data**					
Ampasina, Sahambavy, Lalangina, HAUTE MATSIATRA	12/11/08	1/31/09	**Year**	**DEC**	**JAN**			
			1982-2004	6-9	27-30			
			1999-2007	12-15	21-24			
			2008	21-24				
			2009		15-18			
Region	**Start Date**	**End Date**	**Rainfall Data**					
Ambonifehidrano, Fianarantsoa, Fianarantsoa I, HAUTE MATSIATRA	12/13/08	1/31/09	**Year**	**DEC**	**JAN**			
			1982-2004	12-15	24-27			
			1999-2007	15-18	27-30			
			2008	15-18				
			2009		33-36			
Region	**Start Date**	**End Date**	**Rainfall Data**					
Marodinta, Nasandratony, Isandra, HAUTE MATSIATRA	12/13/08	1/31/09	**Year**	**DEC**	**JAN**			
			1982-2004	9-12	30-33			
			1999-2007	12-15	33-36			

			2008	12-15				
			2009		30-33			
Region	**Start Date**	**End Date**	**Rainfall Data**					
Avaradrano, ANTANANARIVO	2/4/08	10/30/08	**Year**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**
			1982-2004	30-33	21-24	21-24	3-6	3-6
			1999-2007	27-30	18-21	18-21	3-6	3-6
			2008	24-27	9-12	3-6	0-3	0-3
Avaradrano, ANTANANARIVO	2/4/08	10/30/08	**Year**	**JUL**	**AUG**	**SEP**	**OCT**	
			1982-2004	0-3	0-3	0-3	0-3	
			1999-2007	0-3	0-3	0-3	0-3	
			2008	0-3	0-3	0-3	6-9	
Region	**Start Date**	**End Date**	**Rainfall Data**					
Andohasahalava, Vohitsaoka, Ambalavao, HAUTE MATSIATRA	3/12/09	5/29/09	**Year**	**MAR**	**APR**	**MAY**		
			1982-2004	15-18	12-15	3-6		
			1999-2005	12-15	12-15	3-6		
			2009	21-24	6-9	0-3		

APPENDIX D

Hot spot results for areas of Rift Valley fever animal outbreaks in Madagascar 2008-2009

Region	Start Date	End Date	Hot Spots					
Antady, Fianarantsoa, Fianarantsoa I, HAUTE MATSIATRA	11/16/08	1/31/09	Year	NOV	DEC	JAN		
			1982-2004	Y	Y	N		
			1999-2007	Y	Y	N		
			2008	Y	Y			
			2009			Y		
Region	Start Date	End Date	Hot Spots					
Nasandratrony, Isandra, HAUTE MATSIATRA	11/16/08	1/31/09	Year	NOV	DEC	JAN		
			1982-2004	Y	Y	N		
			1999-2007	Y	Y	N		
			2008	Y	Y			
			2009			Y		
Region	Start Date	End Date	Hot Spots					
Ambanimaso, Fianarantsoa, Fianarantsoa I, HAUTE MATSIATRA	11/22/08	1/31/09	Year	NOV	DEC	JAN		
			1982-2004	Y	Y	Y		
			1999-2007	Y	Y	Y		
			2008	Y	Y			
			2009			Y		
Region	Start Date	End Date	Hot Spots					
Imandry, Fianarantsoa, Fianarantsoa I, HAUTE MATSIATRA	11/24/08	1/31/09	Year	NOV	DEC	JAN		
			1982-2004	Y	Y	N		
			1999-2007	Y	Y	N		
			2008	Y	Y			
			2009			Y		
Region	Start Date	End Date	Hot Spots					
Tsaramandroso, Fianarantsoa, Fianarantsoa I, HAUTE MATSIATRA	11/29/08	1/31/09	Year	NOV	DEC	JAN		
			1982-2004	Y	Y	Y		
			1999-2007	Y	Y	Y		
			2008	Y	Y			
			2009			Y		
Region	Start Date	End Date	Hot Spots					
Antanifotsy, Fianarantsoa, Fianarantsoa I, HAUTE MATSIATRA	12/10/08	1/31/09	Year	DEC	JAN			
			1982-2004	N	N			
			1999-2007	Y	N			
			2008	Y				
			2009		N			
Region	Start Date	End Date	Hot Spots					
Ampasina, Sahambavy, Lalangina, HAUTE MATSIATRA	12/11/08	1/31/09	Year	DEC	JAN			
			1982-2004	N	Y			
			1999-2007	Y	N			
			2008	Y				
			2009		N			
Region	Start Date	End Date	Hot Spots					
Ambonifehidrano, Fianarantsoa, Fianarantsoa I, HAUTE MATSIATRA	12/13/08	1/31/09	Year	DEC	JAN			
			1982-2004	Y	N			
			1999-2007	Y	N			
			2008	Y				
			2009		N			
Region	Start Date	End Date	Hot Spots					
Marodinta, Nasandratony, Isandra, HAUTE MATSIATRA	12/13/08	1/31/09	Year	DEC	JAN			
			1982-2004	Y	Y			
			1999-2007	Y	Y			
			2008	Y				

			2009		Y			
Region	**Start Date**	**End Date**	**Hot Spots**					
Avaradrano, ANTANANARIVO	2/4/08	10/30/08	**Year**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**
			1982-2004	N	N	N	N	N
			1999-2007	N	N	N	N	N
			2008	Y	N	N	N	N
Avaradrano, ANTANANARIVO	2/4/08	10/30/08	**Year**	**JUL**	**AUG**	**SEP**	**OCT**	
			1982-2004	N	N	N	N	
			1999-2007	N	N	N	N	
			2008	N	N	N	Y	
Region	**Start Date**	**End Date**	**Hot Spots**					
Andohasahalava, Vohitsaoka, Ambalavao, HAUTE MATSIATRA	3/12/09	5/29/09	**Year**	**MAR**	**APR**	**MAY**		
			1982-2004	N	N	N		
			1999-2007	N	N	N		
			2009	N	N	N		

APPENDIX E

A comparison of rainfall data for South Africa prior to and during Rift Valley fever animal outbreaks 2008-2009

Region	Start Date	End Date	Rainfall Data				
Ngwenya, Ehlanzeni, MPUMALANGA	1/14/08	3/14/08	**Year**	**JAN**	**FEB**	**MAR**	
Grootboom, Nkomazi, MPUMALANGA	2/7/08	3/7/08	1982-2004	9-12	9-12	9-12	
Marlothi, Nkomazi, MPUMALANGA	2/7/08	3/7/08					
One Tree Hill, Nkomazi, MPUMALANGA	2/27/08	3/27/08	1999-2007	9-12	9-12	9-12	
Ten Bosch, Nkomazi, MPUMALANGA	1/15/08	2/15/08					
Ten Bosch, Nkomazi, MPUMALANGA	2/1/08	3/1/08	2008	3-6	0-3	6-9	
Vyeboom, Nkomazi, MPUMALANGA	2/1/08	3/1/08					
Richtersnek, Nkomazi, MPUMALANGA	2/12/08	3/1/08					
Region	**Start Date**	**End Date**	**Rainfall Data**				
Buiskop, Bela-Bela, LIMPOPO	3/1/08	4/1/08	**Year**	**MAR**	**APR**	**MAY**	
			1982-2004	9-12	3-6	0-3	
Langkuil, Bela-Bela, LIMPOPO	3/1/08	4/1/08	1999-2007	9-12	3-6	0-3	
Leewdoorns, Bela-Bela, LIMPOPO	4/1/08	5/1/08	2008	9-12	0-3	3-6	
Region	**Start Date**	**End Date**	**Rainfall Data**				
Grietjie, Ba-Phalaborwa, LIMPOPO	3/7/08	5/7/08	**Year**	**MAR**	**APR**	**MAY**	
			1982-2004	12-15	6-9	3-6	
			1999-2007	12-15	6-9	3-6	
Paul, Ba-Phalaborwa, LIMPOPO	3/7/08	4/7/08	2008	0-3	0-3	3-6	
Region	**Start Date**	**End Date**	**Rainfall Data**				
Leeuwkraal, Cullinan, GAUTENG	3/7/08	4/7/08	**Year**	**MAR**	**APR**		
			1982-2004	9-12	6-9		
			1999-2007	9-12	6-9		
			2008	9-12	0-3		
Region	**Start Date**	**End Date**	**Rainfall Data**				
Doornkloof, Pretoria, GAUTENG	4/7/08	5/7/08	**Year**	**APR**	**MAY**		
			1982-2004	6-9	3-6		
			1999-2007	6-9	3-6		
Doornkloof, City of Tshwane, GAUTENG	4/1/08	5/1/08	2008	9-12	0-3		
Region	**Start Date**	**End Date**	**Rainfall Data**				
Leeuwkraal, Moretele, NORTH WEST PROVINCE	4/23/08	5/17/08	**Year**	**APR**	**MAY**		
			1982-2004	6-9	0-3		
			1999-2007	6-9	0-3		

			2008	0-3	0-3		

Region	Start Date	End Date	Rainfall Data				
Witpoort, Bronkhorstspruit, GAUTENG	4/22/08	5/22/08	**Year**	**APR**	**MAY**	**JUN**	
			1982-2004	6-9	3-6	0-3	
			1999-2007	6-9	3-6	0-3	
Witpoort, Kungwini, GAUTENG	5/1/08	6/1/08	2008	0-3	6-9	0-3	

Region	Start Date	End Date	Rainfall Data				
Mamagalieskraal, Madibeng, NORTH WEST PROVINCE	4/23/08	5/23/08	**Year**	**APR**	**MAY**		
			1982-2004	3-6	3-6		
			1999-2007	3-6	3-6		
			2008	0-3	3-6		

Region	Start Date	End Date	Rainfall Data				
Blinkwater, Mbombela, MPUMALANGA	5/1/08	6/1/08	**Year**	**MAY**	**JUN**		
Curlews settlement, Mbombela, MPUMALANGA	5/1/08	6/1/08	1982-2004	3-6	0-3		
Hooggelegen, Mbombela, MPUMALANGA	5/1/08	6/1/08	1999-2007	3-6	0-3		
Vaalbank, Dr JS Moroka, MPUMALANGA	5/1/08	6/1/08	2008	0-3	0-3		

Region	Start Date	End Date	Rainfall Data				
Krokodildrift, Potchefstroom, NORTH WEST PROVINCE	4/1/08	5/1/08	**Year**	**APR**	**MAY**		
			1982-2004	6-9	3-6		
			1999-2007	6-9	3-6		
			2008	0-3	3-6		

Region	Start Date	End Date	Rainfall Data				
Conference, Ingwe, KWAZULU-NATAL	2/25/09	3/15/09	**Year**	**FEB**	**MAR**	**APR**	**MAY**
			1982-2004	15-18	9-12	9-12	3-6
Allandale, Ingwe, KWAZULU-NATAL	2/25/09	3/15/09					
Tyrone, Ingwe, KWAZULU-NATAL	2/27/09	3/15/09					
Stockton, Ingwe, KWAZULU-NATAL	2/18/09	3/15/09					
Eastwold, Ingwe, KWAZULU-NATAL	2/27/09	3/15/09	1999-2007	12-15	9-12	9-12	3-6
Ringstead, Kwa Sani, KWAZULU-NATAL	3/3/09	5/15/09					
Mount Hermon, Ubuhlebezwe, KWAZULU-NATAL	3/9/09	4/15/09					
Burnview, Ingwe, KWAZULU-NATAL	3/23/09	4/30/09					
Greenstead, Lions River, KWAZULU-NATAL	3/17/09	3/31/09					

Ikwezi Trust, KwaSani, KWAZULU-NATAL	4/1/09	4/10/09	2009	15-18	6-9	3-6	0-3
Ilynton, KwaSani, KWAZULU-NATAL	4/2/09	4/15/09					
Firle, Mooi Mpofana, KWAZULU-NATAL	4/2/09	4/15/09					
The Meads, Matatiele, KWAZULU-NATAL	4/24/09	5/15/09					
Rustfontein, Matatiele, KWAZULU-NATAL	4/24/09	5/15/09					

APPENDIX F

Hot spot results for areas of Rift Valley fever animal outbreaks in South Africa 2008-2009

Region	Start Date	End Date	Hot Spots				
Ngwenya, Ehlanzeni, MPUMALANGA	1/14/08	3/14/08	Year	JAN	FEB	MAR	
Grootboom, Nkomazi, MPUMALANGA	2/7/08	3/7/08	1982-2004	Y	Y	N	
Marlothi, Nkomazi, MPUMALANGA	2/7/08	3/7/08					
One Tree Hill, Nkomazi, MPUMALANGA	2/27/08	3/27/08	1999-2007	Y	Y	N	
Ten Bosch, Nkomazi, MPUMALANGA	1/15/08	2/15/08					
Ten Bosch, Nkomazi, MPUMALANGA	2/1/08	3/1/08	2008	N	N	N	
Vyeboom, Nkomazi, MPUMALANGA	2/1/08	3/1/08					
Richtersnek, Nkomazi, MPUMALANGA	2/12/08	3/1/08					

Region	Start Date	End Date	Hot Spots				
Buiskop, Bela-Bela, LIMPOPO	3/1/08	4/1/08	Year	MAR	APR	MAY	
			1982-2004	N	N	N	
Langkuil, Bela-Bela, LIMPOPO	3/1/08	4/1/08	1999-2007	N	N	N	
Leewdoorns, Bela-Bela, LIMPOPO	4/1/08	5/1/08	2008	Y	N	N	

Region	Start Date	End Date	Hot Spots				
Grietjie, Ba-Phalaborwa, LIMPOPO	3/7/08	5/7/08	Year	MAR	APR	MAY	
			1982-2004	Y	Y	N	
			1999-2007	Y	N	N	
Paul, Ba-Phalaborwa, LIMPOPO	3/7/08	4/7/08	2008	Y	N	N	

Region	Start Date	End Date	Hot Spots				
Leeuwkraal, Cullinan, GAUTENG	3/7/08	4/7/08	Year	MAR	APR		
			1982-2004	N	N		
			1999-2007	N	N		
			2008	Y	N		

Region	Start Date	End Date	Hot Spots				
Doornkloof, Pretoria, GAUTENG	4/7/08	5/7/08	Year	APR	MAY		
			1982-2004	N	N		
			1999-2007	N	N		
Doornkloof, City of Tshwane, GAUTENG	4/1/08	5/1/08	2008	Y	N		

Region	Start Date	End Date	Hot Spots				
Leeuwkraal, Moretele, NORTH WEST PROVINCE	4/23/08	5/17/08	Year	APR	MAY		
			1982-2004	N	N		
			1999-2007	N	N		
			2008	N	N		

Region	Start Date	End Date	Hot Spots				
Witpoort, Bronkhorstspruit, GAUTENG	4/22/08	5/22/08	Year	APR	MAY	JUN	
			1982-2004	N	N	N	

			1999-2007	N	N	N	
Witpoort, Kungwini, GAUTENG	5/1/08	6/1/08	2008	N	N	N	
Region	**Start Date**	**End Date**	**Hot Spots**				
Mamagalieskraal, Madibeng, NORTH WEST PROVINCE	4/23/08	5/23/08	**Year**	**APR**	**MAY**		
			1982-2004	N	N		
			1999-2007	N	N		
			2008	N	N		
Region	**Start Date**	**End Date**	**Hot Spots**				
Blinkwater, Mbombela, MPUMALANGA	5/1/08	6/1/08	**Year**	**MAY**	**JUN**		
Curlews settlement, Mbombela, MPUMALANGA	5/1/08	6/1/08	1982-2004	N	N		
Hooggelegen, Mbombela, MPUMALANGA	5/1/08	6/1/08	1999-2007	N	N		
Vaalbank, Dr JS Moroka, MPUMALANGA	5/1/08	6/1/08	2008	N	N		
Region	**Start Date**	**End Date**	**Hot Spots**				
Krokodildrift, Potchefstroom, NORTH WEST PROVINCE	4/1/08	5/1/08	**Year**	**APR**	**MAY**		
			1982-2004	N	N		
			1999-2007	N	N		
			2008	N	N		
Region	**Start Date**	**End Date**	**Hot Spots**				
Conference, Ingwe, KWAZULU-NATAL	2/25/09	3/15/09	**Year**	**FEB**	**MAR**	**APR**	**MAY**
			1982-2004	Y	N	Y	N
Allandale, Ingwe, KWAZULU-NATAL	2/25/09	3/15/09					
Tyrone, Ingwe, KWAZULU-NATAL	2/27/09	3/15/09					
Stockton, Ingwe, KWAZULU-NATAL	2/18/09	3/15/09					
Eastwold, Ingwe, KWAZULU-NATAL	2/27/09	3/15/09	1999-2007	Y	N	Y	N
Ringstead, Kwa Sani, KWAZULU-NATAL	3/3/09	5/15/09					
Mount Hermon, Ubuhlebezwe, KWAZULU-NATAL	3/9/09	4/15/09					
Burnview, Ingwe, KWAZULU-NATAL	3/23/09	4/30/09					
Greenstead, Lions River, KWAZULU-NATAL	3/17/09	3/31/09					
Ikwezi Trust, KwaSani, KWAZULU-NATAL	4/1/09	4/10/09	2009	Y	N	N	N
Ilynton, KwaSani, KWAZULU-NATAL	4/2/09	4/15/09					
Firle, Mooi Mpofana, KWAZULU-NATAL	4/2/09	4/15/09					
The Meads, Matatiele, KWAZULU-NATAL	4/24/09	5/15/09					
Rustfontein, Matatiele, KWAZULU-NATAL	4/24/09	5/15/09					

APPENDIX G

A comparison of tmax and tmin temperature data for Kenya prior to and during Kenyan Rift Valley fever animal outbreaks 2006-2007

Region	Start Date	End Date	Temperature Data								
Galmagara, Garissa, NORTH-EASTERN	12/4/06	6/24/07	Year	DEC		JAN		FEB		MAR	
			1982-2004	Tmax	30-33	Tmax	30-33	Tmax	36-39	Tmax	36-39
				Tmin	21-24	Tmin	21-24	Tmin	21-24	Tmin	21-24
			1999-2005	Tmax	30-33	Tmax	30-33	Tmax	36-39	Tmax	36-39
				Tmin	21-24	Tmin	18-21	Tmin	18-21	Tmin	21-24
			2006	Tmax	30-33						
				Tmin	21-24						
			2007			Tmax	33-36	Tmax	36-39	Tmax	33-36
						Tmin	21-24	Tmin	24-27	Tmin	24-27
Region	Start Date	End Date	Temperature Data								
Galmagara, Garissa, NORTH-EASTERN	12/4/06	6/24/07	Year	APR		MAY		JUN			
			1982-2004	Tmax	30-33	Tmax	33-36	Tmax	33-36		
				Tmin	21-24	Tmin	21-24	Tmin	21-24		
			1999-2005	Tmax	30-33	Tmax	33-36	Tmax	30-33		
				Tmin	21-24	Tmin	21-24	Tmin	18-21		
			2007	Tmax	30-33	Tmax	33-36	Tmax	30-33		
				Tmin	24-27	Tmin	21-24	Tmin	21-24		
Region	Start Date	End Date	Temperature Data								
Hola, Tan River, COAST	12/4/06	4/5/07	Year	DEC		JAN		FEB		MAR	
			1982-2004	Tmax	30-33	Tmax	33-36	Tmax	36-39	Tmax	33-36
				Tmin	21-24	Tmin	21-24	Tmin	18-21	Tmin	21-24
			1999-2005	Tmax	30-33	Tmax	30-33	Tmax	36-39	Tmax	36-39
				Tmin	21-24	Tmin	18-21	Tmin	18-21	Tmin	21-24
			2006	Tmax	30-33						
				Tmin	21-24						
			2007		Tmax	33-36	Tmax	36-39	Tmax	33-36	
					Tmin	21-24	Tmin	21-24	Tmin	24-27	
Region	Start Date	End Date	Temperature Data								
Hola, Tan River, COAST	12/4/06	4/5/07	Year	APR							
			1982-2004	Tmax	30-33						
				Tmin	21-24						
			1999-2005	Tmax	30-33						
				Tmin	21-24						
			2007	Tmax	30-33						
				Tmin	24-27						
Region	Start Date	End Date	Temperature Data								
Kilifi, Kilifi, COAST	1/21/07	4/18/07	Year	JAN		FEB		MAR		APR	
			1982-2004	Tmax	30-33	Tmax	30-33	Tmax	30-33	Tmax	27-30
				Tmin	18-21	Tmin	18-21	Tmin	18-21	Tmin	18-21
			1999-2005	Tmax	30-33	Tmax	30-33	Tmax	30-33	Tmax	27-30
				Tmin	15-18	Tmin	15-18	Tmin	18-21	Tmin	18-21
			2007	Tmax	27-30	Tmax	33-36	Tmax	30-33	Tmax	27-30
				Tmin	15-18	Tmin	21-24	Tmin	18-21	Tmin	18-21
Region	Start Date	End Date	Temperature Data								
Ikanga,	1/21/07	4/18/07	Year	JAN		FEB		MAR		APR	

Region	Start Date	End Date	Temperature Data								
Ndetani, Maliku, Kyoani, Ngungi, Kituti, Kitui, EASTERN			1982-2004	Tmax	27-30	Tmax	27-30	Tmax	27-30	Tmax	27-30
				Tmin	15-18	Tmin	15-18	Tmin	15-18	Tmin	15-18
			1999-2005	Tmax	27-30	Tmax	30-33	Tmax	27-30	Tmax	27-30
				Tmin	12-15	Tmin	12-15	Tmin	15-18	Tmin	15-18
			2007	Tmax	27-30	Tmax	27-30	Tmax	27-30	Tmax	24-27
				Tmin	15-18	Tmin	15-18	Tmin	15-18	Tmin	15-18
Region	**Start Date**	**End Date**	**Temperature Data**								
Olot, Marakwet, RIFT VALLEY	1/21/07	4/18/07	**Year**	**JAN**		**FEB**		**MAR**		**APR**	
			1982-2004	Tmax	21-24	Tmax	21-24	Tmax	21-24	Tmax	21-24
				Tmin	12-15	Tmin	12-15	Tmin	12-15	Tmin	12-15
			1999-2005	Tmax	24-27	Tmax	24-27	Tmax	24-27	Tmax	21-24
				Tmin	12-15	Tmin	12-15	Tmin	12-15	Tmin	12-15
			2007	Tmax	21-24	Tmax	21-24	Tmax	21-24	Tmax	21-24
				Tmin	12-15	Tmin	9-12	Tmin	12-15	Tmin	12-15
Region	**Start Date**	**End Date**	**Temperature Data**								
Baibariu, Meru North, EASTERN	12/4/06	2/22/07	**Year**	**DEC**		**JAN**		**FEB**			
			1982-2004	Tmax	24-27	Tmax	27-30	Tmax	27-30		
				Tmin	12-15	Tmin	15-18	Tmin	15-18		
			1999-2005	Tmax	24-27	Tmax	27-30	Tmax	30-33		
				Tmin	12-15	Tmin	12-15	Tmin	15-18		
			2006	Tmax	24-27						
				Tmin	15-18						
			2007			Tmax	27-30	Tmax	30-33		
						Tmin	15-18	Tmin	15-18		
Region	**Start Date**	**End Date**	**Temperature Data**								
Ngare Ndare Meru Central, EASTERN	12/4/06	5/4/07	**Year**	**DEC**		**JAN**		**FEB**		**MAR**	
			1982-2004	Tmax	24-27	Tmax	27-30	Tmax	27-30	Tmax	27-30
				Tmin	12-15	Tmin	15-18	Tmin	15-18	Tmin	15-18
			1999-2005	Tmax	24-27	Tmax	27-30	Tmax	30-33	Tmax	30-33
				Tmin	12-15	Tmin	12-15	Tmin	15-18	Tmin	15-18
			2006	Tmax	24-27						
				Tmin	15-18						
			2007			Tmax	27-30	Tmax	30-33	Tmax	27-30
						Tmin	15-18	Tmin	15-18	Tmin	18-21
Region	**Start Date**	**End Date**	**Temperature Data**								
Ngare Ndare Meru Central, EASTERN	12/4/06	5/4/07	**Year**	**APR**		**MAY**					
			1982-2004	Tmax	27-30	Tmax	27-30				
				Tmin	15-18	Tmin	15-18				
			1999-2005	Tmax	27-30	Tmax	27-30				
				Tmin	15-18	Tmin	15-18				
			2007	Tmax	24-27	Tmax	27-30				
				Tmin	18-21	Tmin	18-21				
Region	**Start Date**	**End Date**	**Temperature Data**								
Giathugu, Nyeri, CENTRAL	12/4/06	4/5/07	**Year**	**DEC**		**JAN**		**FEB**		**MAR**	
			1982-2004	Tmax	18-21	Tmax	21-24	Tmax	21-24	Tmax	21-24
				Tmin	9-12	Tmin	9-12	Tmin	2-12	Tmin	9-12
			1999-2005	Tmax	18-21	Tmax	21-24	Tmax	21-24	Tmax	21-24
				Tmin	9-12	Tmin	9-12	Tmin	6-9	Tmin	9-12
			2006	Tmax	16-18						
				Tmin	9-12						
			2007			Tmax	18-21	Tmax	18-21	Tmax	19-21
						Tmin	6-9	Tmin	9-12	Tmin	9-12
Region	**Start Date**	**End Date**	**Temperature Data**								
Giathugu,	12/4/06	4/5/07	**Year**	**APR**							

Region	Start Date	End Date	Temperature Data								
Nyeri, CENTRAL			1982-2004	Tmax	18-21						
				Tmin	9-12						
			1999-2005	Tmax	21-24						
				Tmin	9-12						
			2007	Tmax	18-21						
				Tmin	9-12						
Region	**Start Date**	**End Date**	**Temperature Data**								
Gatandu, Gikambura, Kiambu, CENTRAL	2/6/06	4/16/07	**Year**	**FEB**		**MAR**		**APR**		**MAY**	
			1982-2004	Tmax	24-27	Tmax	24-27	Tmax	21-24	Tmax	18-21
				Tmin	9-12	Tmin	12-15	Tmin	12-15	Tmin	12-15
			1999-2005	Tmax	24-27	Tmax	24-27	Tmax	21-24	Tmax	18-21
				Tmin	9-12	Tmin	9-12	Tmin	12-15	Tmin	12-15
			2006	Tmax	24-27	Tmax	24-27	Tmax	24-27	Tmax	21-24
				Tmin	9-12	Tmin	12-15	Tmin	12-15	Tmin	12-15
			2007	Tmax	24-27	Tmax	24-27	Tmax	21-24		
				Tmin	12-15	Tmin	12-15	Tmin	12-15		
Region	**Start Date**	**End Date**	**Temperature Data**								
Gatandu, Gikambura, Kiambu, CENTRAL	2/6/06	4/16/07	**Year**	**JUN**		**JUL**		**AUG**		**SEP**	
			1982-2004	Tmax	18-21	Tmax	18-21	Tmax	21-24	Tmax	21-24
				Tmin	9-12	Tmin	9-12	Tmin	9-12	Tmin	9-12
			1999-2005	Tmax	18-21	Tmax	18-21	Tmax	18-21	Tmax	21-24
				Tmin	9-12	Tmin	9-12	Tmin	9-12	Tmin	9-12
			2006	Tmax	21-24	Tmax	18-21	Tmax	18-21	Tmax	21-24
				Tmin	12-15	Tmin	12-15	Tmin	12-15	Tmin	12-15
Region	**Start Date**	**End Date**	**Temperature Data**								
Gatandu, Gikambura, Kiambu, CENTRAL	2/6/06	4/16/07	**Year**	**OCT**		**NOV**		**DEC**		**JAN**	
			1982-2004	Tmax	21-24	Tmax	18-21	Tmax	21-24	Tmax	21-24
				Tmin	12-15	Tmin	12-15	Tmin	9-12	Tmin	9-12
			1999-2005	Tmax	21-24	Tmax	18-21	Tmax	21-24	Tmax	21-24
				Tmin	9-12	Tmin	12-15	Tmin	9-12	Tmin	9-12
			2006	Tmax	24-27	Tmax	21-24	Tmax	21-24		
				Tmin	12-15	Tmin	12-15	Tmin	12-15		
			2007							Tmax	24-27
										Tmin	9-12
Region	**Start Date**	**End Date**	**Temperature Data**								
Mwatate Sisal, Lualenyi Ranch, Taveta, Tiata Taveta, COAST	12/4/06	1/16/07	**Year**	**DEC**		**JAN**					
			1982-2004	Tmax	24-27	Tmax	24-27				
				Tmin	15-18	Tmin	15-18				
			1999-2005	Tmax	27-30	Tmax	30-33				
				Tmin	15-18	Tmin	15-18				
			2006	Tmax	21-24						
				Tmin	15-18						
			2007			Tmax	24-27				
						Tmin	15-18				
Region	**Start Date**	**End Date**	**Temperature Data**								
Kenol, Maragua, CENTRAL	1/22/07	6/16/07	**Year**	**JAN**		**FEB**		**MAR**		**APR**	
			1982-2004	Tmax	21-24	Tmax	24-27	Tmax	24-27	Tmax	21-24
				Tmin	9-12	Tmin	9-12	Tmin	9-12	Tmin	9-12
			1999-2005	Tmax	21-24	Tmax	24-27	Tmax	24-27	Tmax	21-24
				Tmin	6-9	Tmin	6-9	Tmin	9-12	Tmin	9-12
			2007	Tmax	24-27	Tmax	24-27	Tmax	24-27	Tmax	21-24
				Tmin	9-12	Tmin	9-12	Tmin	9-12	Tmin	9-12
Region	**Start Date**	**End Date**	**Temperature Data**								
Kenol, Maragua, CENTRAL	1/22/07	6/16/07	**Year/ Month**	**MAY**		**JUN**					
			1982-	Tmax	18-21	Tmax	18-21				

Region	Start Date	End Date	Temperature Data								
			2004	Tmin	9-12	Tmin	9-12				
			1999-	Tmax	18-21	Tmax	18-21				
			2005	Tmin	9-12	Tmin	9-12				
			2007	Tmax	24-27	Tmax	21-24				
				Tmin	12-15	Tmin	9-12				
Region	**Start Date**	**End Date**	**Temperature Data**								
Njoguini, Rurii, Murang’a, CENTRAL	12/4/06	6/24/07	**Year**	**DEC**		**JAN**		**FEB**		**MAR**	
			1982-	Tmax	21-24	Tmax	21-24	Tmax	24-27	Tmax	24-27
			2004	Tmin	9-12	Tmin	9-12	Tmin	9-12	Tmin	9-12
			1999-	Tmax	21-24	Tmax	21-24	Tmax	24-27	Tmax	24-27
			2005	Tmin	9-12	Tmin	9-12	Tmin	9-12	Tmin	9-12
			2006	Tmax	21-24						
				Tmin	12-15						
			2007			Tmax	24-27	Tmax	24-27	Tmax	24-27
						Tmin	9-12	Tmin	9-12	Tmin	12-15
Region	**Start Date**	**End Date**	**Temperature Data**								
Njoguini, Rurii, Murang’a, CENTRAL	12/4/06	6/24/07	**Year**	**APR**		**MAY**		**JUN**			
			1982-	Tmax	21-24	Tmax	18-21	Tmax	18-21		
			2004	Tmin	12-15	Tmin	12-15	Tmin	9-12		
			1999-	Tmax	21-24	Tmax	18-21	Tmax	18-21		
			2005	Tmin	12-15	Tmin	12-15	Tmin	9-12		
			2007	Tmax	21-24	Tmax	21-24	Tmax	21-24		
				Tmin	9-12	Tmin	12-15	Tmin	9-12		
Region	**Start Date**	**End Date**	**Temperature Data**								
Dantu, Kutulo, Gari, Didkuro, Mandera, NORTH-EASTERN	12/4/06	3/3/07	**Year**	**DEC**		**JAN**		**FEB**		**MAR**	
			1982-	Tmax	30-33	Tmax	30-33	Tmax	33-36	Tmax	33-36
			2004	Tmin	18-21	Tmin	18-21	Tmin	18-21	Tmin	18-21
			1999-	Tmax	33-36	Tmax	33-36	Tmax	36-39	Tmax	36-39
			2005	Tmin	18-21	Tmin	18-21	Tmin	18-21	Tmin	21-24
			2006	Tmax	33-36						
				Tmin	21-24						
			2007			Tmax	33-36	Tmax	33-36	Tmax	33-36
						Tmin	15-18	Tmin	18-21	Tmin	21-24
Region	**Start Date**	**End Date**	**Temperature Data**								
Lango Baya, Viriku, Malindi, COAST	1/8/07	4/10/07	**Year**	**JAN**		**FEB**		**MAR**		**APR**	
			1982-	Tmax	30-33	Tmax	30-33	Tmax	30-33	Tmax	30-33
			2004	Tmin	21-24	Tmin	21-24	Tmin	21-24	Tmin	21-24
			1999-	Tmax	30-33	Tmax	30-33	Tmax	30-33	Tmax	27-30
			2005	Tmin	21-24	Tmin	21-24	Tmin	21-24	Tmin	21-24
			2007	Tmax	30-33	Tmax	33-36	Tmax	30-33	Tmax	30-33
				Tmin	21-24	Tmin	21-24	Tmin	24-27	Tmin	24-27
Region	**Start Date**	**End Date**	**Temperature Data**								
Karia, Meru Central, EASTERN	12/4/06	5/4/07	**Year**	**DEC**		**JAN**		**FEB**		**MAR**	
			1982-	Tmax	24-27	Tmax	27-30	Tmax	27-30	Tmax	27-30
			2004	Tmin	12-15	Tmin	15-18	Tmin	15-18	Tmin	15-18
			1999-	Tmax	24-27	Tmax	27-30	Tmax	30-33	Tmax	30-33
			2005	Tmin	12-15	Tmin	12-15	Tmin	15-18	Tmin	15-18
			2006	Tmax	24-27						
				Tmin	15-18						
			2007			Tmax	27-30	Tmax	30-33	Tmax	27-30
						Tmin	15-18	Tmin	15-18	Tmin	18-21
Region	**Start Date**	**End Date**	**Temperature Data**								
Karia, Meru Central, EASTERN	12/4/06	5/4/07	**Year**	**APR**		**MAY**					
			1982-	Tmax	27-30	Tmax	27-30				
			2004	Tmin	15-18	Tmin	15-18				

Region	Start Date	End Date	Temperature Data								
			1999-2005	Tmax	27-30	Tmax	27-30				
				Tmin	15-18	Tmin	15-18				
			2007	Tmax	24-27	Tmax	27-30				
				Tmin	18-21	Tmin	18-21				
Region	**Start Date**	**End Date**	**Temperature Data**								
Tebere, Kirinyaga, CENTRAL	12/4/06	5/4/07	**Year**	**DEC**		**JAN**		**FEB**		**MAR**	
			1982-2004	Tmax	18-21	Tmax	18-21	Tmax	21-24	Tmax	21-24
				Tmin	9-12	Tmin	9-12	Tmin	9-12	Tmin	9-12
			1999-2005	Tmax	18-21	Tmax	21-24	Tmax	21-24	Tmax	21-24
				Tmin	9-12	Tmin	9-12	Tmin	9-12	Tmin	9-12
			2006	Tmax	18-21						
				Tmin	9-12						
			2007			Tmax	21-24	Tmax	21-24	Tmax	24-27
						Tmin	9-12	Tmin	9-12	Tmin	12-15
Region	**Start Date**	**End Date**	**Temperature Data**								
Tebere, Kirinyaga, CENTRAL	12/4/06	5/4/07	**Year**	**APR**		**MAY**					
			1982-2004	Tmax	21-24	Tmax	18-21				
				Tmin	12-15	Tmin	12-15				
			1999-2005	Tmax	21-24	Tmax	18-21				
				Tmin	9-12	Tmin	12-15				
			2007	Tmax	21-24	Tmax	21-24				
				Tmin	12-15	Tmin	12-15				
Region	**Start Date**	**End Date**	**Temperature Data**								
Longewan, Sindani, Kiserian, Maji Ndege, Baringo, RIFT VALLEY	2/2/07	5/4/07	**Year**	**FEB**		**MAR**		**APR**		**MAY**	
			1982-2004	Tmax	21-24	Tmax	21-24	Tmax	18-21	Tmax	18-21
				Tmin	6-9	Tmin	9-12	Tmin	9-12	Tmin	12-15
			1999-2005	Tmax	22-24	Tmax	21-24	Tmax	21-24	Tmax	18-21
				Tmin	6-9	Tmin	9-12	Tmin	9-12	Tmin	12-15
			2007	Tmax	24-27	Tmax	24-27	Tmax	21-24	Tmax	24-27
				Tmin	12-15	Tmin	9-12	Tmin	9-12	Tmin	12-15
Region	**Start Date**	**End Date**	**Temperature Data**								
Dadaab, Galmagara, Bura, Shantabak, Mbalambala, Danyiri, Garissa, NORTH-EASTERN	12/4/06	1/19/07	**Year**	**DEC**		**JAN**					
			1982-2004	Tmax	30-33	Tmax	30-33				
				Tmin	21-24	Tmin	21-24				
			1999-2005	Tmax	30-33	Tmax	30-33				
				Tmin	21-24	Tmin	18-21				
			2006	Tmax	30-33						
				Tmin	21-24						
			2007			Tmax	33-36				
						Tmin	21-24				
Region	**Start Date**	**End Date**	**Temperature Data**								
Kavuti, Ikime, Malawa, Mwingi, EASTERN	1/22/07	4/12/07	**Year**	**JAN**		**FEB**		**MAR**		**APR**	
			1982-2004	Tmax	27-30	Tmax	27-30	Tmax	27-30	Tmax	27-30
				Tmin	15-18	Tmin	15-18	Tmin	15-18	Tmin	15-18
			1999-2005	Tmax	27-30	Tmax	30-33	Tmax	27-30	Tmax	27-30
				Tmin	12-15	Tmin	12-15	Tmin	15-18	Tmin	15-18
			2007	Tmax	24-27	Tmax	27-30	Tmax	27-30	Tmax	24-27
				Tmin	15-18	Tmin	15-18	Tmin	18-21	Tmin	15-18
Region	**Start Date**	**End Date**	**Temperature Data**								
Kibao, Machakos, EASTERN	2/12/07	2/26/07	**Year**	**FEB**							
			1982-2004	Tmax	24-27						
				Tmin	9-12						
			1999-2005	Tmax	24-27						
				Tmin	9-12						
			2007	Tmax	24-27						
				Tmin	12-15						

Region	Start Date	End Date	Temperature Data								
Nanyuki, Laikipia, RIFT VALLEY	1/25/07	2/25/07	Year	JAN		FEB					
			1982-2004	Tmax	21-24	Tmax	21-24				
				Tmin	6-9	Tmin	6-9				
			1999-2005	Tmax	21-24	Tmax	22-24				
				Tmin	9-12	Tmin	6-9				
			2007	Tmax	18-21	Tmax	18-21				
				Tmin	6-9	Tmin	6-9				
Region	**Start Date**	**End Date**	**Temperature Data**								
Masalani, Ijara, NORTH-EASTERN	12/4/06	3/3/07	Year	DEC		JAN		FEB		MAR	
			1982-2004	Tmax	30-33	Tmax	30-33	Tmax	36-39	Tmax	36-39
				Tmin	21-24	Tmin	21-24	Tmin	21-24	Tmin	21-24
			1999-2005	Tmax	30-33	Tmax	30-33	Tmax	36-39	Tmax	36-39
				Tmin	21-24	Tmin	18-21	Tmin	18-21	Tmin	21-24
			2006	Tmax	30-33						
				Tmin	21-24						
			2007			Tmax	30-33	Tmax	33-36	Tmax	30-33
						Tmin	21-24	Tmin	24-27	Tmin	24-27
Region	**Start Date**	**End Date**	**Temperature Data**								
Kinango, Musiu, Lunga Lunga, Kidzumbani, Kwale, COAST	12/4/06	4/16/07	Year	DEC		JAN		FEB		MAR	
			1982-2004	Tmax	27-30	Tmax	30-33	Tmax	30-33	Tmax	30-33
				Tmin	18-21	Tmin	18-21	Tmin	18-21	Tmin	18-21
			1999-2005	Tmax	27-30	Tmax	30-33	Tmax	30-33	Tmax	30-33
				Tmin	18-21	Tmin	15-18	Tmin	15-18	Tmin	18-21
			2006	Tmax	27-30						
				Tmin	18-21						
			2007			Tmax	27-30	Tmax	33-36	Tmax	30-33
						Tmin	15-18	Tmin	21-24	Tmin	18-21
Region	**Start Date**	**End Date**	**Temperature Data**								
Kinango, Musiu, Lunga Lunga, Kidzumbani, Kwale, COAST	12/4/06	4/16/07	Year	APR							
			1982-2004	Tmax	27-30						
				Tmin	18-21						
			1999-2005	Tmax	27-30						
				Tmin	18-21						
			2007	Tmax	27-30						
				Tmin	18-21						
Region	**Start Date**	**End Date**	**Temperature Data**								
Kasuvi, Kathyaka, Ntahnge, Makueni, EASTERN	1/23/07	5/14/07	Year	JAN		FEB		MAR		APR	
			1982-2004	Tmax	24-27	Tmax	27-30	Tmax	27-30	Tmax	24-27
				Tmin	15-18	Tmin	15-18	Tmin	15-18	Tmin	15-18
			1999-2005	Tmax	27-30	Tmax	30-33	Tmax	27-30	Tmax	24-27
				Tmin	12-15	Tmin	12-15	Tmin	15-18	Tmin	15-18
			2007	Tmax	24-27	Tmax	27-30	Tmax	27-30	Tmax	24-27
				Tmin	15-18	Tmin	15-18	Tmin	18-21	Tmin	15-18
Region	**Start Date**	**End Date**	**Temperature Data**								
Kasuvi, Kathyaka, Ntahnge, Makueni, EASTERN	1/23/07	5/14/07	Year	MAY							
			1982-2004	Tmax	24-27						
				Tmin	15-18						
			1999-2005	Tmax	24-27						
				Tmin	15-18						
			2007	Tmax	27-30						
				Tmin	15-18						
Region	**Start Date**	**End Date**	**Temperature Data**								
Township, Meru South, EASTERN	1/31/07	4/7/07	Year	JAN		FEB		MAR		APR	
			1982-2004	Tmax	27-30	Tmax	27-30	Tmax	27-30	Tmax	27-30
				Tmin	15-18	Tmin	15-18	Tmin	15-18	Tmin	15-18

Region	Start Date	End Date	Temperature Data								
			1999-2005	Tmax	27-30	Tmax	30-33	Tmax	30-33	Tmax	27-30
				Tmin	12-15	Tmin	15-18	Tmin	15-18	Tmin	15-18
			2007	Tmax	27-30	Tmax	30-33	Tmax	27-30	Tmax	24-27
				Tmin	15-18	Tmin	15-18	Tmin	18-21	Tmin	18-21

Region	Start Date	End Date	Temperature Data								
Ruiru, Thika, CENTRAL	12/4/06	6/22/07	Year	DEC		JAN		FEB		MAR	
			1982-2004	Tmax	21-24	Tmax	21-24	Tmax	24-27	Tmax	24-27
				Tmin	9-12	Tmin	9-12	Tmin	9-12	Tmin	9-12
			1999-2005	Tmax	21-24	Tmax	21-24	Tmax	24-27	Tmax	24-27
				Tmin	9-12	Tmin	9-12	Tmin	9-12	Tmin	9-12
			2006	Tmax	21-24						
				Tmin	12-15						
			2007			Tmax	24-27	Tmax	24-27	Tmax	
						Tmin	9-12	Tmin	9-12	Tmin	

Region	Start Date	End Date	Temperature Data								
Ruiru, Thika, CENTRAL	12/4/06	6/22/07	Year	APR		MAY		JUN			
			1982-2004	Tmax	21-24	Tmax	18-21	Tmax	18-21		
				Tmin	12-15	Tmin	12-15	Tmin	9-12		
			1999-2005	Tmax	21-24	Tmax	18-21	Tmax	18-21		
				Tmin	12-15	Tmin	12-15	Tmin	9-12		
			2007	Tmax	21-24	Tmax	21-24	Tmax	18-21		
				Tmin	12-15	Tmin	12-15	Tmin	9-12		

Region	Start Date	End Date	Temperature Data								
Kasarani, Nairobi, NAIROBI AREA	12/4/06	4/5/07	Year	DEC		JAN		FEB		MAR	
			1982-2004	Tmax	21-24	Tmax	21-24	Tmax	24-27	Tmax	24-27
				Tmin	9-12	Tmin	9-12	Tmin	9-12	Tmin	9-12
			1999-2005	Tmax	21-24	Tmax	21-24	Tmax	24-27	Tmax	24-27
				Tmin	9-12	Tmin	9-12	Tmin	9-12	Tmin	9-12
			2006	Tmax	21-24						
				Tmin	12-15						
			2007			Tmax	21-24	Tmax	21-24	Tmax	24-27
						Tmin	9-12	Tmin	12-15	Tmin	12-15

Region	Start Date	End Date	Temperature Data								
Kasarani, Nairobi, NAIROBI AREA	12/4/06	4/5/07	Year	APR							
			1982-2004	Tmax	21-24						
				Tmin	12-15						
			1999-2005	Tmax	21-24						
				Tmin	12-15						
			2007	Tmax	21-24						
				Tmin	12-15						

Region	Start Date	End Date	Temperature Data								
Lamu, Lamu, COAST	12/4/06	2/23/07	Year	DEC		JAN		FEB			
			1982-2004	Tmax	30-33	Tmax	30-33	Tmax	30-33		
				Tmin	24-27	Tmin	24-27	Tmin	24-27		
			1999-2005	Tmax	27-30	Tmax	30-33	Tmax	30-33		
				Tmin	24-27	Tmin	24-27	Tmin	24-27		
			2006	Tmax	27-30						
				Tmin	24-27						
			2007			Tmax	30-33	Tmax	33-36		
						Tmin	21-24	Tmin	24-27		

Region	Start Date	End Date	Temperature Data								
Mombasa, Mombasa, COAST	1/4/07	2/3/07	Year	JAN		FEB					
			1982-2004	Tmax	27-30	Tmax	27-30				
				Tmin	24-27	Tmin	24-27				
			1999-	Tmax	27-30	Tmax	27-30				

Region	Start Date	End Date	Temperature Data								
			2005	Tmin	24-27	Tmin	24-27				
			2007	Tmax	27-30	Tmax	27-30				
				Tmin	24-27	Tmin	24-27				
Region	Start Date	End Date	Temperature Data								
Evurore, Karaba, Waschoro, Mutito, Mbeere, EASTERN	12/4/06	5/10/07	Year	DEC		JAN		FEB		MAR	
			1982-2004	Tmax	18-21	Tmax	20-21	Tmax	22-24	Tmax	22-24
				Tmin	9-12	Tmin	9-12	Tmin	9-12	Tmin	9-12
			1999-2005	Tmax	18-21	Tmax	21-24	Tmax	22-24	Tmax	21-24
				Tmin	9-12	Tmin	9-12	Tmin	6-9	Tmin	9-12
			2006	Tmax	21-24						
				Tmin	12-15						
			2007			Tmax	21-24	Tmax	24-27	Tmax	24-27
						Tmin	12-15	Tmin	9-12	Tmin	12-15
Region	Start Date	End Date	Temperature Data								
Evurore, Karaba, Waschoro, Mutito, Mbeere, EASTERN	12/4/06	5/10/07	Year	APR		MAY					
			1982-2004	Tmax	20-21	Tmax	27-30				
				Tmin	12-15	Tmin	12-15				
			1999-2005	Tmax	21-24	Tmax	27-30				
				Tmin	9-12	Tmin	12-15				
			2007	Tmax	24-27	Tmax	24-27				
				Tmin	12-15	Tmin	12-15				
Region	Start Date	End Date	Temperature Data								
Karurumo, Embu, EASTERN	12/4/06	3/3/07	Year	DEC		JAN		FEB		MAR	
			1982-2004	Tmax	24-27	Tmax	27-30	Tmax	27-30	Tmax	27-30
				Tmin	12-15	Tmin	15-18	Tmin	15-18	Tmin	15-18
			1999-2005	Tmax	24-27	Tmax	27-30	Tmax	30-33	Tmax	30-33
				Tmin	12-15	Tmin	12-15	Tmin	15-18	Tmin	15-18
			2006	Tmax	24-27						
				Tmin	15-18						
			2007			Tmax	24-27	Tmax	24-27	Tmax	24-27
						Tmin	9-12	Tmin	12-15	Tmin	9-12
Region	Start Date	End Date	Temperature Data								
Adadi Jole, Wajir, NORTH-EASTERN	12/27/06	1/29/07	Year	DEC		JAN					
			1982-2004	Tmax	30-33	Tmax	33-36				
				Tmin	18-21	Tmin	18-21				
			1999-2005	Tmax	30-33	Tmax	30-33				
				Tmin	18-21	Tmin	18-21				
			2006	Tmax	30-33						
				Tmin	21-24						
			2007			Tmax	33-36				
						Tmin	21-24				
Region	Start Date	End Date	Temperature Data								
Godoma, Moyale, EASTERN	1/29/07	3/30/07	Year	JAN		FEB		MAR			
			1982-2004	Tmax	33-36	Tmax	33-36	Tmax	33-36		
				Tmin	18-21	Tmin	18-21	Tmin	18-21		
			1999-2005	Tmax	33-36	Tmax	33-36	Tmax	33-36		
				Tmin	15-18	Tmin	15-18	Tmin	18-21		
			2007	Tmax	33-36	Tmax	36-39	Tmax	33-36		
				Tmin	21-24	Tmin	21-24	Tmin	21-24		
Region	Start Date	End Date	Temperature Data								
Tara, Machakos, EASTERN	12/4/06	1/26/07	Year	DEC		JAN					
			1982-2004	Tmax	21-24	Tmax	21-24				
				Tmin	9-12	Tmin	9-12				
			1999-2005	Tmax	21-24	Tmax	21-24				
				Tmin	9-12	Tmin	9-12				

Region	Start Date	End Date	Temperature Data								
			2006	Tmax	21-24						
				Tmin	12-15						
			2007			Tmax	21-24				
						Tmin	12-15				
Region	**Start Date**	**End Date**	**Temperature Data**								
Nodnyo, Laresoro, Lerata, Sereolipi, Samburu, RIFT VALLEY	2/5/07	4/1/07	**Year**	**FEB**		**MAR**		**APR**			
			1982-2004	Tmax	30-33	Tmax	30-33	Tmax	27-30		
				Tmin	18-21	Tmin	18-21	Tmin	18-21		
			1999-2005	Tmax	30-33	Tmax	30-33	Tmax	27-30		
				Tmin	15-18	Tmin	18-21	Tmin	18-21		
			2007	Tmax	33-36	Tmax	30-33	Tmax	27-30		
				Tmin	18-21	Tmin	18-21	Tmin	18-21		
Region	**Start Date**	**End Date**	**Temperature Data**								
Marula, Nakuru, RIFT VALLEY	12/4/06	3/8/07	**Year**	**DEC**		**JAN**		**FEB**		**MAR**	
			1982-2004	Tmax	21-24	Tmax	24-27	Tmax	24-27	Tmax	24-27
				Tmin	9-12	Tmin	9-12	Tmin	8-9	Tmin	9-12
			1999-2005	Tmax	21-24	Tmax	21-24	Tmax	24-27	Tmax	24-27
				Tmin	9-12	Tmin	6-9	Tmin	6-9	Tmin	9-12
			2006	Tmax	21-24						
				Tmin	9-12						
			2007			Tmax	24-27	Tmax	24-27	Tmax	24-27
						Tmin	9-12	Tmin	9-12	Tmin	9-12

APPENDIX H

A comparison of tmax and tmin temperature data for Madagascar prior to and during Kenyan Rift Valley fever animal outbreaks 2008-2009

Region	Start Date	End Date	Temperature Data								
Antady, Fianarantsoa, Fianarantsoa I, HAUTE MATSIATRA	11/16/08	1/31/09	Year	NOV		DEC		JAN			
			1982-	Tmax	21-24	Tmax	21-24	Tmax	21-24		
			2004	Tmin	15-18	Tmin	15-18	Tmin	15-18		
			1999-	Tmax	21-24	Tmax	21-24	Tmax	18-21		
			2007	Tmin	15-18	Tmin	15-18	Tmin	9-12		
			2008	Tmax	21-24	Tmax	21-24				
				Tmin	15-18	Tmin	15-18				
			2009					Tmax	21-24		
								Tmin	15-18		
Region	Start Date	End Date	Temperature Data								
Nasandratrony, Isandra, HAUTE MATSIATRA	11/16/08	1/31/09	Year	NOV		DEC		JAN			
			1982-	Tmax	21-24	Tmax	21-24	Tmax	21-24		
			2004	Tmin	15-18	Tmin	15-18	Tmin	15-18		
			1999-	Tmax	21-24	Tmax	21-24	Tmax	18-21		
			2007	Tmin	15-18	Tmin	15-18	Tmin	9-12		
			2008	Tmax	21-24	Tmax	21-24	Tmax			
				Tmin	15-18	Tmin	15-18	Tmin			
			2009					Tmax	21-24		
								Tmin	15-18		
Region	Start Date	End Date	Temperature Data								
Ambanimaso, Fianarantsoa, Fianarantsoa I, HAUTE MATSIATRA	11/22/08	1/31/09	Year	NOV		DEC		JAN			
			1982-	Tmax	21-24	Tmax	21-24	Tmax	21-24		
			2004	Tmin	12-15	Tmin	15-18	Tmin	15-18		
			1999-	Tmax	21-24	Tmax	21-24	Tmax	21-24		
			2007	Tmin	15-18	Tmin	15-18	Tmin	15-18		
			2008	Tmax	21-24	Tmax	21-24				
				Tmin	15-18	Tmin	12-15				
			2009					Tmax	21-24		
								Tmin	15-18		
Region	Start Date	End Date	Temperature Data								
Imandry, Fianarantsoa, Fianarantsoa I, HAUTE MATSIATRA	11/24/08	1/31/09	Year	NOV		DEC		JAN			
			1982-	Tmax	21-24	Tmax	21-24	Tmax	21-24		
			2004	Tmin	15-18	Tmin	15-18	Tmin	15-18		
			1999-	Tmax	21-24	Tmax	21-24	Tmax	21-24		
			2007	Tmin	15-18	Tmin	15-18	Tmin	15-18		
			2008	Tmax	21-24	Tmax	21-24				
				Tmin	15-18	Tmin	15-18				
			2009					Tmax	21-24		
								Tmin	15-18		
Region	Start Date	End Date	Temperature Data								
Tsaramandroso, Fianarantsoa, Fianarantsoa I, HAUTE MATSIATRA	11/29/08	1/31/09	Year	NOV		DEC		JAN			
			1982-	Tmax	30-33	Tmax	27-30	Tmax	27-30		
			2004	Tmin	21-24	Tmin	21-24	Tmin	21-24		
			1999-	Tmax	27-30	Tmax	27-30	Tmax	27-30		
			2007	Tmin	18-21	Tmin	21-24	Tmin	18-21		
			2008	Tmax	27-30	Tmax	27-30				
				Tmin	21-24	Tmin	21-24				
			2009					Tmax	27-30		

Region	Start Date	End Date	Temperature Data								
								Tmin	21-24		
Region	**Start Date**	**End Date**	**Temperature Data**								
Antanifotsy, Fianarantsoa, Fianarantsoa I, HAUTE MATSIATRA	12/10/08	1/31/09	Year	DEC		JAN					
			1982-2004	Tmax	27-30	Tmax	27-30				
				Tmin	24-27	Tmin	24-27				
			1999-2007	Tmax	27-30	Tmax	27-30				
				Tmin	24-27	Tmin	24-27				
			2008	Tmax	27-30						
				Tmin	24-27						
			2009			Tmax	27-30				
						Tmin	24-27				
Region	**Start Date**	**End Date**	**Temperature Data**								
Ampasina, Sahambavy, Lalangina, HAUTE MATSIATRA	12/11/08	1/31/09	Year	DEC		JAN					
			1982-2004	Tmax	27-30	Tmax	27-30				
				Tmin	21-24	Tmin	21-24				
			1999-2007	Tmax	27-30	Tmax	27-30				
				Tmin	21-24	Tmin	21-24				
			2008	Tmax	27-30						
				Tmin	21-24						
			2009			Tmax	27-30				
						Tmin	21-24				
Region	**Start Date**	**End Date**	**Temperature Data**								
Ambonifehidrano, Fianarantsoa, Fianarantsoa I, HAUTE MATSIATRA	12/13/08	1/31/09	Year	DEC		JAN					
			1982-2004	Tmax	24-27	Tmax	24-27				
				Tmin	18-21	Tmin	18-21				
			1999-2007	Tmax	24-27	Tmax	24-27				
				Tmin	18-21	Tmin	18-21				
			2008	Tmax	27-30						
				Tmin	18-21						
			2009			Tmax	24-27				
						Tmin	18-21				
Region	**Start Date**	**End Date**	**Temperature Data**								
Marodinta, Nasandratony, Isandra, HAUTE MATSIATRA	12/13/08	1/31/09	Year	DEC		JAN					
			1982-2004	Tmax	21-24	Tmax	21-24				
				Tmin	15-18	Tmin	15-18				
			1999-2007	Tmax	21-24	Tmax	21-24				
				Tmin	15-18	Tmin	15-18				
			2008	Tmax	21-24						
				Tmin	15-18						
			2009			Tmax	21-24				
						Tmin	15-18				
Region	**Start Date**	**End Date**	**Temperature Data**								
Avaradrano, ANTANANARIVO	2/4/08	10/30/08	Year	FEB		MAR		APR		MAY	
			1982-2004	Tmax	21-24	Tmax	21-24	Tmax	21-24	Tmax	18-21
				Tmin	15-18	Tmin	15-18	Tmin	12-15	Tmin	9-12
			1999-2007	Tmax	21-24	Tmax	21-24	Tmax	21-24	Tmax	18-21
				Tmin	15-18	Tmin	15-18	Tmin	12-15	Tmin	9-12
			2008	Tmax	21-24	Tmax	21-24	Tmax	21-24	Tmax	18-21
				Tmin	15-18	Tmin	12-15	Tmin	12-15	Tmin	9-12
Region	**Start Date**	**End Date**	**Temperature Data**								
Avaradrano, ANTANANARIVO	2/4/08	10/30/08	Year	JUN		JUL		AUG		SEP	
			1982-2004	Tmax	15-18	Tmax	18-21	Tmax	18-21	Tmax	21-24
				Tmin	9-12	Tmin	9-12	Tmin	7-9	Tmin	9-12
			1999-2007	Tmax	18-21	Tmax	18-21	Tmax	18-21	Tmax	21-24
				Tmin	9-12	Tmin	9-12	Tmin	7-9	Tmin	9-12

Region	**Start Date**	**End Date**	**Temperature Data**							
			2008	Tmax	15-18	Tmax	15-18	Tmax	18-21	Tmax	21-24
				Tmin	9-12	Tmin	7-9	Tmin	9-12	Tmin	9-12
Region	**Start Date**	**End Date**	**Temperature Data**							
Avaradrano, ANTANANARIVO	2/4/08	10/30/08	**Year**	**OCT**						
			1982-2004	Tmax	21-24						
				Tmin	12-15						
			1999-2007	Tmax	21-24						
				Tmin	12-15						
			2008	Tmax	21-24						
				Tmin	12-15						
Region	**Start Date**	**End Date**	**Temperature Data**							
Andohasahalava, Vohitsaoka, Ambalavao, HAUTE MATSIATRA	3/12/09	5/29/09	**Year**	MAR		APR		MAY			
			1982-2004	Tmax	21-24	Tmax	21-24	Tmax	18-21		
				Tmin	15-18	Tmin	12-15	Tmin	12-15		
			1999-2007	Tmax	21-24	Tmax	21-24	Tmax	18-21		
				Tmin	15-18	Tmin	12-15	Tmin	12-15		
			2009	Tmax	21-24	Tmax	18-21	Tmax	18-21		
				Tmin	15-18	Tmin	12-15	Tmin	12-15		

APPENDIX I

A comparison of tmax and tmin temperature data for South Africa prior to and during Kenyan Rift Valley fever animal outbreaks 2008-2009

Region	Start Date	End Date	Temperature Data								
Ngwenya, Ehlanzeni, MPUMALANGA	1/14/08	3/14/08	Year	JAN		FEB		MAR			
Grootboom, Nkomazi, MPUMALANGA	2/7/08	3/7/08	1982-2004	Tmax	27-30	Tmax	27-30	Tmax	24-27		
Marlothi, Nkomazi, MPUMALANGA	2/7/08	3/7/08		Tmin	18-21	Tmin	18-21	Tmin	18-21		
One Tree Hill, Nkomazi, MPUMALANGA	2/27/08	3/27/08									
Ten Bosch, Nkomazi, MPUMALANGA	1/15/08	2/15/08	1999-2007	Tmax	27-30	Tmax	27-30	Tmax	24-27		
Ten Bosch, Nkomazi, MPUMALANGA	2/1/08	3/1/08		Tmin	18-21	Tmin	18-21	Tmin	18-21		
Vyeboom, Nkomazi, MPUMALANGA	2/1/08	3/1/08									
Richtersnek, Nkomazi, MPUMALANGA	2/12/08	3/1/08	2008	Tmax	24-27	Tmax	27-30	Tmax	24-27		
				Tmin	18-21	Tmin	18-21	Tmin	18-21		
Region	Start Date	End Date	Temperature Data								
Buiskop, Bela-Bela, LIMPOPO	3/1/08	4/1/08	Year	MAR		APR		MAY			
			1982-2004	Tmax	24-27	Tmax	24-27	Tmax	21-24		
Langkuil, Bela-Bela, LIMPOPO	3/1/08	4/1/08		Tmin	12-15	Tmin	12-15	Tmin	6-9		
Leewdoorns, Bela-Bela, LIMPOPO	4/1/08	5/1/08	1999-2007	Tmax	24-27	Tmax	24-27	Tmax	21-24		
				Tmin	12-15	Tmin	12-15	Tmin	6-9		
			2008	Tmax	24-27	Tmax	24-27	Tmax	21-24		
				Tmin	15-18	Tmin	9-12	Tmin	9-12		
Region	Start Date	End Date	Temperature Data								
Grietjie, Ba-Phalaborwa, LIMPOPO	3/7/08	5/7/08	Year	MAR		APR		MAY			
			1982-2004	Tmax	27-30	Tmax	27-30	Tmax	24-27		
				Tmin	18-21	Tmin	15-18	Tmin	12-15		
Paul, Ba-Phalaborwa, LIMPOPO	3/7/08	4/7/08	1999-2007	Tmax	27-30	Tmax	27-30	Tmax	24-27		
				Tmin	15-18	Tmin	15-18	Tmin	12-15		
			2008	Tmax	27-30	Tmax	27-30	Tmax	24-27		
				Tmin	18-21	Tmin	15-18	Tmin	12-15		
Region	Start Date	End Date	Temperature Data								
Leeuwkraal, Cullinan, GAUTENG	3/7/08	4/7/08	Year	MAR		APR		MAY			
			1982-2004	Tmax	21-24	Tmax	21-24	Tmax	24-27		
				Tmin	12-15	Tmin	9-12	Tmin	12-15		
			1999-	Tmax	21-24	Tmax	21-24	Tmax	24-27		

Region	Start Date	End Date	Temperature Data								
			2007	Tmin	12-15	Tmin	9-12	Tmin	12-15		
			2008	Tmax	21-24	Tmax	21-24	Tmax	24-27		
				Tmin	12-15	Tmin	9-12	Tmin	12-15		
Region	**Start Date**	**End Date**	**Temperature Data**								
Leeuwkraal, Cullinan, GAUTENG	3/7/08	4/7/08	**Year**	**MAR**		**APR**		**MAY**			
			1982-2004	Tmax	21-24	Tmax	21-24	Tmax	24-27		
				Tmin	12-15	Tmin	9-12	Tmin	12-15		
			1999-2007	Tmax	21-24	Tmax	21-24	Tmax	24-27		
				Tmin	12-15	Tmin	9-12	Tmin	12-15		
			2008	Tmax	21-24	Tmax	21-24	Tmax	24-27		
				Tmin	12-15	Tmin	9-12	Tmin	12-15		
Region	**Start Date**	**End Date**	**Temperature Data**								
Doornkloof, Pretoria, GAUTENG	4/7/08	5/7/08	**Year**	**APR**		**MAY**					
			1982-2004	Tmax	21-24	Tmax	18-21				
				Tmin	9-12	Tmin	9-12				
			1999-2007	Tmax	21-24	Tmax	18-21				
Doornkloof, City of Tshwane, GAUTENG	4/1/08	5/1/08		Tmin	12-15	Tmin	9-12				
			2008	Tmax	18-21	Tmax	18-21				
				Tmin	9-12	Tmin	9-12				
Region	**Start Date**	**End Date**	**Temperature Data**								
Leeuwkraal, Moretele, NORTH WEST PROVINCE	4/23/08	5/17/08	**Year**	**APR**		**MAY**					
			1982-2004	Tmax	24-27	Tmax	21-24				
				Tmin	12-15	Tmin	9-12				
			1999-2007	Tmax	24-27	Tmax	21-24				
				Tmin	12-15	Tmin	9-12				
			2008	Tmax	24-27	Tmax	21-24				
				Tmin	9-12	Tmin	9-12				
Region	**Start Date**	**End Date**	**Temperature Data**								
Witpoort, Bronkhorstspruit, GAUTENG	4/22/08	5/22/08	**Year**	**APR**		**MAY**		**JUN**			
			1982-2004	Tmax	21-24	Tmax	18-21	Tmax	15-18		
				Tmin	9-12	Tmin	6-9	Tmin	3-6		
			1999-2007	Tmax	21-24	Tmax	18-21	Tmax	15-18		
Witpoort, Kungwini, GAUTENG	5/1/08	6/1/08		Tmin	9-12	Tmin	6-9	Tmin	3-6		
			2008	Tmax	21-24	Tmax	18-21	Tmax	15-18		
				Tmin	9-12	Tmin	9-12	Tmin	6-9		
Region	**Start Date**	**End Date**	**Temperature Data**								
Mamagalieskraal, Madibeng, NORTH WEST PROVINCE	4/23/08	5/23/08	**Year**	**APR**		**MAY**					
			1982-2004	Tmax	24-27	Tmax	27-30				
				Tmin	12-15	Tmin	9-12				
			1999-2007	Tmax	27-30	Tmax	21-24				
Mamagalieskraal, Madibeng, NORTH WEST PROVINCE	4/23/08	5/23/08		Tmin	12-15	Tmin	9-12				
			2008	Tmax	27-30	Tmax	24-27				
				Tmin	12-15	Tmin	12-15				
Region	**Start Date**	**End Date**	**Temperature Data**								
Blinkwater, Mbombela, MPUMALANGA	5/1/08	6/1/08	**Year**	**MAY**		**JUN**					
			1982-	Tmax	21-24	Tmax	21-24				

Region	Start Date	End Date	Temperature Data								
Curlews settlement, Mbombela, MPUMALANGA	5/1/08	6/1/08	2004	Tmin	12-15	Tmin	12-15				
Hooggelegen, Mbombela, MPUMALANGA	5/1/08	6/1/08	1999-2007	Tmax	21-24	Tmax	21-24				
Vaalbank, Dr JS Moroka, MPUMALANGA	5/1/08	6/1/08		Tmin	12-15	Tmin	12-15				
			2008	Tmax	21-24	Tmax	18-21				
				Tmin	15-18	Tmin	12-15				
Region	Start Date	End Date	Temperature Data								
Krokodildrift, Potchefstroom, NORTH WEST PROVINCE	4/1/08	5/1/08	Year	APR		MAY					
			1982-2004	Tmax	21-24	Tmax	18-21				
				Tmin	9-12	Tmin	6-9				
			1999-2007	Tmax	21-24	Tmax	18-21				
				Tmin	9-12	Tmin	6-9				
			2008	Tmax	21-24	Tmax	18-21				
				Tmin	9-12	Tmin	6-9				
Region	Start Date	End Date	Temperature Data								
Conference, Ingwe, KWAZULU-NATAL	2/25/09	3/15/09	Year	FEB		MAR		APR		MAY	
Allandale, Ingwe, KWAZULU-NATAL	2/25/09	3/15/09	1982-2004	Tmax	21-24	Tmax	21-24	Tmax	18-21	Tmax	15-18
Tyrone, Ingwe, KWAZULU-NATAL	2/27/09	3/15/09		Tmin	12-15	Tmin	12-15	Tmin	6-9	Tmin	6-9
Stockton, Ingwe, KWAZULU-NATAL	2/18/09	3/15/09									
Eastwold, Ingwe, KWAZULU-NATAL	2/27/09	3/15/09	1999-2007	Tmax	21-24	Tmax	21-24	Tmax	18-21	Tmax	18-21
Ringstead, Kwa Sani, KWAZULU-NATAL	3/3/09	5/15/09		Tmin	12-15	Tmin	12-15	Tmin	9-12	Tmin	6-9
Mount Hermon, Ubuhlebezwe, KWAZULU-NATAL	3/9/09	4/15/09									
Burnview, Ingwe, KWAZULU-NATAL	3/23/09	4/30/09	2009	Tmax	21-24	Tmax	21-24	Tmax	21-24	Tmax	18-21
Greenstead, Lions River, KWAZULU-NATAL	3/17/09	3/31/09		Tmin	12-15	Tmin	12-15	Tmin	9-12	Tmin	6-9
Ikwezi Trust, KwaSani, KWAZULU-NATAL	4/1/09	4/10/09									
Ilynton, KwaSani, KWAZULU-NATAL	4/2/09	4/15/09									
Firle, Mooi Mpofana, KWAZULU-NATAL	4/2/09	4/15/09									
The Meads,	4/24/09	5/15/09									

Region	Start Date	End Date	Temperature Data								
Matatiele, KWAZULU-NATAL											
Rustfontein, Matatiele, KWAZULU-NATAL	4/24/09	5/15/09									

APPENDIX J

An analysis of rainfall in relation to Rift Valley fever outbreaks in Kenya, Madagascar and South Africa

ABSTRACT

Rift Valley fever (RVF) activity has been known to follow periods of high rainfall due to an increase in mosquito vectors following these periods. Studies in Kenya and northern Senegal have correlated RVF outbreaks with periods of widespread and heavy rainfall. With the spread of RVF into ecologically diverse regions rainfall activity has not been associated with RVF outbreaks in countries outside of sub-Saharan Africa. Geographic information systems, time series and statistical analysis is used to analyze gridded rainfall data for Kenya, South Africa and Madagascar to determine if rainfall can be associated with RVF outbreaks within these countries. Geographic information systems and statistical analysis showed a relationship exists between rainfall and Rift Valley fever activity in Kenya but these results were not found in Madagascar and South Africa.

INTRODUCTION

Rift Valley fever (RVF) is an arboviral disease, first described in Kenya in 1931, that causes epizootics and associated human epidemics throughout Africa (Gerdes, 2004). RVF virus is transmitted by infected *Aedes* and *Culex* species mosquitoes. Rift Valley fever is often considered a disease primarily of sub-Saharan and southern Africa, but in 1977 an outbreak occurred in Egypt and since then outbreaks in Saudi Arabia, Yemen and Madagascar has shown RVF to be able to invade ecologically diverse regions (Gaff, 2007). RVF activity has been shown to follow periods of abnormally high and widespread rainfall in Kenya and northern Senegal (Meegan and Bailey 1988, Wilson et al. 1994, Digoutte and Peters 1989, Linthicum *et al.* 1999, Anyamba 2001, Bicout 2004). It has been assumed that increased rainfall rates increase the number of breeding sites for *Aedes* floodwater mosquitoes resulting in an increase in RVF activity. *Aedes* infected breeding habitats serve for the development of secondary vectors (*Culex* species) and result in an increase in RVF activity in animal and human populations. Although this phenomenon has been well studied in Kenya to date no studies have been done in South Africa and Madagascar both of which are ecologically different from Kenya.

Over the past few decades, significant changes in the distribution and intensity of Rift Valley fever (RVF) has been recorded (WHO, 2007). Since the isolation of the virus in 1931 in the Rift Valley in Kenya it has been held responsible for several epizootics in small ruminants, causing abortions and stillborn droppings in the ovine species in Eastern and Southern Africa (Gerdes, 2004). Epizootics first occurred in regions of high altitude such as South Africa in 1951, Zimbabwe in 1958, Nigeria in 1958, and Chad and Cameroon in 1967 (WHO, 2007). Until the 1970s human infection remained low, and the agent mostly affected breeders in contact with affected or dead animals. In 1973 after the first source of infection appeared in the White Nile in Sudan, a human epidemic soon began in South Africa with the first recognized human deaths (Peters, 1994). Human outbreaks then occurred in Egypt in 1977 causing 598 human deaths (Gerdes, 2004), in 1987 causing 200 human deaths, and in Kenya and Somalia in 1997 causing 478 human deaths (CDC, 1998). In 2000, cases of RVF were discovered in Saudi Arabia and Yemen marking the spread of the disease outside of Africa and the Rift Valley (Jupp, 2002). By November 2000, over 500 cases of serious RVF were discovered in Saudi Arabia, with 87 deaths. In Yemen, between August and November 2000, there were over 1,000 suspected occurrences of the disease among humans. The result of the outbreak in Yemen was 121 deaths. Since 2000 outbreaks have occurred in Kenya and Somalia in 2006, Tanzania and Sudan in 2007 and Madagascar and South Africa in 2008.

Epizootics in sub-Saharan Africa, which occur simultaneously over geographic areas separated by several hundred kilometers, are consistently reported (Meegen & Bailey, 1988). They are associated with unusually heavy rainfall and a large number of mosquitoes (Davies, 1985). The Rift Valley fever virus (RVFV) outbreaks in Kenya, from 1950 to 1998, followed periods of abnormally heavy rainfall (Anyamba, 2001). In the study of the various mosquito borne diseases such as malaria and West Nile Virus (WNV) geographic analysis has discovered a relationship between the vectors and the environmental variable rainfall. Mosquito vectors are very diverse in their biology, with some species preferring extremely wet climates and others preferring extremely dry climates. The relationship between the vectors responsible for the spread of RVF has not been fully studied and understood. Geographic and statistical analysis of the an environmental variable such as rainfall and its relationship with Rift Valley fever will allow for further understanding of the predictive indicators needed to forecast future RVF outbreaks in Africa and beyond.

MATERIALS AND METHODS

Data characterization

In November of 2006 Rift Valley fever activity in humans was reported to the World Health Organization (WHO) in 11 regions in Kenya. RVF activity for cattle, sheep, goats and camelidae was reported in 19 regions in Kenya to the World Organization for Animal Health (OIE) in December of 2006. In April of 2008 an outbreak in the Alaotra-Mangoro region in Toamasina Province of eastern Madagascar was reported with 59 confirmed human cases and 17 suspected human deaths due to RVF. In February of 2008 an RVF outbreak in Antananarivo-Avaradrano was reported in cattle and in November of 2008 and March of 2009 in the Haute Matsiatra region in

Fianarantsoa Province of Madagascar RVF activity was reported in cattle. In January of 2008 in the Mpumalanga province in South Africa, in March of 2008 in the Limpopo and Gauteng province in South Africa, and in February of 2009 in the Kwazulu-Natal province in South Africa RVF activity in cattle, goats and buffalo was reported to the OIE. No human RVF activity was reported to the WHO for 2008 and 2009 in South Africa.

Gridded rainfall data for Africa was acquired from the National Oceanic & Atmospheric Administration (NOAA) Climate Prediction Center Famine Early Warning System Rainfall Estimates archives. Rainfall estimates are from 4 sources: 1) Daily GTS rain gauge data for up to 1000 stations; 2) AM SU microwave satellite rainfall estimates up to 4 times per day; 3) SSM /I satellite rainfall estimates up to 4 times per day; and 4) GPI cloud-top IR temperature rainfall estimates on a half-hour basis. Three satellite estimates are first combined linearly using predetermined weighting coefficients, then are merged with station data to determine final rainfall amount. Binary graphical output files are produced daily at approximately 3pm EST with a resolution of 0.1° and spatial extent from 40°S-40°N and 20°W-55°E. Data is archived and available from 1982 to present day.

Rainfall data was retrieved as bin files and converted to attribute tables using PERL scripts on a Linux based station. Daily rainfall rates from January 1982 to July of 2009 were averaged to create monthly datasets for the countries of Kenya, Madagascar and South Africa. For Kenya a long term dataset was created with averaged monthly gridded rainfall data from 1982 through 2004, a short term dataset with averaged monthly gridded rainfall data from 1999 through 2005 and two datasets were created with monthly gridded rainfall data from 2006 and 2007 during which RVF activity was reported in Kenya. For Madagascar a long term dataset was created with averaged monthly gridded rainfall data from 1982 through 2004, a short term dataset with averaged monthly gridded rainfall data from 1999 through 2007 and two datasets were created with monthly gridded rainfall data from 2008 and January through July of 2009 during which RVF activity was reported in Madagascar. For South Africa a long term dataset was created with averaged monthly gridded rainfall data from 1982 through 2004, a short term dataset with averaged monthly gridded rainfall data from 1999 through 2007 and two datasets were created with monthly gridded rainfall data from 2008 and January through July of 2009 during which RVF activity was reported in South Africa.

Time series analysis was used to identify the nature of the phenomenon represented by the sequence of observations requiring that the pattern of observed time series data is identified and more or less formally described. In order to complete time series for the temperature and rainfall data time series mean (x) monthly values for all datasets is calculated and graphed for the countries of Kenya, Madagascar and South Africa using Excel 2007. Geographic information systems analysis is used to map the location of outbreaks in Kenya, Madagascar and South Africa and create rainfall maps to compare rainfall rates in the outbreak areas during the RVF outbreaks and compare rates to long term and short term datasets created.

Geographic information systems

Long term, short term and datasets during outbreaks were added into a personal geodatabase using Arc Catalog 9.3 before being added into Arc Map 9.3. Outbreak data collected from the World Animal Health Information System for Kenya, Madagascar and South Africa was geocoded based on latitude and longitude of specific administrative boundaries. Shapefiles for Kenya, Madagascar and South Africa were obtained from the Center for Disease Controls (CDC) EpiInfo and were added into Arc Map 9.3. For Kenya 132 grid points were overlaid on the Kenya shapefile, for Madagascar 216 grid points were overlaid on the Madagascar shapefile and for South Africa 391 grid points were overlaid on the South Africa shapefile.

The first data set consisted of monthly data from 1982 through 2004 with rainfall amounts for each month for the countries of Kenya, Madagascar and South Africa individually. A total of 36 maps for rainfall (rain) was created for the long term dataset ((Kenya * 12 months * rain) + (Madagascar * 12 months * rain) + (South Africa * 12 months * rain) = 36 maps)). A second data set was created consisting of monthly data from the years 1999 through 2005 for the country of Kenya and a third dataset was created consisting of monthly data from the years 1999 through 2007 for the countries Madagascar and South Africa with rainfall events for each month to represent the short term datasets. For the short term dataset for Kenya a total of 12 maps were created (Kenya * 12 months * rain = 12 maps) and for the short term datasets for Madagascar and South Africa a total of 24 maps were created ((Madagascar * 12 months * rain) + (South Africa * 12 months * rain) = 24 maps)). The outbreak in Kenya under analysis occurred in 2006 and 2007 therefore two separate datasets were created for each of these years for a total of 24 maps ((Kenya * 12 months * rain) + (Kenya * 12 months * rain) = 24 maps)). The outbreaks in Madagascar and South Africa under analysis occurred in 2008 through 2009 and therefore four datasets were created resulting in a total of 48 maps created ((Madagascar * 12 months * rain) + (Madagascar * 12 months * rain)+ (South Africa * 12 months * rain) + (South Africa * 12 months * rain) = 72 maps = 48 maps)) . Maps were created using Arc Map 9.3 with a resulting 144 maps created for geographic information systems analysis.

The created maps were analyzed for each outbreak area to discover the rainfall amounts for that particular grid point covering outbreak area for the months the outbreak occurred in that area. For most areas results were presented at the 3 inches range for rainfall data.

Statistical analysis

Statistical analysis was used to determine 99% Confidence Interval (CI) and statistical significance for the short term datasets and datasets during outbreaks for Kenya, Madagascar and South Africa. For the purposes of this study the 99% CI values is used to determine whether or not a rainfall anomaly had occurred. Monthly mean values for each month from January 1999 through July of 2009 for Kenya, Madagascar and South Africa were obtained. A positive rainfall anomaly indicates a mean value higher than the average while a negative rainfall anomaly indicates a mean value lower than the average. GIS analysis was first used to determine if an above average amount of rainfall had occurred at the beginning of the Rift Valley fever outbreak in each perspective country. If GIS analysis signified that an above average rainfall amount had occurred, analysis was run on the dataset beginning with the year 1999 through the year prior to the outbreak. If it was not signified by GIS analysis that an above average rainfall amount had occurred at the beginning of the Rift Valley fever outbreak, statistical analysis was run on the dataset beginning with the year 1999 and through the last year of the outbreak to determine when rainfall anomalies had occurred during and before the outbreak.

Statistical analysis was run in Microsoft Excel 2007 using calculated standard deviations and an alpha level of .01 to determine 99% confidence intervals for the 1999-2005 Kenya dataset, 1999-July 2009 Madagascar dataset and the 1999-2009 South Africa dataset. Values falling underneath lower end of confidence intervals were considered negative rainfall anomalies and values falling above higher end of confidence intervals were considered positive rainfall anomalies.

RESULTS AND DISCUSSION

Time series

Prior to the 2006-2007 Rift Valley fever outbreak rainfall rates were highest in the month of May and lowest in March and August according to the long term (May x=10.89; March x =2.02; August x=1.91) and short term dataset (May x=10.59; March x=2.29; August x=2.80). In the year 2006 although rainfall rates were highest in May an above average amount of rainfall was found in the month of October, November and December (October x=7.70; November x=14.54; December x=7.44) as compared to the long term (October x=2.41; November x=5.14; December x=11.31) and short term dataset (October x=2.92; November x=5.11; December x=7.22). In 2007 rainfall rates in Kenya were relatively stable with May (May x=9.78) being the month with the highest amount of rainfall and August (August x=2.94) the lowest amount of rainfall. On average mean rainfall tends to be highest in the month of May and November and lowest in March, July, August and September. Time series graph for rainfall for the long term dataset (1982-2004), short term dataset (1999-2005) and for the years of the outbreak (2006, 2007) is described in Figure 1.

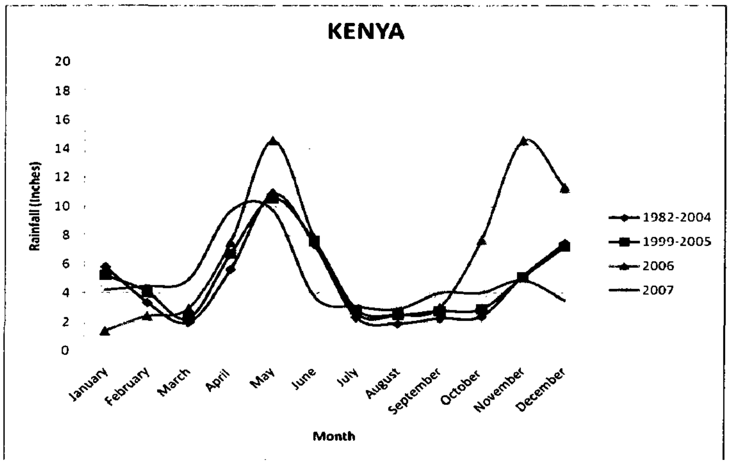


FIG 1: Monthly rainfall in Kenya for long term dataset (1982-2004), short term dataset (1999-2005) and the years of the Rift Valley fever outbreak (2006, 2007)

In the long term (1982-2004) and short term (1999-2007) dataset for Madagascar rainfall was highest in the month of February ((x=24.799(long term); x=23.00(short term)) and lowest in the month of October ((x=1.0(long term); x=1.40(short term)). Although in 2008 and 2009 rainfall was highest in January ((x=18.16(2008); x=17.91(2009)) this was not an unusual amount of rainfall for January as compared to the long term (January x=17.33) and short term (January x=18.10) dataset. March and April of 2008 reported a substantially lower amount of rainfall as well as February of 2009. A mean of 8.64 was reported in March of 2008, 6.07 in April of 2008, and 13.18 in February of 2009 while a mean of 17.55 in March and April in the 1982-2004 dataset and 16.71 in March and 16.83 in April in the short term dataset. Time series graph for rainfall for the long term dataset (1982-2004), short term dataset (1999-2007) and for the years of the outbreak (2008, 2009) for Madagascar is described in Figure 2.

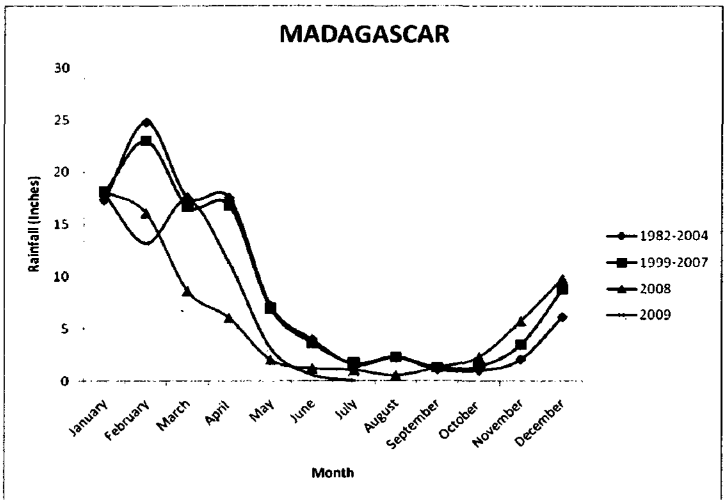


FIG 2: Monthly rainfall in Madagascar for long term dataset (1982-2004), short term dataset (1999-2007) and the years of the Rift Valley fever outbreak (2008, 2009)

In the long term (1982-2004) and short term (1999-2007) the highest amount of rainfall was in March ((x=7.36(long term); x=7.17(short term)) while in 2008 and 2009 the highest amount of rainfall was found to be in the month of January ((x=7.78(2008); x=7.91(2009)). July was found to have the lowest amount of rainfall in the long term (July x=1.54) and short term (July x=1.52) dataset and October was found to have the lowest amount of rainfall in 2008 (x=2.31). No month in 2008 was found to have an unusually high or unusually low amount of rainfall when compared to the short term and long term dataset. June of 2009 reported a high amount of rainfall while July of 2009 reported a lower than normal amount of rainfall. . Time series graph for rainfall for the long term dataset (1982-2004), short term dataset (1999-2007) and for the years of the outbreak (2008, 2009) for South Africa is described in Figure 3.

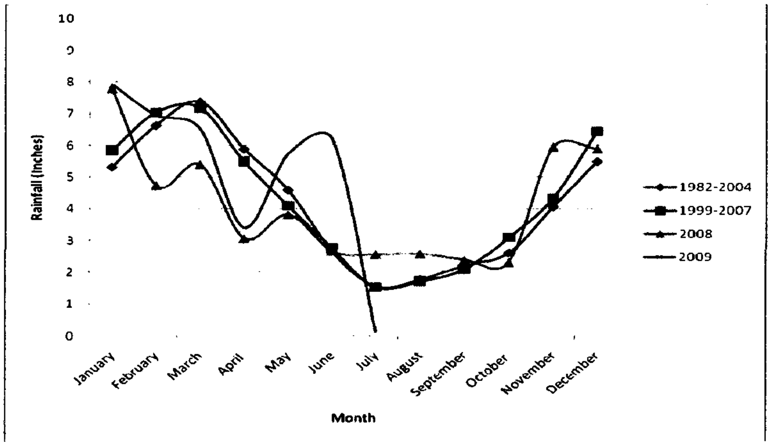
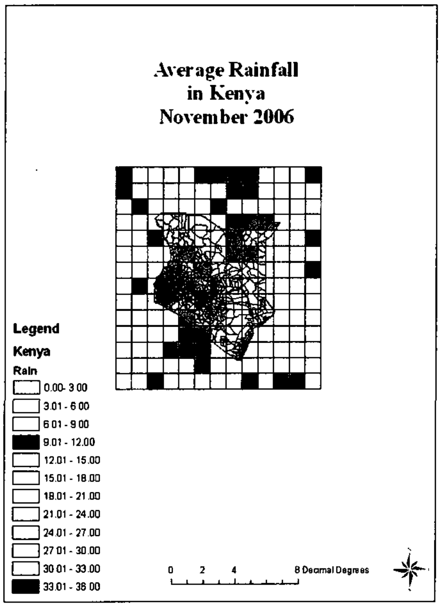
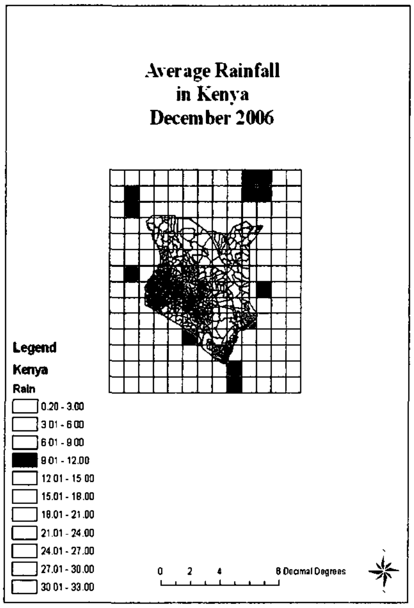


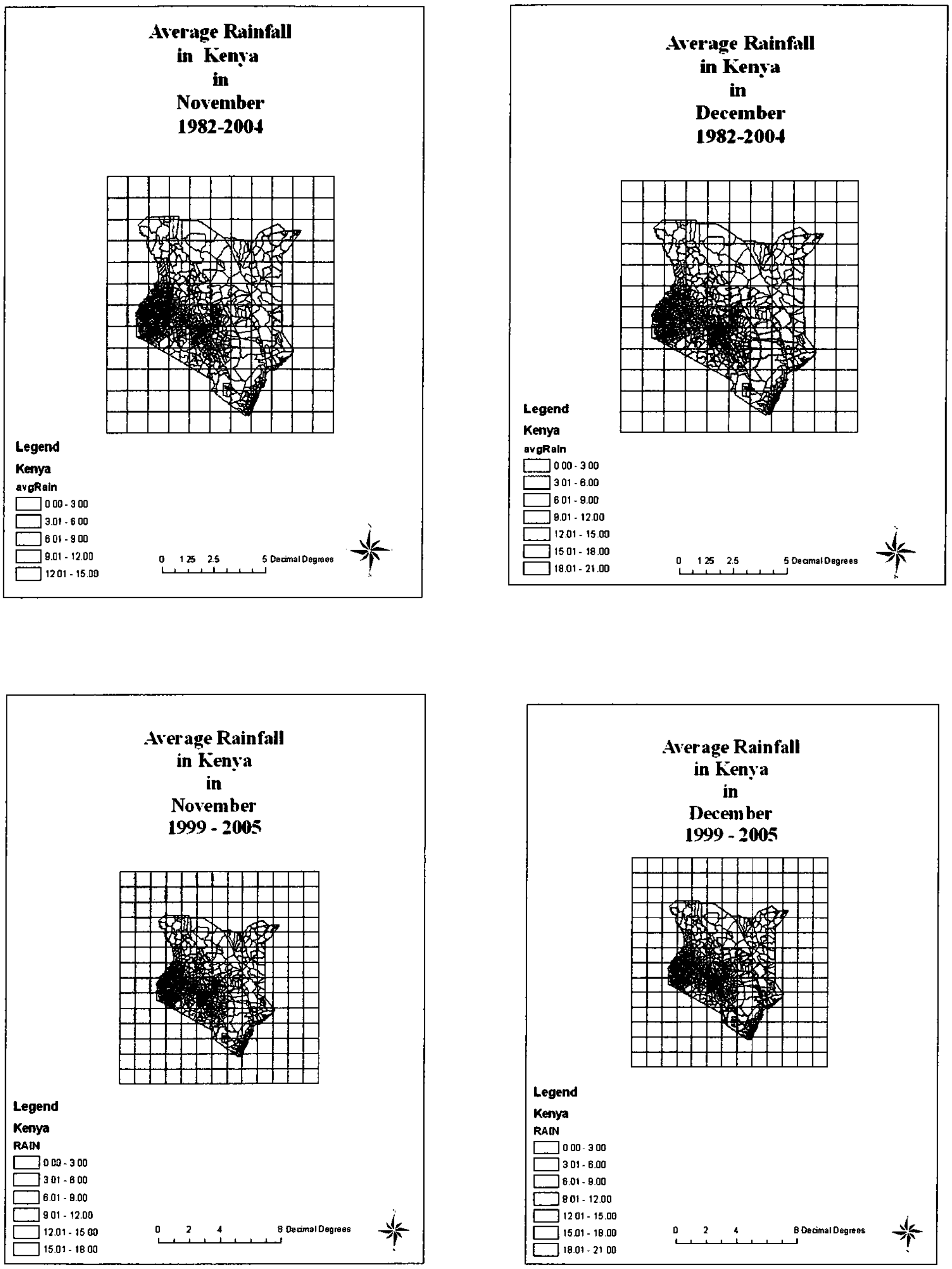
FIG 3: Monthly rainfall in South Africa for long term dataset (1982-2004), short term dataset (1999-2007) and the years of the Rift Valley fever outbreak (2008, 2009)

Geographic information systems

Despite a Rift Valley fever outbreak in Kiambu, Kenya that began in February 2006 and ended in April 2007 most RVF animal outbreaks occurring in Kenya began in December of 2006 and ended in April of 2007. Human RVF outbreak activity began in November of 2006 and ended in March of 2007 according to the WHO. GIS analysis showed heavy and widespread rainfall to have occurred in November and December of 2006 thus showing a relationship may exist between rainfall and Rift Valley fever outbreaks. Figure 4 shows GIS gridded rainfall maps for Kenya comparing rainfall rates in November and December of 2006 as compared to the short term dataset (1999-2005) and the long term dataset (1982-2004)






Average Rainfall in Kenya in November 1982-2004

Average Rainfall in Kenya in December 1982-2004

Average Rainfall in Kenya in November 1999 - 2005

Average Rainfall in Kenya in December 1999 - 2005

FIG 4: Geographic Information Systems (GIS) maps comparing rainfall amounts in Kenya for November and December for the long term dataset (1982-2004), short term dataset (1999-2005) and during years of outbreak in Kenya (2006, 2007)

Aside from an outbreak in the Antananarivo province that began in February of 2008 and ended in October of 2008 and an outbreak in the Vohitsaoko province that began in March of 2009 and ended in May of 2009, most Rift Valley fever animal outbreaks began in November or December of 2008 and ended by January of 2009 in

Madagascar. GIS analysis showed certain outbreak areas to have slightly higher rainfall rates at the beginning of the RVF outbreak in Madagascar but no heavy or widespread rainfall was found to have occurred during 2008 and 2009 in Madagascar. In South Africa this same phenomenon was found as well.

Statistical analysis

Kenya

Statistical analysis for Kenya was done from January 1999 through December of 2005. Statistical analysis was not perfomred on the years 2006 and 2007 during which an RVF outbreak occurred in Kenya due to the fact GIS analysis had shown a relationship to exist between rainfall and RVF activity in Kenya. Statistical analyis for Kenya was done solely for the purpose of discovering whether a ranfall anomaly could occur with no reported RVF activity. Results of statistical analysis signified positive rainfall anomalies for January of 2003, April of 1999, April of 2002, June of 2005, November of 2002, and December of 1999 yet no Rift Valley fever activity was discovered during these times. This signified that although rainfall may be a factor involved in RVF activity in Kenya it is cannot by itself predict outbreaks as positive rainfall anomalies can occur with no RVF activity.

Month	**Year**	**Mean**	**$CI_{.99}$**
January	2003	9.09	3.25-7.20
April	1999	12.10	4.42-9.06
June	2005	12.09	4.99-10.23
November	2002	7.54	3.42-6.81
December	1999	14.67	3.91-10.53

TABLE 1: Statistical analysis results showing higher than average mean rainfall amounts for Kenya for January 2003, April 1999, June 2005, November 2002, and December 1999. No Rift Valley fever activity was reported during of directly after these positive rainfall anomalies

Madagascar

GIS analysis showed no relationship between RVF activity and rainfall rates therefore furthur statistical analysis was done on data from January 1999 through July of 2009 to discover when positive rainfall anomlies had occurred during the time period of RVF activity and during the time period without RVF activity. Statistical analysis results showed that positive rainfall anomalies occurred in May and Septemer of 1999. In 2000 above average rainfall was discovered in March, July, August and September. In 2001 no above average rainfall amounts were discovered. In 2002 March and June were found to have above average amounts of rainfall. In 2003 February, March, and June were found to have above average amounts of rainfall. April of 2004 also had an above average amount of rainfall while 2005 had no above average amounts of rainfall. November and December of 2006 and January of 2007 had above average amounts of rainfall. No above average amounts of rainfall were discovered for 2008 or 2009 during which Rift Valley fever activity was reported.

Month	**Year**	**Mean**	**$CI_{.99}$**
January	2007	32.90	13.51-22.50
February	2003	32.22	17.43-26.84
March	2000	21.94	11.94-20.14
March	2002	23.72	11.94-20.14
March	2003	22.22	11.94-20.14
April	2004	21.07	11.70-19.01
May	1999	10.06	3.80-8.48
June	2002	6.07	1.55-4.68
June	2003	6.34	1.55-4.68
July	2000	5.80	.20-2.74
August	2000	9.69	.28-4.48
September	2000	3.19	.41-2.13
September	1999	3.16	.41-2.13
November	2006	10.77	1.34-6.06
December	2006	19.67	4.35-13.36

TABLE 2: Statistical analysis results showing higher than average mean rainfall amounts for Madagascar for January 2007, February 2003, March 2000, March 2002, March 2003, April 2004, May 1999, June 2002, June 2003, July 2000, August 2000, September 2000, September 1999, November 2006 and December 2006. No Rift Valley fever activity was reported during of directly after these positive rainfall anomalies

South Africa

Since GIS analysis showed no relationship between RVF activity and rainfall rates furthur statistical analysis was done on data from January 1999 through July of 2009 to discover when positive rainfall anomalies had occurred during the time period of RVF activity and during the time period without RVF activity. Statistical analysis results concluded that positive rainfall anomalies had occurred in 1999, 2000, 2001, 2002, 2006 and 2007, and 2009. In 1999 December was found to have positive rainfall anomaly. In 2000 January, February, March, and April were found to have above average amounts of rainfall. In 2001 May displayed above average amounts of rainfall. In 2002 August and September showed above average rainfall amounts. In 2006 February was found to have above average amounts of rainfall and in 2007 October and November were discovered to have above average amounts of rainfall. No Rift Valley fever was reported during these times. In 2008 and 2009 when Rift Valley fever activity a positive rainfall anomaly was discovered in June of 2009 but no other month.

Month	Year	Mean	$CI_{.99}$
January	2000	9.09	4.79-7.54
February	2000	10.24	4.6-8.39
February	2006	10.45	4.6-8.39
March	2000	14.75	4.54-9.36
April	2000	11.22	3.29-6.86
May	2001	7.11	3.10-5.33
August	2002	3.51	1.09-2.5
September	2002	3.81	1.44-2.79
October	2007	4.77	2.26-3.77
November	2007	6.23	3.59-5.40
December	1999	11.83	4.34-8.42

TABLE 3: Statistical analysis results showing higher than average mean rainfall amounts for South Africa for January 2000, February 2000, February 2006, March 2000, April 2000, May 2001, August 2002, September 2002, October 2007, November 2007, and December 1999. No Rift Valley fever activity was reported during of directly after these positive rainfall anomalies

Month	Year	Mean	$CI_{.99}$
June	2009	6.19	1.99-4.12

TABLE 4: Statistical analysis results showing higher than average mean rainfall amount for South Africa for June of 2009. Rift Valley fever activity was reported from January 2008 through May 2009.

CONCLUSION

As has been described in previous studies in Kenya rainfall activity seem to a factor with RVF outbreak as the RVF outbreak occurring in Kenya in 2006-2007 began after widespread and heavy rainfall that occurred in November and December of 2006. Statistical analysis showed positive rainfall anomalies can occur in Kenya without any RVF activity reported. This signifies that although rainfall does play a role in RVF activity in Kenya many other variables are at play and heavy and widespread rainfall does not automatically signify an RVF outbreak. In Madagascar and South Africa although rainfall was present during their outbreaks it was neither heavy nor widespread and often less than or equal to normal amounts of rainfall for these areas was reported. Rainfall therefore cannot be used as a factor in predicting RVF activity in countries such as Madagascar and South Africa as it has been used in Kenya. This study signifies that further studies need to be done in order to understand the variables that play a role in Rift

Valley fever outbreaks in countries such as Madagascar and South Africa. This will allow for further refinement of predictive models for RVF activity and thus better containment of the disease.

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VITA

EDUCATION

Ph.D. in Health Services Research, College of Health Sciences, Old Dominion University, Norfolk, VA. Dissertation: A GIS Analysis of the Environmental Variables Related to Rift Valley Fever Outbreaks. May 2010

Master of Public Health, Eastern Virginia Medical School, Norfolk, VA. 2006.

Bachelor of Science, Biology, Old Dominion University, Norfolk, VA. 2004.

WORK EXPERIENCE

2010-Present	Optima Healthcare, Virginia Beach, Virginia, Information Architect
2009-Present	Regent University, Virginia Beach, Virginia, Adjunct Professor
2008-2010	NASA Langley Research Center, Hampton, Virginia, GIS Technician

HONORS AND AWARDS

University Graduate Fellowship, Old Dominion University	2009-2010
University Graduate Assistantship, Old Dominion University	2006-2009