Investigating the impact of climate variability and climate change on tick borne diseases in Chiredzi District

By

Miriam Fadziso Gavera

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Supervisor Dr E Mashonjowa

The Department of Physics
Faculty of Science
University of Zimbabwe

Abstract

The impact of climate variability and climate change on tickborne diseases in Chiredzi District was investigated. Ticks are responsible for several diseases (tickborne diseases) that significantly affect livestock, especially cattle. The treatment of tickborne diseases and the resulting secondary infections result in very high economic losses in cattle production. Ticks attach themselves on the cattle and this causes irritation and this affects the feeding of cattle resulting in reduced milk production and poor meat quality. Several methods have been developed in tick control, however a more climate based method is required especially where climate variability and change are significant. A climate based method if combined with the already present methods like the use of acaricides and vaccines allows better resource use and more efficient disease management. The research used historic climatic data provided by the Zimbabwe Meteorological Services Department (ZMSD). The data included total monthly precipitation, maximum and minimum temperature values. The data was used to construct time series graphs which showed that generally rainfall is on the decrease while temperature has increased for the periods 1965/66 – 2007/08 and 1979-2007 respectively. Data on tickborne disease incidence was obtained from the Department of Veterinary Services Zimbabwe (DVSZ) as collected by local farmers at household level. Downscaled climate data from Global climate models were used to make future climatic prediction for the period 2046-2065 using the Climate Change Explorer Tool. Regression analyses as well as RMSE analysis were done to assess model efficiency. The models performed better in predicting minimum and maximum temperatures with R^2 values of about 0.80 and 0.6 respectively. However the models were very poor in predicting rainfall values. An epidemic risk model was developed relating temperature and rainfall to disease occurrence incidence. An equation y=0.451x+2.013 was developed where y is the disease incidence and x is percentage epidemic risk which is derived from the equation

The equation relates temperature (T) and rainfall (R) data to percentage epidemic risk. From the data given the epidemic risk model was validated for its ability to predict disease occurrence using previously recorded data. The R^2 value for observed disease occurrence against the disease occurrence values predicted by the model was R^2= 0.589.

KEYWORDS

Ticks; tickborne diseases, climate change; climate variability

Dedications

To my daughter Chenesai Janet Moyo, even at my worst I know I am still your best, you give me strength to wake up every morning; I cannot imagine life without you.

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Lastly to my family, you showed me the real meaning of true love, God bless you.

Glossary of abbreviations

CCE	**:** Climate change explorer
CSAG	**:** Climate systems analysis group
CwDCC	**:** Coping with drought and climate change
DVSZ	**:** Department of Veterinary Services, Zimbabwe
ER	**:** Epidemic risk
GAMP	**:** Guide to Agricultural Meteorological Practice
GCM	**:** Global Climate Models
GHG	**:** Green house gases
IPCC	**:** Intergovernmental Panel on Climate Change
LTM	**:** Long term mean
NEWU	**:** National Early Warning Unit
RCM	**:** Regional climate models
RMSE	**:** Root mean square error
SADC	**:** Southern Africa Development Community
SRES	**:** Special report on emission scenarios
TBD	**:** Tick borne diseases
USAID	**:** United states Agency for International Development
ZMSD	**:** Zimbabwe Meteorological Services department

Glossary of terms

Acaricides- these are pesticides that kill ticks and mites

Climate variable- refers to a measure of the climate for example temperature or precipitation

Disease outbreak- the occurrence of a disease in excess of what is normally expected in a defined community

Downscaling- a strategy used in generating locally relevant climate data from GCM at resolution of less than 50km

Endemic- refers to a disease that is constantly present in a production system and can only be eliminated with very intensive efforts.

Epidemic- refers to diseases occurring in a region or community in excess of expectancy

Epidemic risk- refers to the probability of an epidemic occurring and it is expressed as a percentage

Forecasting- to predict future state or condition of a given entity in this case weather and disease occurrence

Greenhouse gas- refers to a gas that is fairly transparent to solar radiation but efficient at absorbing long wave radiation emitted from the earth surface as well as from the atmosphere

Tick borne diseases- diseases that are caused by pathogens carried by ticks

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CHAPTER 1

1.0 Introduction

1.1 Background

Weather and climate both influence animal production as well as agronomic production directly and indirectly, (WMO, 2010). Weather refers to the actual state of the atmosphere at a particular time while climate is the average weather pattern over a long period and it is described in terms of mean values of weather variables for example temperature, precipitation and wind patterns means, (Intergovernmental Panel for Climate Change, IPCC, 2007) . Weather and climate directly influence crop growth, development and yields, water needs of both plants and animals, fertilizer requirements and indirectly influence the incidence of pests and diseases, (WMO, 2010).

In Zimbabwe ticks are common pests in animal production. Ticks are small insects that are present throughout the world and are numerous in the Tropical and Subtropical areas of the world, (Bram, 2001). This is because ticks require warm temperatures and humidity for their metamorphism and development. They are cold blooded vectors that are ectothermic in nature, that is, they are very sensitive to environmental climatic factors. They are blood sucking parasites whose hosts include domestic and wild animals as well as humans (Karanja, 2009).

Tick borne diseases were not a problem for Zimbabwean indigenous livestock breeds like the Nguni and Tuli until the 1890s, when exotic breeds were introduced (Maham, 1999). Tick borne diseases are diseases spread between animals by the bite of an infected tick. The most common tickborne diseases in Zimbabwe are Babesiosis (red water), Anaplasmosis (gall sickness), Theileriosis (January disease), Cowdriosis (heart water) and tick worry. Ticks become infected by feeding on either already sick animals or healthy animals that have the parasite in their blood (carriers), (Turton, 1999) and pass on the pathogens to healthy animals when they feed on their blood. Ticks can host bacterial, viral and protozoan and other disease causing agents more than any other vector, and because ticks can harbor more than one disease causing agent at the same time, they can infect an animal with several pathogens at the same time making disease diagnosis very difficult, (Sonnershine, 1991).

According to the Intergovernmental Panel on Climate Change (IPCC, 2007), Fourth assessment report, climate change contributes to the global burden of diseases and premature deaths in both animals and humans. This increase in disease occurrence can be attributed to changes in the abundance, dynamics and geographical distribution of many vector borne diseases including tick bone diseases, (Lindgren, 1998). Because ticks spend more of their time in the environment than on the host, climate change is most likely to affect their distribution, abundance and subsequently the incidence of tick borne diseases, (Gray et al, 2009). The proliferation of ticks depends intimately on climate as well as an appropriate animal host population for reproduction, survival and population establishment, (Olwoch,et al 2009).

1.2 Problem statement

The temperature and rainfall patterns in Zimbabwe and in the World have been changing most over the past two decades (IPCC, 2007) and this has affected the ecosystem, development and distribution of organisms. The IPCC report also claims that among other consequences climate change will change the range of some infectious disease vectors.

1.3 Justification

Ticks result in high economic losses involved in preventing and controlling tick borne diseases as well as treatment of secondary infections. Globally losses of US$13.9 to US$18.7 billion per year are estimated and over 800 million cattle are exposed to ticks and tick related threats, (Karanja, 2009). In Zimbabwe heart water alone has an estimated economic loss of US$ 5.6 million over 10 years with the cost of acaricides only at 76%, followed by 18% in milk loss and 5% in disease treatment, (Mukhebi *et.al*, 1999). This led to the establishment of the Heart water research project in the country.

Ticks cause tick borne diseases and irritation (tick worry) in cattle and this affects the feeding behavior of animals reducing animal productivity, that is poor quality meat and hides are produced as well as low milk quantity and quality. The rapidly rising costs of tick control make it important to consider the economies of strategies for control ticks and tick borne diseases.

Increasing world population and more rural to urban migration has led to an increase in world meat demand hence the shift to more intensive animal production system to meet the demand. This therefore calls for an improved animal disease management system and this can be done by complimenting early warning systems and better disease management practices, (D'Silva, 2000)

This study aims at developing a model that can then be used by the National Early Warning Unit (NEWU), veterinary personal and farmers to forecast the possible occurrence of tick borne diseases in their area using climatic data so that the most suitable control method can then be implemented in order to avoid tick borne disease outbreaks. Forecasting tick borne diseases will present an important approach to the sustainable control of insects, parasites and pest related diseases, (Wall and Pitts, 2007) and allow the deployment of disease control measures only when the weather conditions are suitable for a tick borne disease outbreak. Such disease early warning systems reduce the need for prophylactic insecticide use reducing production costs and save farmers and the nation money, (Goulson et al, 2005). Disease forecasting reduces uncertainties thus allows better use of resources and better disease management (Githeko and Ndegwa, 2001).

1.4 Objectives and hypothesis

Overall objective

The main objective of the study is to investigate the impacts of climate variability and change on the prevalence of tick borne diseases in Chiredzi district in Zimbabwe.

Specific Objectives

- To develop a mathematical model that can be used to predict the occurrence of tick borne diseases using climate variables for Chiredzi District
- To outline appropriately downscaled global climate change models with resolution adequate for local level climate projections in Chiredzi District
- To determine the potential impacts of climate change and climate extremes on disease dynamics in Chiredzi District through the use of the prediction equation (model) and the projected climate.

Hypothesis

H_o: Climate variability and change have no effect on tick borne diseases in selected communities in Chiredzi District.

1.5 Expected Benefits of the study

The study is expected to produce a mathematical model that uses projected weather conditions to forecast the possible occurrence of tick borne diseases outbreaks and send out early warnings to farmers in order to avoid high losses which are incurred in treatment of affected cattle as well as losses due to reduced productivity by diseased animals. This may also mean revising the present dipping regime being used by the Department of Veterinary Services Zimbabwe. According to Barnett, (1974), better global control of tick borne diseases of livestock and their vectors would also contribute substantially to improved meat and milk production hence more income to livestock farmers. The study is also expected to improve on the methods of tick disease control already being used, as prevention is always better than cure.

CHAPTER 2

2. Literature review

2.1 Introduction

This chapter summarizes the effects of climate change on animal health and the impact of climate on ticks and tick borne diseases. The different tick borne diseases, their signs and symptoms are also described as well as the development of ticks through their stages of growth. Five global climate models and their predictions of future climate scenarios are also described. The study site of the project is Chiredzi district. The agricultural production activities in this district are also described in this chapter.

2.2 Ticks in Zimbabwe

Ticks are a hazard in livestock production as they have the following impacts; tick-borne disease transmission, tick paralysis and toxicity and also tick caused physical damage. They also cause irritation (tick worry), damage to animal hides and predispose the animals they attack to other bacterial and fungal attacks as well as screw worm attack, (Walker, 1997). Disease transmission occurs when a tick bites an infected animal, feeds on its blood and then bites an uninfected animal. Ticks are responsible for great economic losses in animal production and are regarded as the worst animal health problem in Africa, (Karanja, 2009). Most governments in Africa have implemented several methods in order to control the effect of ticks and tick borne diseases in cattle production by establishing and maintaining dipping tanks, spraying as well as the use of acaricides. However these tick control methods and the labour involved in tick prevention also add greatly to the production cost of cattle production.

Even though climatic factors may increase disease transmission the outcome of clinical signs depends on the level of immunity and the response to treatment and the effectiveness of the treatment,(Githeko and Ndegwa, 2001). The proliferation of tick borne diseases can therefore be attributed to the following animal related factors or vulnerabilities that increase cattle's susceptibility to diseases.

- Type of breed- exotic *Bos taurus* cattle breeds like the Brahman are more susceptible to tick borne diseases than indigenous *Bos indicus* breeds like the Nguni and Tuli breeds
- Age of animal- older animals may easily suffer from tick borne diseases due to reduced immunity when compared to younger cattle
- Animals that are moved from disease free areas to high disease areas are more vulnerable to disease attack
- Cattle born in winter can be more easily attacked by tick borne diseases than animals born in summer. The latter will have already been exposed to the parasites at birth and will have developed natural immunity
- Poor cattle management, that is, poor nutrition and poor health practices contribute to animals' susceptibility to tick borne diseases

The risk of exposure of animals to infected tick bites depends on a wide range of environmental factors both biotic (tick and host distribution and abundance) and abiotic (climate and landscape features) as well as socio economic factors (use of acaricides and vaccines) and animal related factors (age and breed), (Sumilo et al, 2000).

The most common ticks in Zimbabwe are the blue ticks that is, *Rhipicephalus decolatus* and the *Rhipicephalus appendiculatus.* These two species are responsible for the diseases Babesiosis also known as red water, Anaplasmosis also called gall sickness and Theileriosis which is also known as January disease. These species usually prefer cattle as their main hosts though they can be found on horses, donkeys, sheep, goats and wild ungulates.

2.3 Anatomy and physiology of ticks

Ticks are of over 500 species worldwide, (Jacobs, 2012) and like most insects have bodies that are divided into two that is, the anterior known as the *capitalum* which has the head and the mouthparts and the posterior (*idiosoima*) which has the legs, digestive tract and reproductive organs. Adult ticks have eight legs which when not used for walking remain tightly folded against the body. The legs also have the sensory organ known as Haller's organ which is sensitive to temperature and air currents. The diet of ticks is heamathatophagy, that is, ticks feed on blood to satisfy all their nutritional needs. Ticks extract blood from their host by cutting holes in the epidermis and then insert their hypostome or feeding tube to draw the blood. They also excrete an anticoagulant in the process so that the blood does not clot as well as saliva with an anesthetic so that the host does not feel the pain of being bitten, (De'Silva, 2000)

Ticks can be classified according to body type hence there are of three types, that is, hard ticks (*Ixodidae*), soft ticks (*Argasidae*) and *Nuttalliellidae* ticks. Hard ticks have one long blood meal per developmental stage; they are close to 700 species and a female hard tick may have one batch of several hundreds of eggs at a time while soft ticks have several batches of tens of eggs per female. Soft ticks have almost 200 species and feed on several short blood meals per developmental stage. *Nuttalliellidae* ticks have only one species, (Vourc'h and Vial, 2008).

Ticks can be differentiated according to the number of hosts that they have during their lifecycle, that is,

- One host tick- ticks develop from the larva stage to adult stages only on one animal or organism
- Two host tick- tick drop off its host once the nymph has fed and find another host on which they develop into an adult tick
- Three host tick- the larva, nymph and adult all have different hosts,

The process of moving from an infected host to an uninfected host results in the transmission of disease causing pathogens between animals, this is the way in which ticks are involved in the spread of diseases.

2.4 The Life cycle of ticks

The life cycle of a tick begins after an egg hatches into a six legged larva which looks like an adult tick with two missing legs. The metamorphosis from the egg to the larval stage is affected by low temperatures which hinder this development. The larva seeks a host usually small mammals, rodents, birds or even humans in order to feed and grow. After feeding the larva drops to the ground to digest and begins to grow. The larva then begins to moult into a nymph. A nymph is a smaller version of an adult tick as it also has eight legs. Nymphs also feed on small mammals or humans and then fall to the ground to moult and develop into an adult tick. Some soft tick species will moult and feed several times before they finally grow into adult ticks.

The main function of adult ticks is to reproduce. Both the female and male ticks feed before mating and the female is usually bigger than the male tick. After mating the male tick usually dies while the female tick first lays its eggs before dying. The process by which hard ticks seek a host is known as questing and it is facilitated by the Haller's organ which is a unique sensory organ found on the legs that detects odors and chemicals released by the host as well as sensing changes in temperature and air currents in the environment, (Mehlhorn,2008)

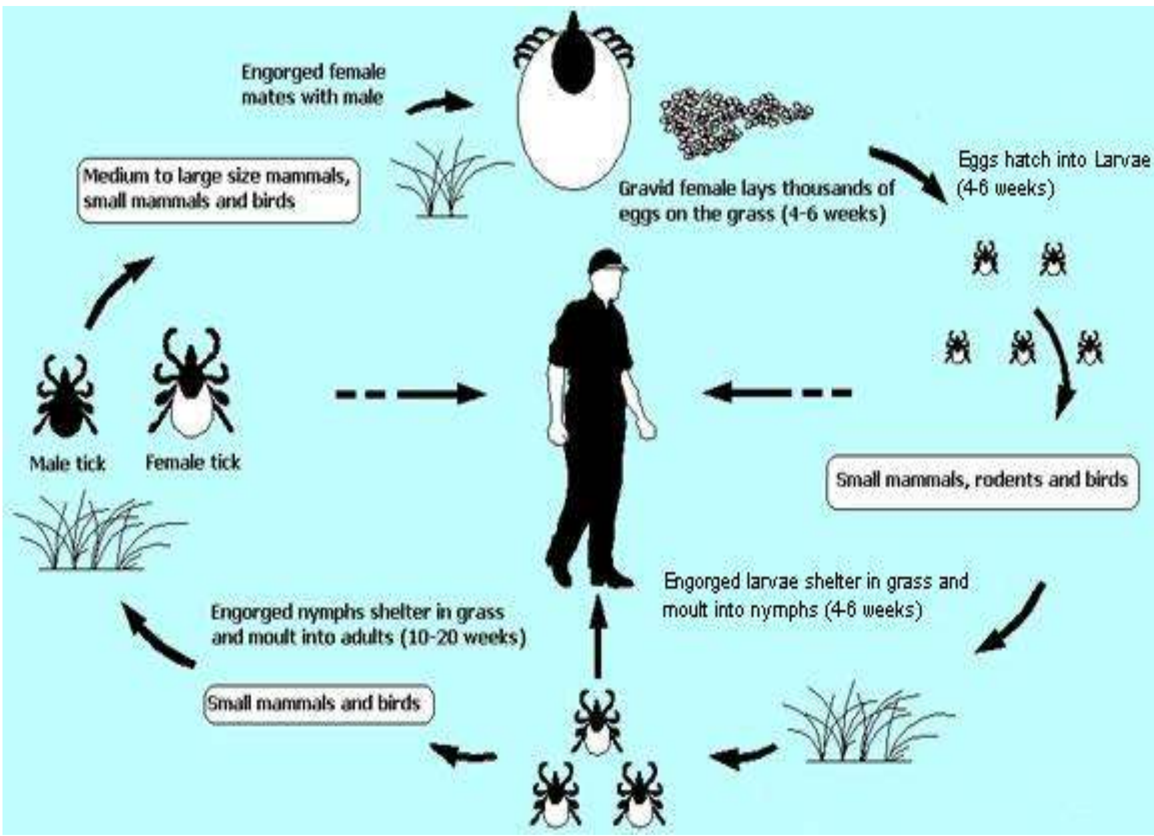

Figure 2.1 An illustration of the life cycle of ticks

Adapted from www.bada-uk.org/homesection/about/tick/lifecycle.php

2.5 Common tick borne diseases in Zimbabwe

2.5.1 Heart water

Heart water is an infectious non contagious disease of ruminants infected by *Erhliria ruminantium* formerly known as *Cowdria ruminantium.* The parasite initially reproduces in white blood cells (macrophages) and then invades and multiplies in blood vessel cells, (Kahn, 2005). Blood vessels will then leak out and fill the sack around the heart hence the name heart water. This condition is also known as hydropericadium. Heart water is a serious constraint of livestock development in Zimbabwe and Sub Saharan Africa. The disease is found in areas where ticks are present hence it is endemic in Africa and Caribbean Islands. Wildlife like the wildebeests in these areas are carriers and sustain the disease in nature. Large economic losses as a result of heart water in Zimbabwe led to the establishment of the heart water research project in Zimbabwe which is a partnership between University of Florida, USAID and SADC and its aim is to develop an inactivated vaccine (which does not require cold chain in transportation) for heart water disease, (Mukhebi *et.al* 1999). The use of the vaccine is meant to improve the traditional method of using chemical acaricides in controlling heart water and the tick vector. Chemical acaricides alone amount up to 76% of the production cost in commercial cattle production. Therefore the vaccine is a cheaper (in the long run) and a more sustainable method, (Mukhebi, *et.al*, 1999).

Clinical signs and symptoms of heart water are high fever and also lung oedema symptoms like difficulties in breathing.

Heart water occurs in 4 stages, that is,

- Para acute- this stage is rare and occurs in exotic breeds, for example Jersey and Guernsey breeds that are introduced into endemic areas. Heavily pregnant cows usually develop the para acute form of heart water. Clinical signs include fever, severe respiratory distress, convulsion and sometimes diarrhea especially in the Jersey and Guernsey breeds. This form results in sudden death (IOWA State University, 2006)
- Acute-most common condition characterized by respiratory distress, rapid breathing and nervous system signs which include excessive chewing, eyelid twitching, tongue protrusions and walking in circles with high stepping gait. Some animals even have convulsions and death occurs in less than a week, (IOWAS State University, 2006)
- Sub acute - a rare case and clinical signs include prolonged fever and coughing due to the presence of fluids in the heart. If recovery does not occur in 1-2 weeks the animal dies. (IOWA State University, 2006).
- Mild/ subclinical- most common in calves older than 3 weeks because animals younger than 3 weeks develop natural immunity to heart water. The sub clinical stage is

characterized by fluctuating fever known as heart water fever, (IOWA State University, 2006).

2.5.2 Babesiosis

Babesiosis is an infection of the red blood cells caused by single cell protozoa known as *Babesia*. It is transmitted by the black legged tick known as *Ixodes scapularis* (Kahn, 2005). The tick injects the protozoa into the blood stream of the host and it quickly invades the red blood cells and begins to divide eventually rupturing the cell. In extreme cases blood appears in urine (haemogloburiuria) hence the name Red water. Death may also occur in older animals. The disease has significant impact on animal productivity and fertility is also affected in cattle.

Other symptoms of Babesiosis include fever, fatigue and anemia. In addition Babesiosis results in diarrhea which after 36hours becomes constipation. In pregnant cows Babesiosis may cause miscarriages. In some cases the disease is present without symptoms, that is, asymptomatic and the disease can only be picked up during post mortem diagnosis, (Coetzer and Tustin, 2004). The main symptom of Babesiosis is red urine and death is very rare (NADIS, 2012)

2.5.3 Tick paralysis

Tick paralysis refers to the loss of muscle function that results when a tick bites. It is not a disease but a condition caused by toxins released from salivary glands of female ticks and injected into its host during feeding, (Mandell *et. al*, 2009) The toxins are neuro-toxins because they affect the function of the nervous system. Symptoms include unsteady gait, weakness in both legs that progresses to paralysis and the paralysis ascends to the trunk, head and this may lead to respiratory failure. Respiratory failure will ultimately lead to death, (Merk Sherp, 2011)

Removal of the ticks removes the source of the neuro toxins therefore recovery is most likely after ticks have been removed. This is usually done using acaricides. Smaller and younger animals are more at risk than older animals.

2.5.4 Anaplasmosis or Gall sickness

Gall sickness is caused by a rickettsial parasite *Anaplasma marginale* or *Anaplasma centrale* which spread from one animal to another not only through tick bites but also by biting flies and by blood on instruments and needles used for example during vaccination, injections, dehorning and castration. The parasite destroys red blood cells. Symptoms include fever, pale to yellow eyes and gums, trouble during walking and heavy breathing, constipation and eventually death. Post mortem diagnosis shows a large gall bladder filled with thick brownish-green bile and also yellowish carcass and a large spleen. Animals suffering from gall sickness should not be excited or allowed to move around because it may die therefore feed and water should be placed close to sick animals. Pregnant animals suffering from gall sickness should be closely monitored for abortions.

2.6 Prevention of tick borne diseases

Several methods of tick control have been developed and implemented in cattle production and some of these methods have their limitations. The methods of controlling tick borne diseases include,

- The use of more resistant indigenous cattle breed and their crosses. These breeds usually have low productivity (milk and meat yield) compared to pure exotic breeds
- Guinea fowls can also be used in natural tick control because the birds are known to consume ticks in mass quantities,(2 birds can clear 2 acres, 8100m^2 in one year), (Duffy et.al , 1992)
- The use of acaricides. Acaricides are chemicals that are used to reduce the number of the tick vector which in turn reduces disease transmission. Acaricides are the chemicals used in dipping and spraying to reduce the number of ticks. Acaricides and other chemicals used in tick control are usually very expensive, but are the most effective way of controlling ticks and tick borne diseases in most developing countries including Zimbabwe. Acaricides can be applied through spraying, dipping, spot on or pour on applications.
- Immunization using live vaccines which are injected intravenously into the blood stream. Live vaccines carry the risk of introducing diseases into disease free areas where vectors (ticks) may be present but diseases absent. Vaccines also follow a cold chain which may be difficult to maintain especially in rural areas where refridgerators are not easily accessible. This method cannot be used for pregnant cows as it causes abortion.

- Monitoring and prophylactic treatment to animals moved from disease free areas to endemic areas

(Adapted from Rushton *et.al*, 2002)

Current studies in tick control include the development of recombinant RNA vaccines which are more user friendly than the live vaccines. This study focuses on another tick borne disease control method which requires the use of forecasted meteorological information (early warning systems) to predict the possibility of an outbreak and couple this with the use of acaricides to prevent serious outbreaks.

2.7 Climate Change and animal health

Climate change is caused by a variety of factors but there is high confidence that human activities since 1750 have contributed to the global warming, (Intergovernmental Panel on Climate Change, IPCC, 2007). Science has proved that the climate is changing due to the increase in the concentration of greenhouse gases in the atmosphere as well as the natural variability that the atmosphere goes through. The IPCC (1997) has projected a temperature increase of between 1.4-5.8° C by the year 2100. Greater changes are expected over land as well as in the higher latitudes. The major impact of climate change on livestock health has been on diseases that are vector borne. Climate may also influence incidence of diseases indirectly by influencing animal distribution. As weather conditions become more arid, animal survival is compromised especially exotic breeds and only the harder crossbreeds (between exotic and indigenous breeds) as well as purely indigenous breeds survive. These breeds are more resistant to diseases thus reducing disease incidences.

Gray et al in 2009 defined climate suitability for a tick population as the fitness of a set of climatic conditions for the existence of that tick population in a given region of microclimatic factors including soil surface temperature, slope, aspect, vegetation cover and soils. These factors among others may be important in determining a suitable niche for a tick population. Climate change is expected to directly affect survival, activity and development of ticks. However there is not enough evidence that an increase in temperature will result in an increase in number of ticks by increasing rates of development, rather by making ticks available to new areas by changing the day length, (Gray, 2009)

Temperature change due to global warming is expected to affect all the major climatology processes in the atmosphere hence humidity, rainfall, wind, photoperiodism among other factors will be affected. Climate change does not act in isolation (Lindgren et al, 2010). It also results in changes in incidences and geographical distribution of diseases which are a result of climatic variables interacting with underlying vulnerabilities. Figure 2.2 shows the interaction of climate variables and other vulnerabilities in increasing disease occurrence.

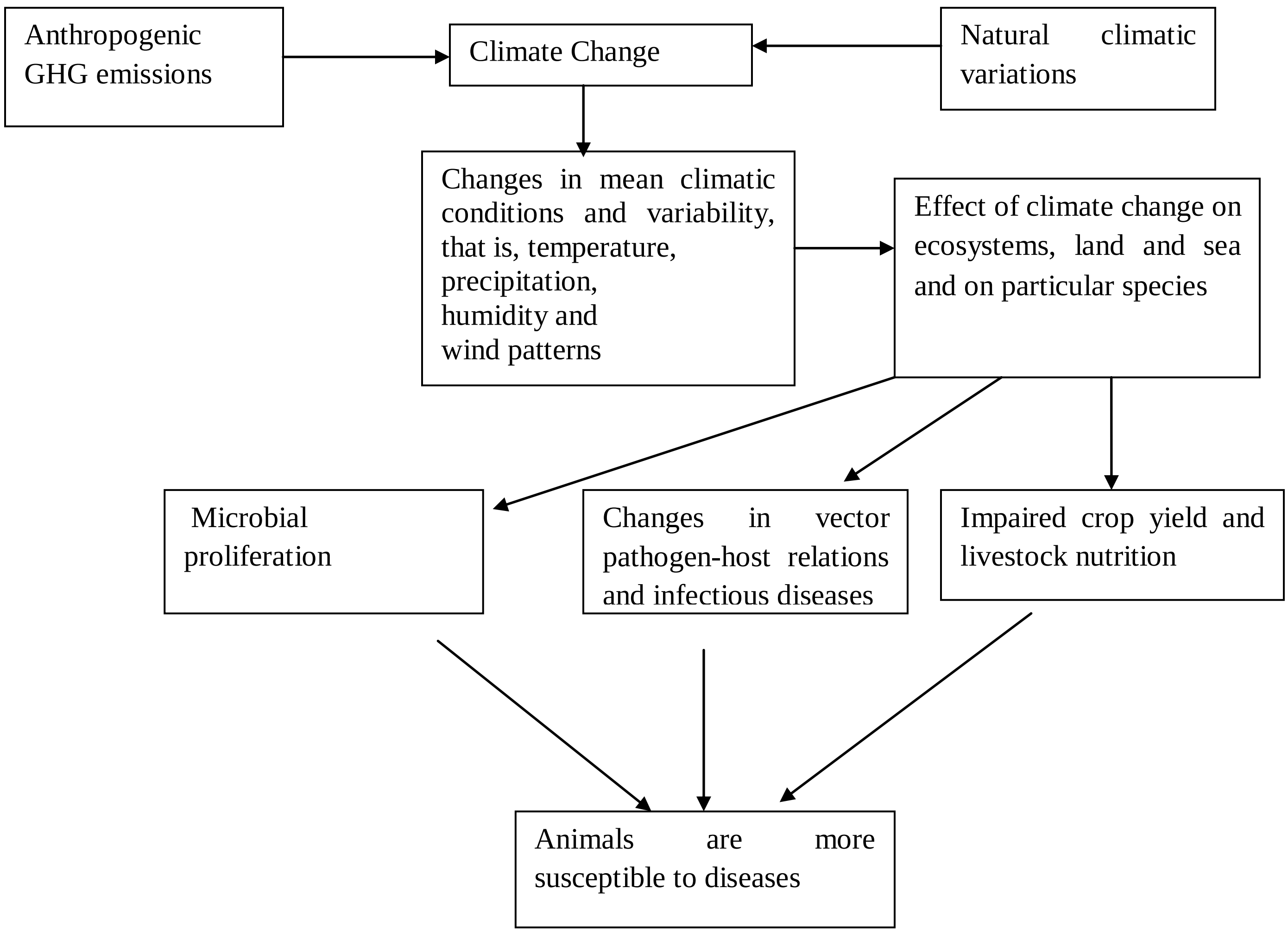

Figure 2.2 Summary of the effect of climate change on animal health

2.8 Climate and tick borne diseases

According to Olson and Patz, (2010), tick development and behavior and tick borne disease transmission is linked to climate cues. The onset period between the previously mentioned stages is known as diapause and it is affected by photoperiod which relates to latitude, (Olson and Patz, 2010). Temperature increases cause an increase in the biting rate of ticks thereby ensuring higher tick survival and tick activity. Randolph in 1997 showed that between 27 and 67% of larvae incubated at 40°C attached well to skin of cattle while only 0-6% larvae incubated at 25°C attached successfully. This shows that the higher the incubation temperature the better the chances of tick survival and the higher the chances of the ticks ability to transmit diseases.

Weather conditions may either promote the proliferation of pests and diseases or cause their decline directly or indirectly. Weather affects vegetation growth which provide a home for tick development and growth between feeding, (Palumbo, 2011). The most prolific weather conditions in tick development are temperature and moisture.

2.8.1 Temperature

Temperature is the major driving force behind growth, development and behavior of ticks. Because ticks are ectotherms their internal body temperature depends on the temperature of the environment. An experiment was carried out by Yano et al (2007) using controlled temperatures from 12-30°C at 100% humidity to monitor and investigate the critical temperatures for growth and development of ticks. The results showed that at 12°C, oviposition, egg hatching and moulting of larva did not occur. Generally low winter temperatures reduce egg production, prolong hatching, oviposition and incubation periods. Ticks and the pathogens they carry have a development threshold controlled by temperature; above this threshold temperature development is shortened. In addition global warming results in the once cooler latitudes, becoming warmer hence tick become more able to survive in the once cooler latitudes thus affecting the geographical distribution of ticks. During summer months temperatures are warm and the grass is green hence animals spend more time grazing and expose themselves to ticks moulting in the grass.

2.8.2 Moisture

Ticks do not require free water to survive as they obtain enough during feeding. However rainfall and relative humidity can influence growth and behavior of ticks, the latter affecting ticks' ability to lose water. Dry conditions affect incubation periods, larval survival and reduce hatching by 29-38%, (Sumilo et al, 2009). Relatively wet conditions make favourable tick habitats, however excessive rainfall and floods may be catastrophic as they wash away breeding sites. Table 2.1 shows a summary of the effects of climatic variables on tick borne diseases.

Table 2.1 A summary of the effects of other climate variables on tick borne diseases.

Factor	Adverse Effects	Beneficial effects
Temperature	Temperature rise may create conditions suitable for pathogen proliferation in areas previously unsuitable Temperature increase may introduce vectors and diseases in area where they did not exist. Further temperature increase leads to hypothermia in animals	Increase in temperatures above 30°C may lead to poor survival of ticks which is beneficial to the farmer.
Rainfall	Moist environments are suitable for vector and disease development Floods may cause death and injuries to animals reducing tick host Drought causes death of animals due to starvation and thirst (poor nutrition)	Too much/too little water may impair reproduction and survival of vectors (ticks) Rainfall extremes may cause failure of some pathogens and vectors to proliferate
Wind	Strong winds may lead to the introduction of pathogens into new areas	Strong winds may blow pathogen away thus reducing infection that can be carried by ticks

Reduced fodder yields	May cause the reduction in animal condition due to poor nutrition hence animals become more susceptible to diseases	Reduces the vegetation which houses vectors (ticks) before they find a host

2.9 Agriculture production in Chiredzi District

Chiredzi district is located in the Southeast low veld of Zimbabwe in Masvingo province. The district receives an average of 575mm of annual rainfall and average annual temperature of 22°C, (Unganai, 2008). Communal farmers practice semi-intensive agriculture growing maize and sorghum as the main cereals. Cotton, cowpeas, millet and sunflower are also grown. The district is the major sugar cane production centre in the country. Game ranching is also popular at Gonarezhou National Park and other conservancies in the district. Since most of the agricultural production is rain fed, it is greatly affected by low rainfall as well as the frequent mid-season droughts, (Unganai, 2008) that are experienced in the district.

2.9.1 Livestock production

Livestock production in Chiredzi District is dominated by goat, cattle and donkey rearing. During several field surveys conducted in the district by Mavedzenge et al in 2006, farmers were asked to rank cattle diseases according to importance and the results were as follows;

Table 2.2 Ranking cattle diseases according to importance in Chiredzi District.

Rank	Disease
1	Blackleg
2	Red water
3	Heart water
4	Gall sickness
5	Foot and mouth
6	Boils
7	Mastitis
8	Anthrax
9	Worms

10	Eye infections
11	Lumpy Skin

Source: Mavedzenge et al 2006

Table 2.2 shows that tick borne diseases in the form of heart water, red water and gall sickness (ranked 2, 3 and 4) have a huge impact on cattle production in Chiredzi district. This impact is attributed to a reduction in dipping frequency with many dips not functioning due to lack of water, dipping chemicals and maintenance, (Mavedzenge et al, 2006). In resettlement areas dips if available are too far for the new settlers to dip frequently and there is lack of finance and institutional support to install dips, for example in May 2005 the veterinary services department had one working vehicle being shared among 114 workers on ground, (Unganai, 2008).

Some farmers who can afford buy dipping chemicals and with the knapsacks they use in cotton spraying to

spray their animals for ticks. This however is an expensive process and in most cases farmers are not aware on how much chemical they are supposed to use since the farmers lack any formal training in animal health, (Mavedzenge, *et.al* , 2006). Even though spraying is expensive it saves animals from diseases as well as farmers from the more expensive disease treatment, (Mavedzenge *et.al*, 2006). Some farmers have even resorted to using home remedies to treat tick borne infections. Common home remedies are outlined in table 2.3 below.

Table 2.3 Home remedies for tick borne diseases

Tick borne Disease	Home remedy
Gall sickness	Give cattle cooking oil mixed with warm water
Red water (*Weti ineropa*)	Mix *nhundurwa* fruits with *murumanyama* bark and boil. Give animals to drink
	Mix donkey dung with water and give animals to drink
	Mix *hora yedamba*, *masoso* leaves in water and give animals to drink
	Crush *mufandichimuka* stem and bark, soak in water and let animals drink

Heart water	Take soot formed in kitchen roof and mix with salt before giving animals

Source: Mavedzenge *et.al*, 2006

2.10 Global climate models (GCMs)

Decision makers and policy makers require information about future changes in climate in order for them to be better prepared for potential impacts of climate change, (White et al, 2009). This information can be obtained using Global Climate models. Global climate models (GCMs) are a group of computer generated simulations that are used to forecast present weather, understand weather patterns as well as predict future weather and climate trends, (Environews, 2012). They represent processes on the earth's surface and simulate the effect of climate system response in the global setting, (IPCC-TGICA, 2007). Several GCMs are available for use and one has to be critical before selecting a specific model.

2.10.1Selecting GCM to use

The following points have to be considered when one is selecting the GCM to use in making future climate predictions.

- Vintage- recent models are usually more reliable than older ones because they incorporate the latest knowledge in their constructions and they are built on strengthening the weakness of older models
- Resolution- recent models have finer resolution than older ones. High resolution models have more spatial detail than low resolution ones for example they show the effect of topography and also processes like El Nino Southern Oscillation (ENSO). However high resolution does not necessarily guarantee better model performance
- Accurate-models should adequately simulate present day conditions
- Validity-model validity is determined by comparing observed data with simulated data. This can also be done by up scaling observed data to a GCM grid size and compare the data with GCM simulated data

- Representativeness of results- results from more than one GCM should be applied in an impact assessment so that a range of changes and adaptation mechanisms can be illustrated and uncertainties get reduced
- Accessibility-models should be straight forward to obtain, interpret and apply

(White *et.al*, 2009)

2.10.2 GCM simulation scenarios

GCMs simulate the interactions of the atmosphere, oceans, land and snow surfaces and the interaction between them to study the dynamics of the climate system and then project into the future. In order to determine how climate may change in the future the concentration of atmospheric components which affect the Earth's energy balance have to be known, (CCIS, 2005). These interactions take into account incoming short wave radiation from the sun and the long wave radiation from the earth whose imbalances result in changes in atmospheric temperatures. (IPCC, 2007). Greenhouse gas (GHG) emissions are said to be the main cause of radiation variations in the future therefore GCMs take into account different scenarios of GHG concentrations. Several scenarios were formulated but only six marker or illustrative scenarios are used by modeling teams to come up with future climate predictions, (CCIS, 2005). These projection scenarios of socioeconomic change are, (A1B, A1T, A1F1,A2, B1 and B2) and they are used for assessing future GHG concentration and future impacts and vulnerability to climate change, (White et al, 2009). After the GCMs have been generated they are the downscaled, that is, used to relate local and regional scale climate variables to the larger scale atmospheric forcing, (Hewitson and Crane, 1996). The IPCC produced a special report on the four emission scenarios (A1,A2,B1 and B2) known as SRES in 2000.The scenarios are not prediction but possible future based on a given set of assumptions that are based on energy usage, emission and land use, (Nakicenovic et.al., 2000). The scenarios are described as follows;

<u>A1 scenario</u>

- Assumes very rapid economic growth, global population that peaks in mid century and rapid introduction of new and more efficient technologies.
- Assumes technology will be easily spread due to increased globalization

- Further divided into three more classes by differences in the use of energy resources, that is, A1F1 (fossil intensive), A1T (no fossil energy resources) and A1B (balance across all energy sources), (CARA, 2006).

<u>A2 scenario</u>

- A2 assumes a heterogeneous world with high population growth, slow economic development and slow technology change

<u>B1 scenario</u>

- Assumes scenario similar to A1 but with greater emphasis on sustainability, immediate population and economic growth and instead of technological growth global solutions of sustainability in economy, society and environment are important.

<u>B2 scenario</u>

- Assumes high population growth though lower than A2, intermediate economic growth and emphasis on local solutions to economic, social and environmental preservation and sustainability, (CARA, 2006).
- CO_2 increase is projected at 408, 478 and 559 ppm for the years 2020, 2050 and 2080 respectively, (Travasso et al, 2006). The most likely temperature changes (°C) for each of the 6 scenarios are shown below in figure 2.3.

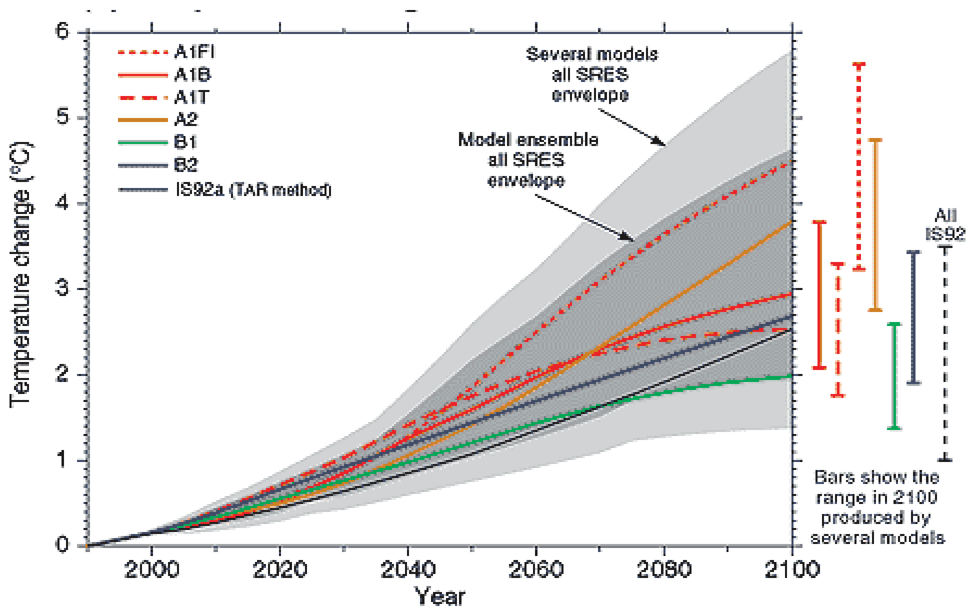

Figure 2.3 Global mean temperature change (□C) associated with the 6 SRES marker scenarios, A1F1, A1B, A1T,A2, B1 and B2

The bars in Fig 2.3 show the range of simple model results in 2100. Possible temperature increases for each IPCC scenario are shown in Figure 2.4 for the period 2000-2100 using previously observed data as the baseline.

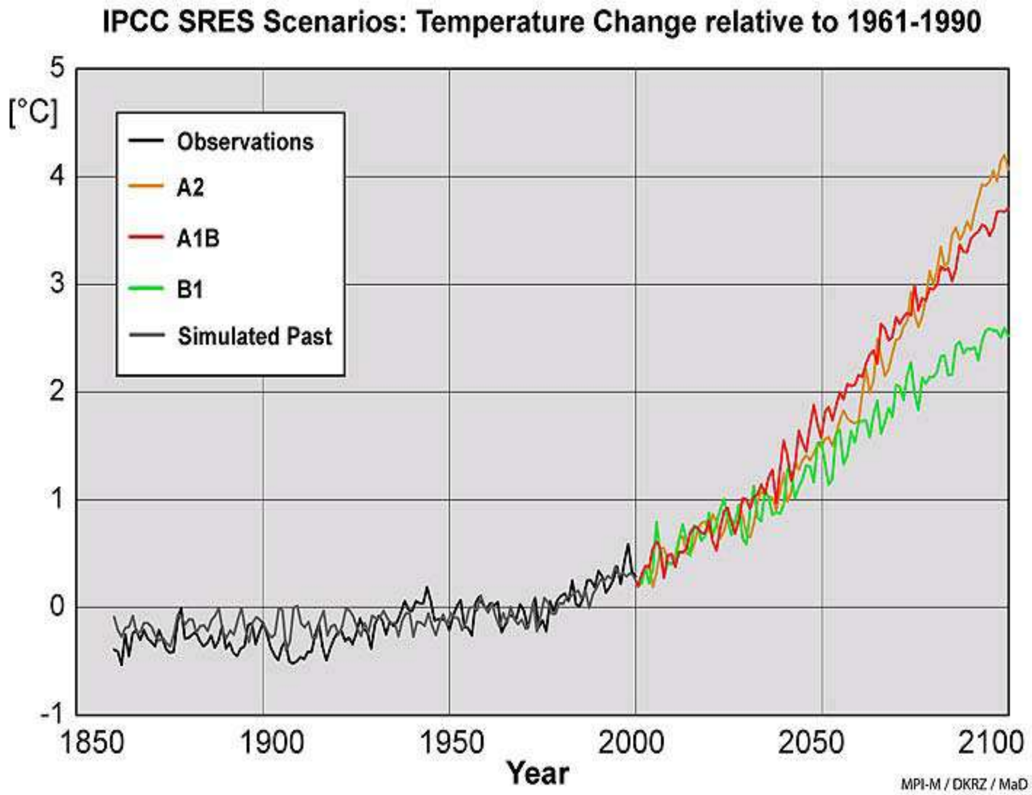

Figure 2.4 IPCC SERES scenario temperature changes

There are several GCMs that are used to generate climate data but only the following five are going to be used in this study.

Table 2.4 Global climate models and their origin

Acronym	Name and Institute
CCCMA_CGCM3_1	The third generation coupled global climate model (CGCM3.1 Model, T47). Canadian Centre for Climate Modeling and Analysis, Canada.
CSIRO_MK3_5	Mark 3.5 Model. Commonwealth Scientific and Industrial Research Organization, Australia.
GFDL_CM2_0	CM2.0 coupled climate model. Geophysical Fluid Dynamics Laboratory, United States.
GISS_MODEL_E_R	ModelE20/Russell. Goddard Institute for Space Studies, United States.
MPI_ECHAM5	European Centre Hamburg Model. Max Planck Institute for Meteorology, Germany.

2.10.3 Downscaling GCM

Downscaling is a strategy of generating locally relevant data from GCMs at spatial resolution of less than 50km, (CSAG, 2008). Downscaling results in the generation of locally relevant projections of long term weather patterns for regions and cities, from GCM (Cooney CM, 2012). It bridges the gap between global and local effects by layering local level data over larger scale climate models to a finer resolution than GCMs. Figure 2.5 below shows the layering process involved in downscaling GCM data.

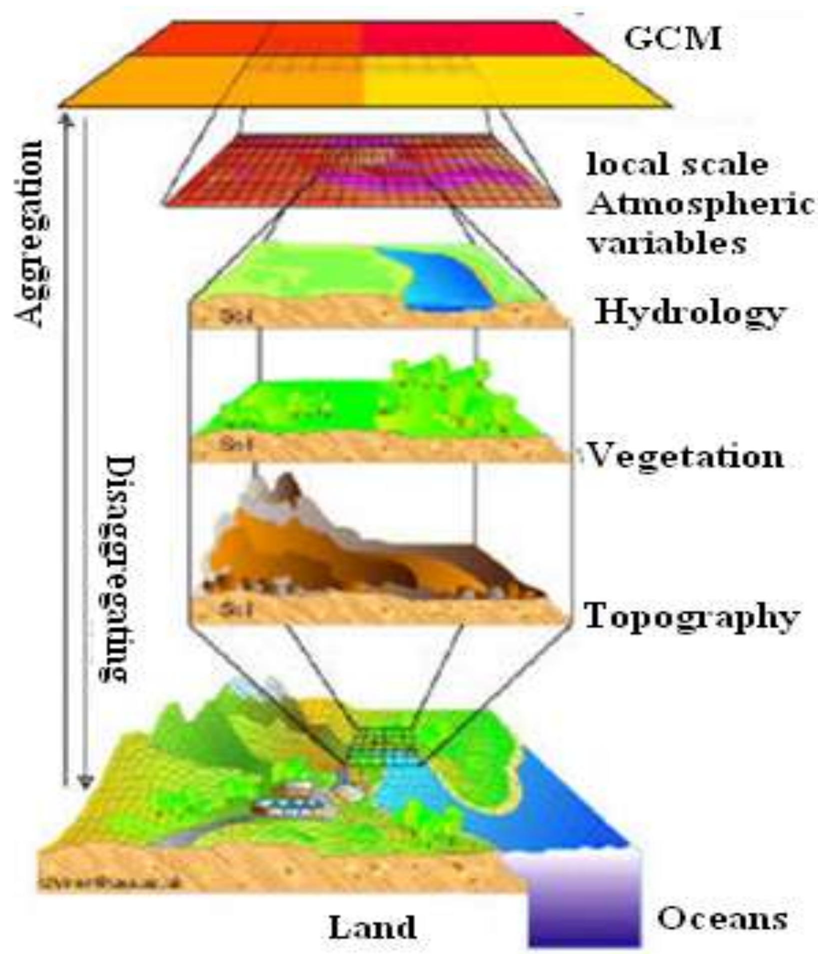

Figure 2.5 Schematic representation of downscaling (adapted from Elaine Barrow CCCIS project)

Downscaling can be done either using the dynamic method which directly reduces GCMs to Regional climate models (RCMs) or with statistical procedures. Dynamic climate modeling uses synoptic data and large scale information from GCMs, (Barrow and Semenov 1995). This method is known as nested climate modeling. It has the advantage of achieving spatial resolution up to10-20km and on temporal scale data at an hour or less may be achieved, unfortunately the method has the disadvantage of being highly computational and computers might not be accessible to everyone, (Hewitson and Crane,1996).

Statistical downscaling uses equations to convert global scale climate output to regional scale conditions, Bader, 2008). This method uses less computational effort than dynamic climate modeling, (Maurer and Hidalgo, 2007). Statistical downscaling allows the use of an ensemble of GCM results rather than concentrating on one model, (Christensen and Lettenmaier, 2006).

2.10.4 Climate Change Explorer Tool

Climate Change Explorer (CCE) is a tool designed to visualize downscaled climate change data. It allows the user to explore the climate variables relevant to their particular adaptation decisions, (Zermoglio, 2007). The CCE aims at facilitating climate information gathering and the application of the gathered information to adaptation strategies and actions. The tool simplifies the tasks associated with extraction and analysis of climate information thereby enabling users to address issues of uncertainty when devising policies and strategies as well as implementing action, (Zermoglio, 2007). When using CCE climate model data is retrieved from CSAG portal and loaded into CCE tool for further analysis. The climate data is a result of running different climate models under particular future climate scenarios, (Masanganise, 2007).

2.11 Climate based model

Climate based models try to explain the interaction between disease vectors, the environment and the climate variables in this case temperature and rainfall, (Descloux *et.al*, 2012).

2.11.1 Model calibration

Models contain a number of quantitative relationships, that is, equations relating various parameters. Coefficients in these equations have to be obtained from experiments and deriving these coefficients is known as calibrating the model, (Hillel, 1977). Calibration is a process of adjusting a set of parameters in a model so that the model is in maximum agreement with the set of experimental data, (Trucano, *et.al*, 2006). Calibration is important especially when adapting a model into a new environment.

2.11.2 Model validation

Validation is quantifying confidence in the models' ability to predict a given output through comparison of the models' results and the observed data, (Trucano, *et.al*, 2006). It involves testing a calibrated model using new data to get a result that is already known (Hillel, 1977). Validation gives substantial evidence on whether the model is applicable or not in a satisfactory range of accuracy which is consistent with the intended model application, (Refsgaard, 2000)

2.11.3 Epidemic risk model

An epidemic is a widespread outbreak of an infectious disease, (Merriam-Webster, 2012). It occurs when new disease cases in a given population exceed what is expected or what is the norm based on past experiences, (Green et al, 2002). The Epidemic risk model is an example of a climate based model. The epidemic risk model used in the study was developed by Andrew Githeko and William Ndegwa in an attempt to predict malaria epidemics in the Kenyan Highlands. The model was developed after noticing that permissive climatic conditions in the normally cool highlands are required for a malaria epidemic to occur, (Githeko and Ndegwa, 2001). The same can be said about tick borne diseases, that is, even though they are infectious they are most prevalent during some months of the year where climatic conditions are most suitable for their proliferation.

CHAPTER 3

3. Materials and methods

3.1 Introduction

This chapter describes the study site and its climate. It also describes the type of data used in the study as well as its source and the methods of data analysis that were used in trying to meet the objectives of the study.

3.2 Study site

The study site is Chiredzi District. Chiredzi District is located in the South east part of Zimbabwe in Masvingo province. It is in an arid to semi-arid region with mean annual rainfall of between 500mm in the South and 800mm in the north eastern area. The district is the major sugar production centre in the country and game ranching is also practiced. Local communal farmers practice mixed crop-livestock production systems. Crops grown include drought tolerate sorghum, millet, cowpeas, cotton and sunflower. Maize is also grown though yields are very low. Figure 3.1 shows the position of Chiredzi district with reference to the country.

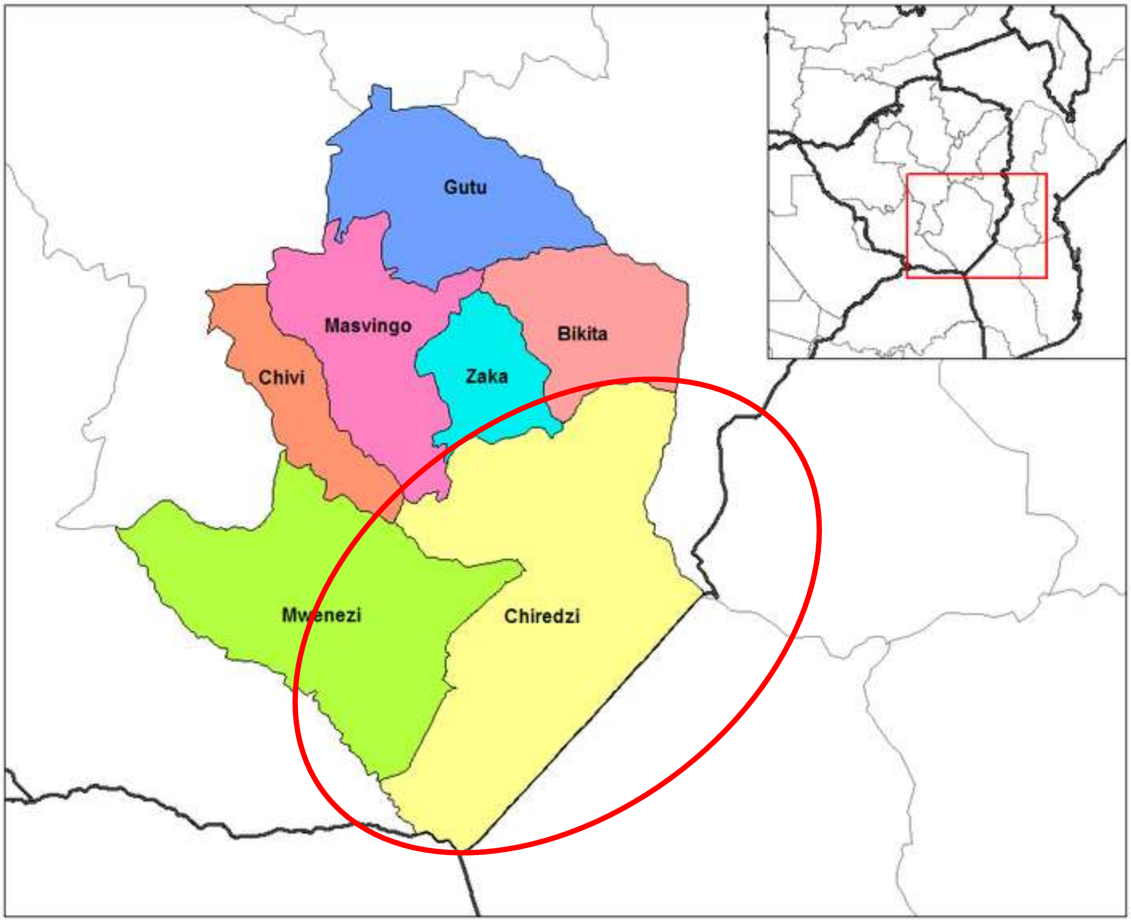

Figure 3.1 Map of Zimbabwe showing the location of Chiredzi District (source: http://en.wikipedia.org/wiki/Districts_of_Zimbabwe)

Zimbabwe is divided into five agro-ecological regions, I-V and the sub-divisions are based on, among other factors, rainfall amounts received (Vincent and Thomas, 1960). Chiredzi district lies wholly in agro-ecological region V (Figure 3.2). Region V is characterized by low and erratic rainfall and as such Chiredzi district is predominantly semi-arid to arid with annual rainfall generally below 600 mm and annual evaporation exceeding 1600 mm.

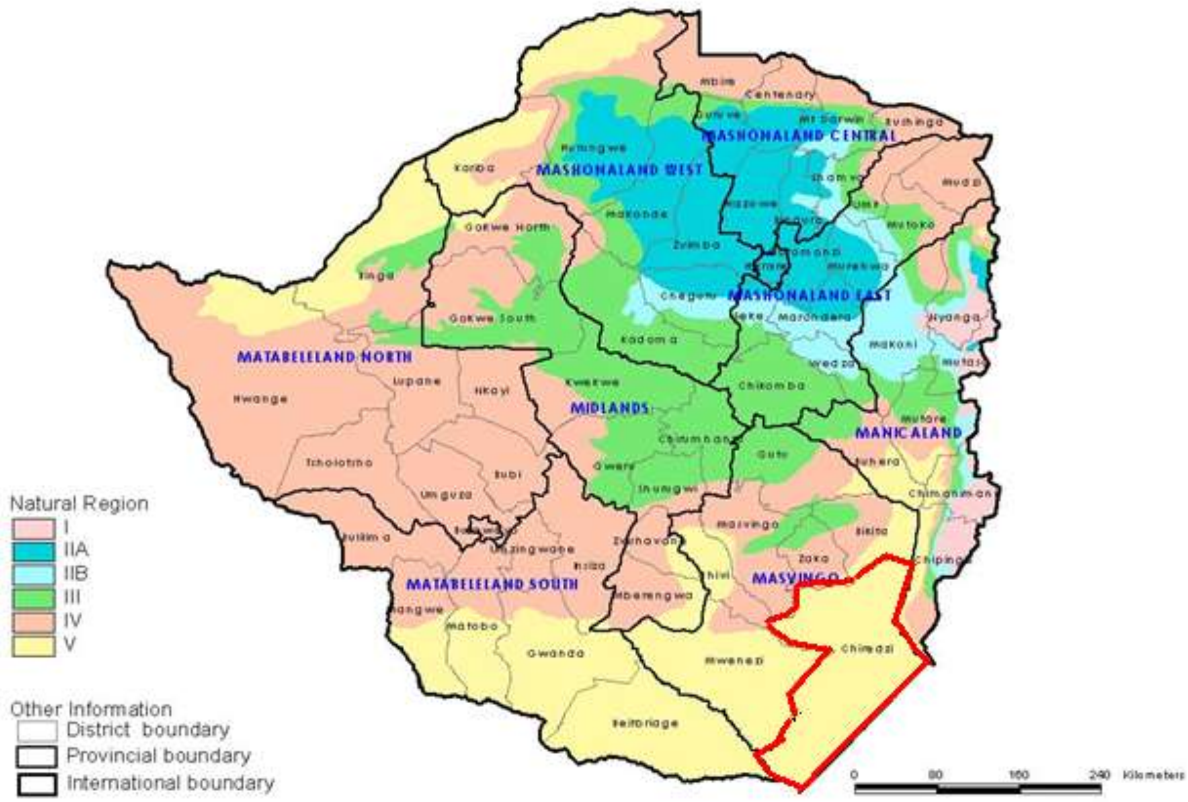

Figure 3.2 Agro-ecological zones map for Zimbabwe, showing the location of Chiredzi district (Source: www.relief.int/map/zimbabwe/zimbabwe-agro-ecological-zones-map-2-2)

3.3 Types and sources of data

3.3.1 Climate data

The climate data used in the study consists of both observed climate data and data derived from climate models. Observed climate data is from Buffalo Range climatological station in Chiredzi District. Buffalo Range station is run by the Zimbabwe Meteorological Services department (ZMSD). The model data derived from the global climate models was provided by the Climate Systems Analysis Group (CSAG) in South Africa via the portal, http://data.csag.uct.ac.za.

3.3.1.1 Temperature

Mean daily maximum and minimum temperature data was available for Chiredzi district as recorded at Buffalo Range station during the period 1979-2007 which is a period of 27years. This period is long enough to show impact of climate change if any has been recorded in the area. The daily maximum and minimum temperature values were averaged to mean monthly values for use in the analysis. Downloaded model data from CSAG consists of daily and monthly average minimum and maximum temperatures for the period 1961-2000, 2046-2065 and 2081-2100. However the data from 2081-2100 data was not used though it was available.

3.3.1.2 Rainfall data

Total daily rainfall data was available for Chiredzi district as recorded at Buffalo Range station for the rainfall season 1965/66-2007/08. Daily rainfall data was summed to get monthly total values. Downloaded model data from CSAG comprises of monthly total rainfall for the periods 1961-2000, 2046-2065 and 2081-2100.

3.3.1.3 Climate data analyses

Time series analyses on the observed temperature and rainfall data were done in EXCEL to show variability as well as the general trends in each parameter over time. Time series analysis of rainfall trends allows one to identify seasons as either normal, above normal and below normal. They also allow one to deduce any extreme events that may have occurred during the period observed. In addition other methods like climographs and anomaly graphs were also used. Deviations from long term means for temperatures, both minimum and maximum and rainfall were also analysed.

3.3.2 Global climate model selection

Several global climate models are available but for this study only five models were selected for use. The reason for selecting these models is because they are all based on the A2 Scenario of socio-economic change and this scenario is very practical and applicable for regions in Southern Africa, (Matarira *et.al.* 2004) as outlined in previous climate change modeling studies and how well they simulate present climate, (Hulme and Sneard, 1999). Table 3.1 shows the resolution of each model used.

Table 3.1 Characteristics of the global climate models used in the study, (Dai, 2006)

Acronym	Atmospheric resolution (latitude x longitude)
CCCMA_CGCM3_1	3.75 º x 3.75 º
CSIRO_MK3_5	1.88 º x 1.88 º
GFDL_CM2_0	2.0 º x 2.5 º
GISS_MODEL_E_R	4.0 º x 5.0 º
MPI_ECHAM5	1.88 º x 1.88 º

The GCM were run by the CSAG and the data was downscaled and loaded into the CSAG database. The downscaling method used for the data is the statistical downscaling method.

3.3.2.1 Global climate model performance

The five global climate models (GCM) used in the study are listed in Table 3.1. The data derived from these models has to be compared with observed data in order to assess the ability of the model to simulate the climate of the study area. The comparison of observed and modeled data is important because it allows one to find out whether the model can be used to predict future climates. Different statistical methods are used to in order to establish the relationship between the observed and modeled data.

3.3.2.2 Regression analysis

Regression analysis is used to analyse the relationship between two or more variables, in this case it is used to analyse the relationship between observed and modeled climate data. The closeness of the relationship is measured by the coefficient of determination R^2 whose value lies between 0 and 1 where 1 represents a perfect correlation. Regression analysis was carried out for minimum and maximum temperature data and rainfall data using EXCEL. The observed data was plotted against model control data and the R^2 was determined.

3.3.2.3 Root mean square error (RMSE)

The RMSE is used to verify how close the regression line is to all the plotted points. The RMSE was calculated for both temperature and rainfall data using the formula;

(1)

Where: P_i= predicted value from the model and O_i= observed value

3.3.3 Application of the Climate change Explorer tool

Climate data downloaded from the CSAG portal was loaded into the Climate Change explorer tool version 1.0. This version uses historical data which in this case is referred to as the control and it is the data from the year 1961-2000. The control data is run in different GCM in order to obtain projected or future climate data. The control data is from 1961-2000 and the projections are from 2046-2065 (known as future a) and 2081-2100 (known as future b). For this study only the near future data was used, that is, projections for 2046-2065. Figure 3.3 shows the main menu of CCE tool.

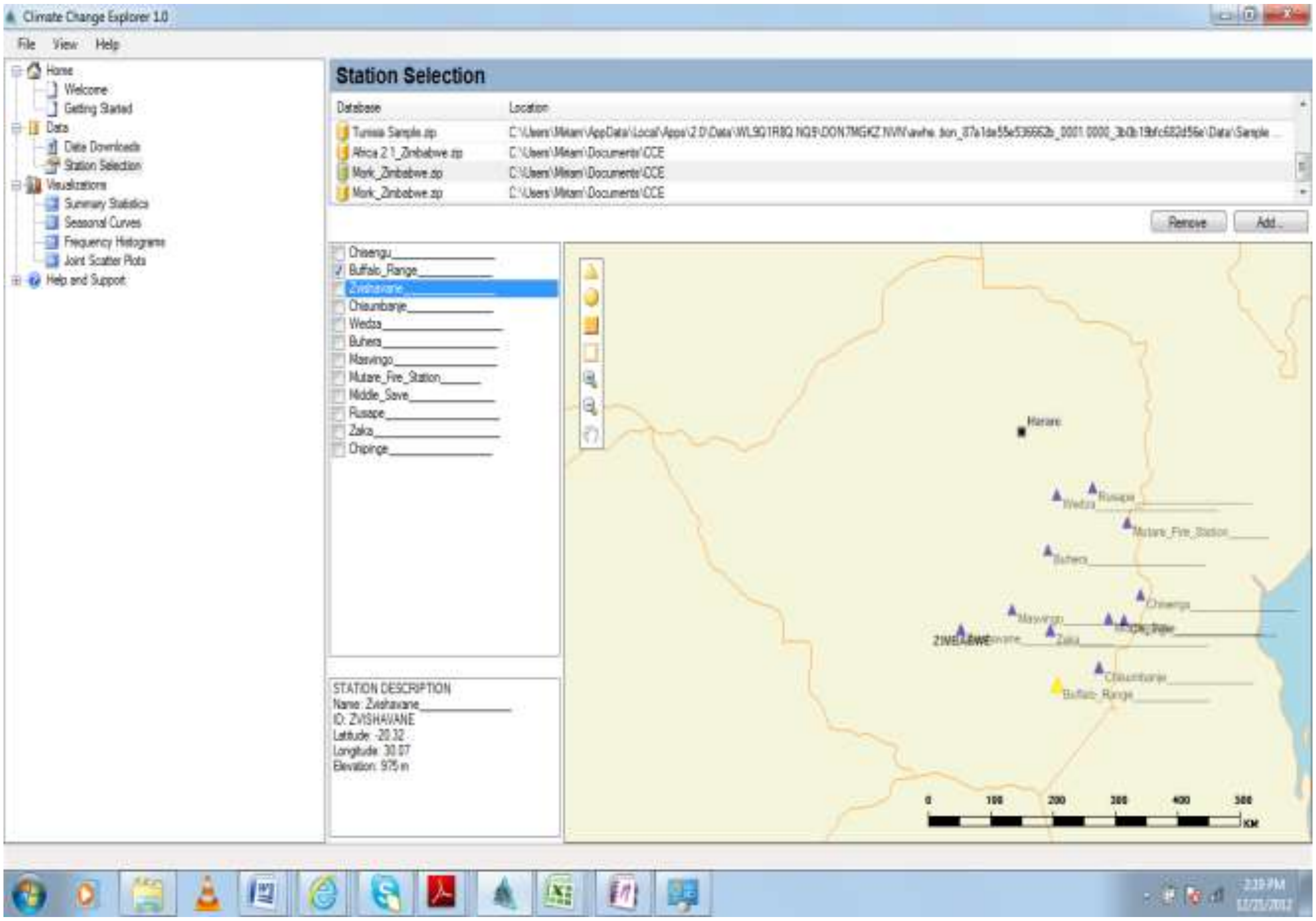

Figure 3.3 The main menu of CCE

Data in the highlighted folder named Mork Zimbabwe zip was loaded to the database by clicking on the Add Button. The station of interest in this case buffalo range was selected by clicking on the station selection function on the tree view menu on the left. The selected station is automatically highlighted in the map of Zimbabwe by the yellow icon as shown in Figure 3.3.

The summary statistics panel contains control and downscaled data and options to download the data either as daily or monthly data. The option to select either daily or monthly data is found under the icon named climatology. In this study monthly data is used. The particular GCM is selected by clicking on the Scenarios options button. Figure 3.4 shows the statistics summary menu.

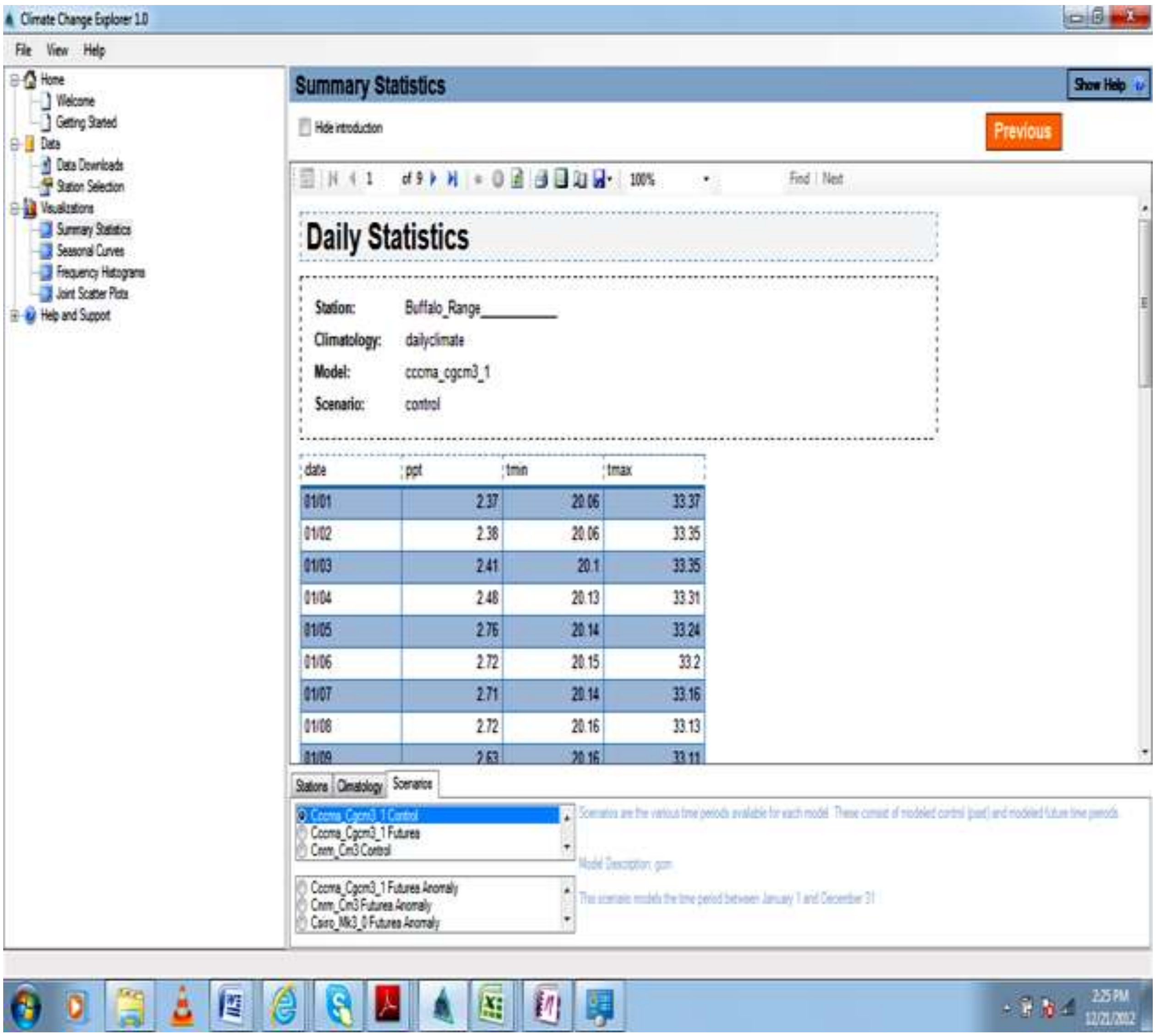

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Figure 3.4 Summary statistics panel menu

The seasonal curves panel option allows the user to select the particular variable of interest, both minimum and maximum temperature and rainfall by clicking on the variables button. The CCE then runs the particular descriptive statistics which is represented as a graph. Figure 3.5 shows the seasonal curves panel menu.

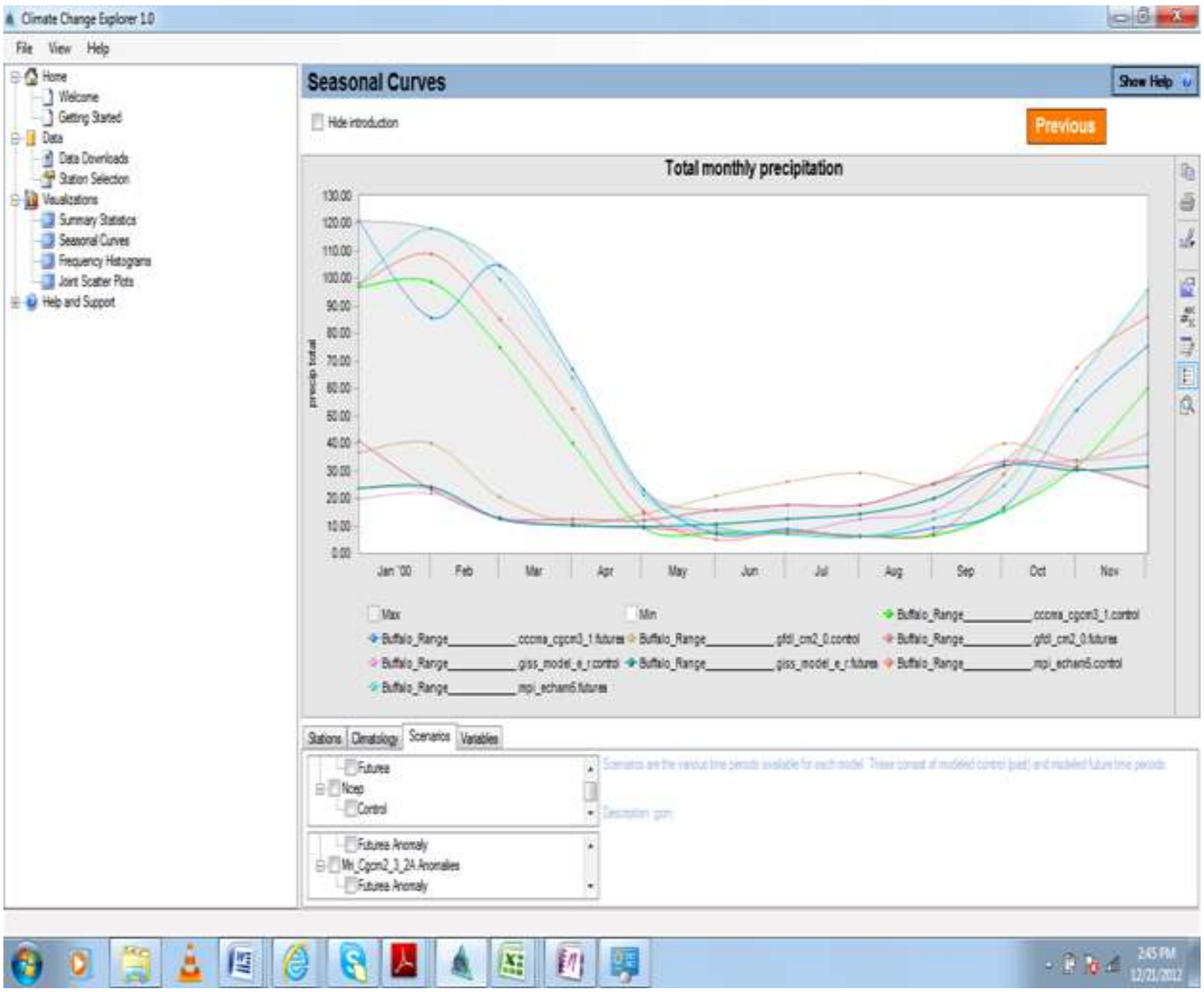

Figure 3.5 Seasonal Curves panel

3.4 Tick borne disease incidence data

Data on the incidence of tickborne disease was obtained from the Department Veterinary Services Department of Zimbabwe (DVSZ) for a period of 17 years, from 1995 to 2010, however there were missing records for the year 2007. The data included the date of observation, province and district, total number of disease cases, mortality, and total number of animals at risk of disease, disease name, and type of treatment among other observations. The data was collected and recorded at household level.

Analysis on the data was done to show the general trends of tick borne disease and their interaction with corresponding climatic factors. Correlation of climate variable trends and disease occurrence was also done in order to pick out the most outstanding variable in influencing tickborne disease and also to see how each climatic variable influences the occurrence of tickborne diseases.

3.5 Epidemic risk model

A climate based model was adapted from a study done by Githeko and Ndegwa in 2001on predicting malaria epidemics in the Kenyan Highlands. The model was adapted for this particular study and validated before it could be used for this study. Even though malaria and tickborne infections are different as diseases they are both caused by vectors that react almost the same to climatic factors with rainfall and temperature having a more profound effect on the growth and development of these vectors. In both diseases maximum temperature is more significant effect than minimum temperature. Any small changes in the temperature conditions results in a large difference in vector activity and disease transmission hence temperature affects disease occurrence exponentially while rainfall affects linearly. The equation developed is known as the percentage epidemic risk model, (Githeko and Ndegwa, 2002).

ER_i = Epidemic risk for the particular month of interest

R_{i-1} = Monthly rainfall total for the previous month

R_o= is the long term monthly rainfall average

T_i = is the maximum temperature for the particular month of interest

T_o= is the long term mean monthly maximum temperature

If the difference between monthly temperature and the long term monthly average gave a negative value, that particular month was classified as a low risk month with little or no chance of an epidemic occurring.

To determine tick borne disease trends the long term mean (LTM) disease incidence was calculated. The long term mean disease value was then used to calculate monthly disease anomalies by subtracting the number of monthly disease cases recorded from the long term mean. The monthly disease anomaly is better represented as a percentage departure from the long term mean and this value is calculated using the formula below;

$$\overline{} * 100 \quad (3)$$

3.4.1 Requirements of the epidemic risk model

The model requires climate data and disease cases data. Climate data comprises of maximum and minimum temperature values and rainfall data. Disease cases data refers to the total number of cattle that were affected by tick borne diseases. This includes the animals that died because of tick borne diseases (referred to as the mortality) and the animals that were diagnosed with tick borne disease related infections, (clinical or subclinical cases).

3.4.2 Temperature and rainfall data inputs

The model requires monthly maximum temperature as well as monthly total rainfall values. The maximum temperature and rainfall values are subtracted from their long term means. The long term mean monthly maximum temperature is calculated from the whole climatological data set present while the mean monthly average rainfall is the average monthly value of the whole climatological rainfall data set. High average temperature has the effect of building tick populations in permanent breeding sites. Permanent breeding sites are those areas that are always wet or with moisture throughout the year. These include stream and river edges as well as swamps and wetlands. In these areas moisture is not a limiting factor in tick breeding therefore high average temperature result in the permanent presence of ticks and subsequently tick borne diseases are always present.

3.4.3 Rainfall data

Because Chiredzi district is a low rainfall area the presence of any rainfall amount can make an impact in vector development and disease transmission. The long term monthly rainfall average of Chiredzi district was calculated from the dataset from the ZMSD.

3.4.4 Model performance

Contingency tables may be used to evaluate model performance by considering the following statistical scores, fraction of correct estimates (F_c), Correct Success Index (C_{SI}) and False Alarm Ratio (F_{AR}), (Wilks, 1995).

i. Fraction of correct estimates- this is the percentage of periods with correct predictions of tickborne disease epidemic
ii. Correct Success Index-this is the percentage of periods with only the success or positive event, it distinguishes between events and non events
iii. False alarm ratio- is the percentage of periods with false predictions

Table 3.2 The contingency table used to calculation of statistical scores.

	Observed	
	Yes	No
Predicted		
Yes	(A) hits	(B) false alarms
No	(C) misses	(D) correct negatives

If within a particular month the model correctly estimates a percentage epidemic risk above 50% it is scored in Box A; that is, a hit. If it fails to predict an outbreak in a particular month it is scored in the Box C: a miss. If however the model predicts an outbreak which fails to occur it raises false alarm hence a score in Box B. If the model correctly predicts the non occurrence of an outbreak it scores in Box D (correct negative).

CHAPTER 4

4. Results and Discussion

4.1 Introduction

This section shows the results of the time series analysis done for the rainfall and temperature data of Chiredzi district. This is then followed by the evaluation of the global climate models and their ranking in simulating the climate of the study area and also the application of the climate change explorer tool. The final section relates the epidemic risk model to the observed and predicted climatic variables.

4.2 Climate characterization

The graphs below show the general trends in rainfall received in Chiredzi District annually as well as the rainfall anomalies with reference to the annual average in the district.

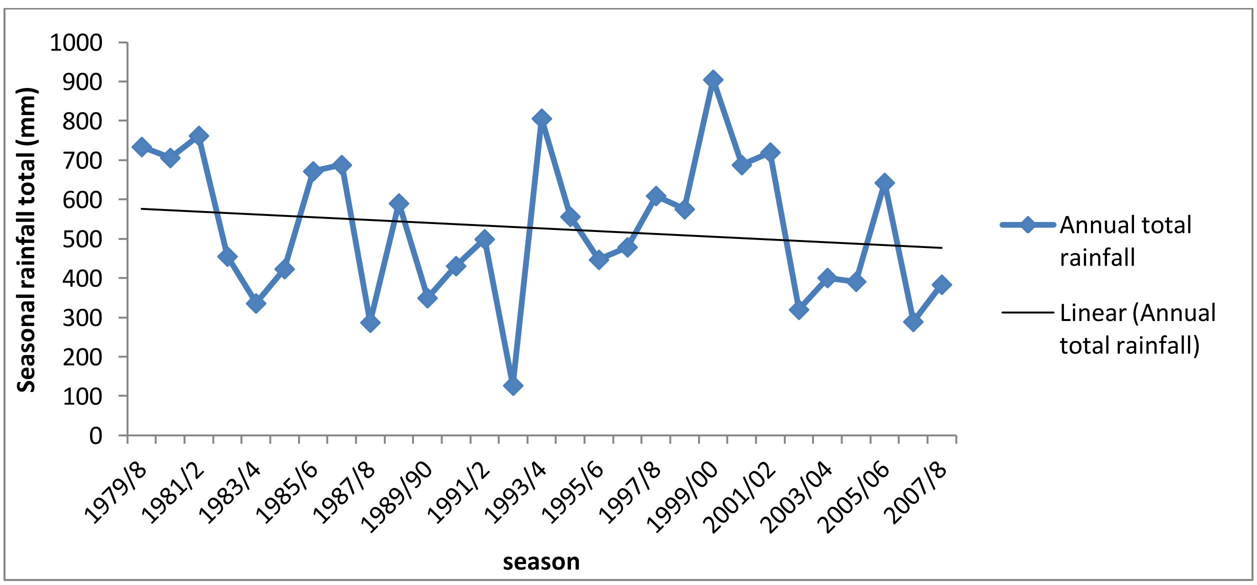

Figure 4.1 Annual rainfall totals for Chiredzi from 1979/80 to 2007/8 seasons

Anomalies for Chiredzi rainfall between 1978/79 and 2007/8 seasons

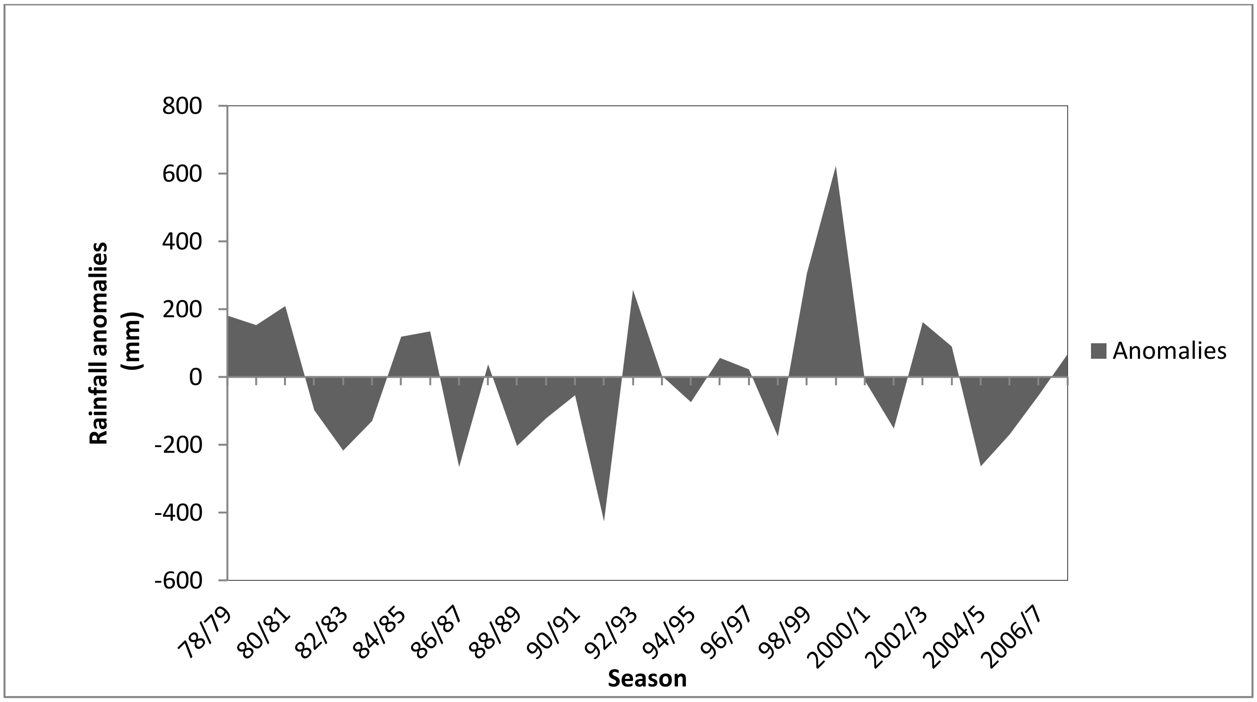

Figure 4.2 Deviation from mean annual rainfall for Chiredzi from 1979/80 to 2007/8 seasons

Figure 4.1 above shows that generally the rainfall received in Chiredzi district is decreasing though the variance is small. The deviations from the mean rainfall are shown in Figure 4.2 which is displaying the rainfall anomalies. The graphs mostly lies below the 0 mark showing that the area is drought prone as it receives rainfall below its normal amount mark. The lowest amount of rainfall was received during the 1992 season. This corresponds with the country drought which was experienced during the same season. The highest rainfall amount was received in 1999/2000 season due to the Cyclone Eline which caused floods in most parts of the country.

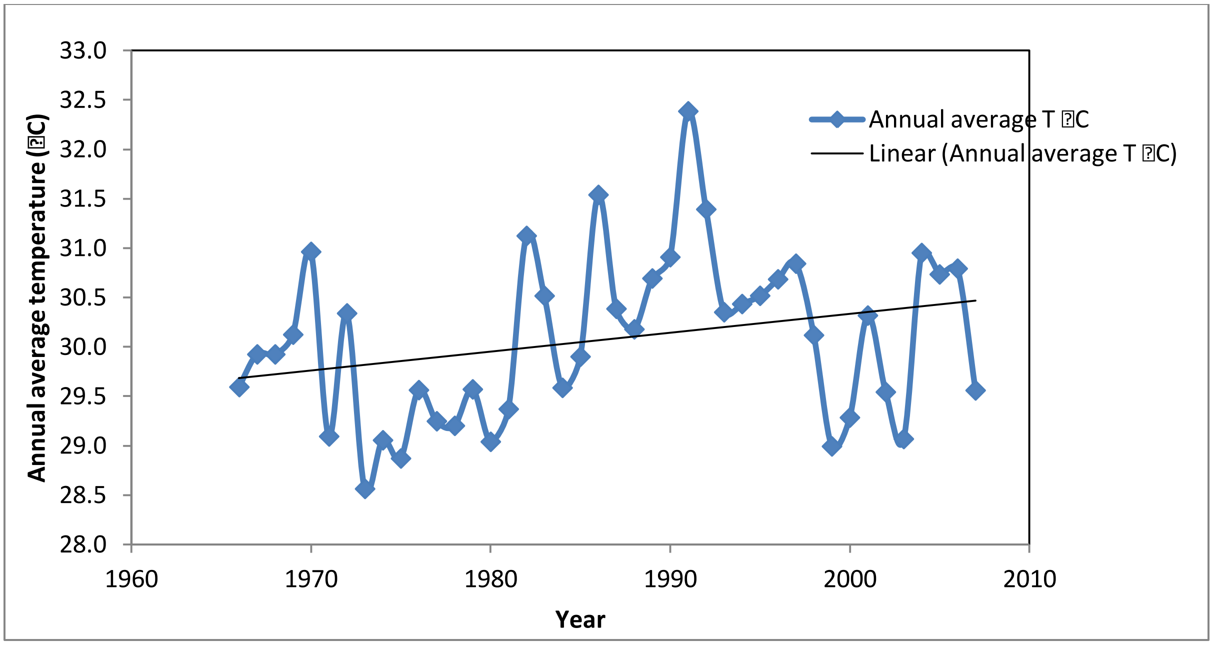

Figure 4.3 Annual average temperatures for Chiredzi District

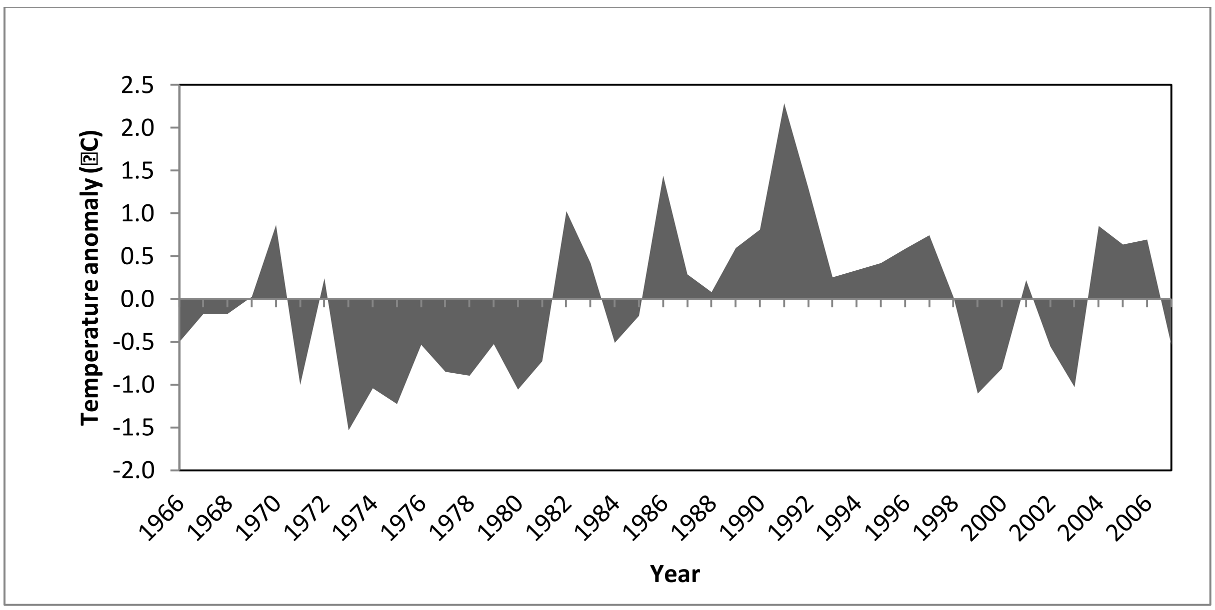

Figure 4.4 Temperature anomalies for Chiredzi District from 1966-2007

The graph in Figure 4.3 and figure 4.4 show that Chiredzi District might be experiencing increasing temperature variability with mostly above normal values being recorded. The trendline in Figure 4.3 shows an upward change while in Figure 4.4 most values lie above the zero line which represents normal temperatures. This may be regarded as evidence for a possibility of warming being experienced as a result of a changing climate. Temperature increases lies between 1and 2C. because temperature has an exponential effect on vector development this temperature increase between 1-2C is most likely to cause an increase in the development of ticks and if accompanied by a corresponding increase in rainfall may result in an increase in tick borne diseases.

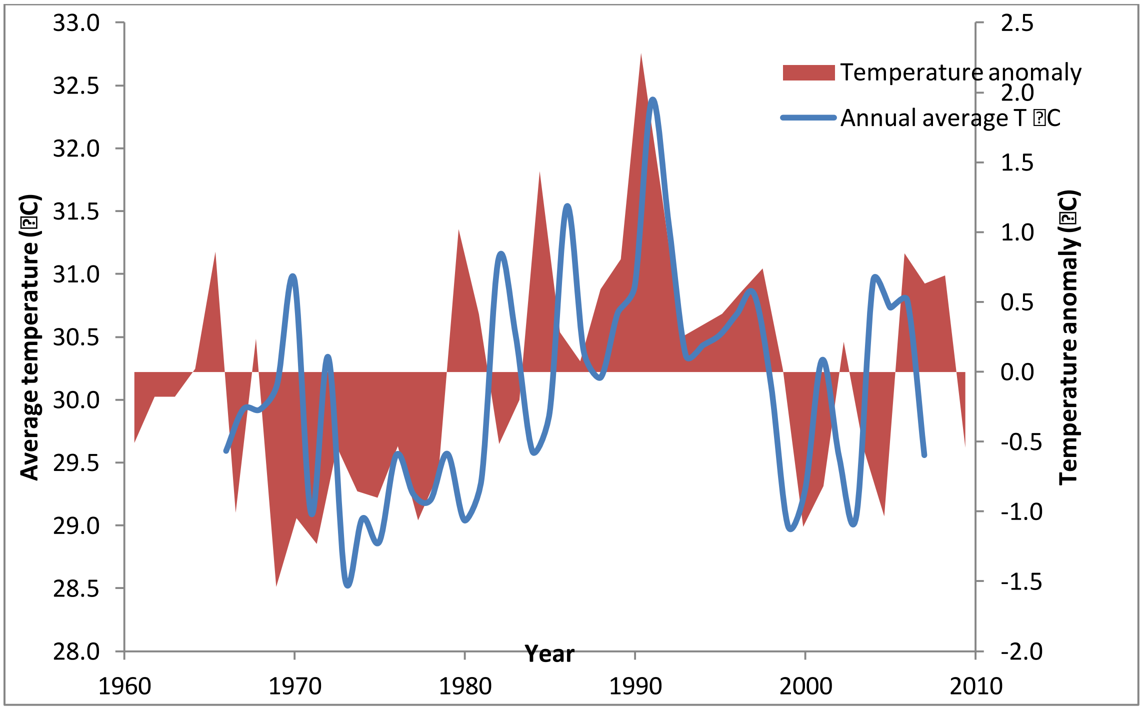

Figure 4.5 Annual average temperatures and temperature anomalies for Chiredzi District

Figure 4.5 shows that the general temperature trend of Chiredzi District is increasing. The sudden downward plunge in temperature around the year 2000 is also associated with wet conditions as a result of the cyclone. The presence or absence of cloud cover may have caused the negative anomaly, (Unganai, 2008). Temperature increase is in line with the global trends which according to IPCC estimated a global temperature increase of between 0.3-0.6C from 1900-2000, (IPCC, 2007), and nationally Zimbabwe has recorded an increase of 0.4C within the same period, (Unganai, 2010). Though the temperature increase may seem very small its effects on tick borne diseases are significant because temperature has an exponential effect on vector borne disease, (Githeko and Ndegwa, 2001). Figure 4.6 below shows the global temperature trends from 1979 to 2010 which can be comparable to what was recorded for Chiredzi district. The thinner graph shows monthly temperature averages while the bolder graph shows 37 year temperature moving averages, (Broham *et.al*, 2005).

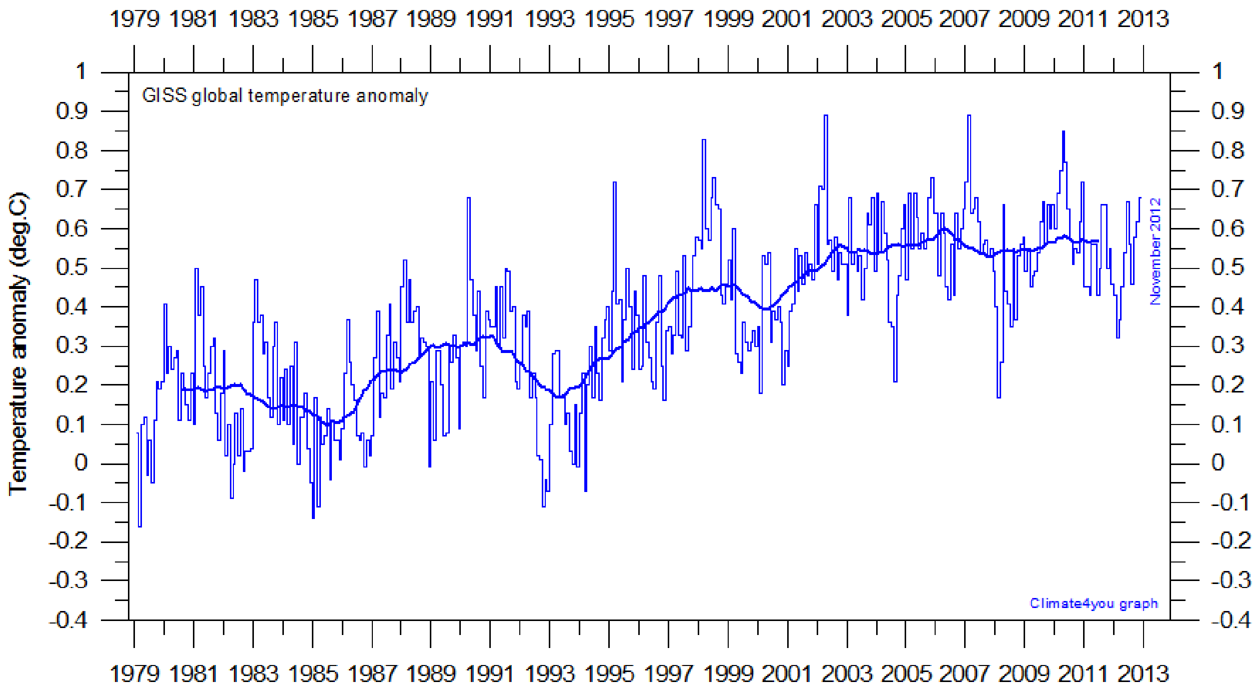

Figure 4.6 The global temperature trend from 1979-2012 (adapted from Broham *et.al*, 2005)

4.3 Tick borne disease analysis

The data on tickborne diseases was analysed for the general trends in disease occurrence from the period 1995-2007. The graph (figure 4.7) shows that the diseases are most prevalent during the raining months with January, February and March having the highest number of cases. This reason may be attributed to the fact that during the life cycle of ticks, hatching of eggs occurs at least 6 weeks after the appropriate weather conditions have prevailed and in this case the limiting factor is rainfall, since Chiredzi district is a high temperature low rainfall area, therefore once the first rains have been experienced the eggs start developing into adult ticks. Ticks are parasitic beginning at the larval stage therefore at this stage they already have the ability to transmit diseases.

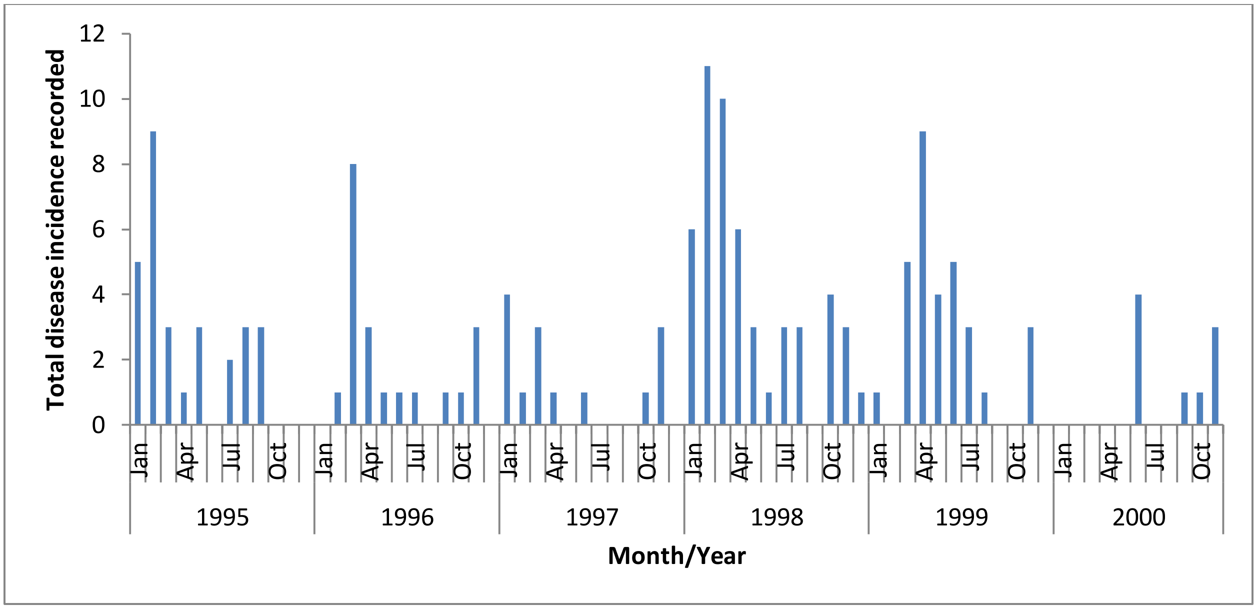

Figure 4.7 Total number of tickborne disease incidence recorded in Chiredzi between 1995 and 2000

The Figure 4.7 shows the relationship between tickborne disease cases recorded in Chiredzi from 1995 to 2007 and total annual rainfall received and the average temperatures recorded from 1990 to 2007. The graph (figure 4.8) shows the relationship between tick born diseases and the corresponding annual average maximum temperature. It shows that an increase in maximum temperature recorded is followed by an increase in the number of tick borne diseases recorded. For example in 1998 the average maximum temperatures recorded was around 31C and this was followed by an increase in the diseases recorded in 1999. The explanation for this increase is that the hottest months of the year are towards year end, that is September, October and November which is this case may have caused the overall temperature increase in 1998. These temperatures may have resulted in the increase in the rate of development of the tick vector which increased the total number of ticks. The effect of these ticks tick borne diseases was only experienced in the 1999 hence the increase in disease recorded. This increase however has to be supplemented by a corresponding increase in the total rainfall received since the tick vector thrives under hot and humid conditions.

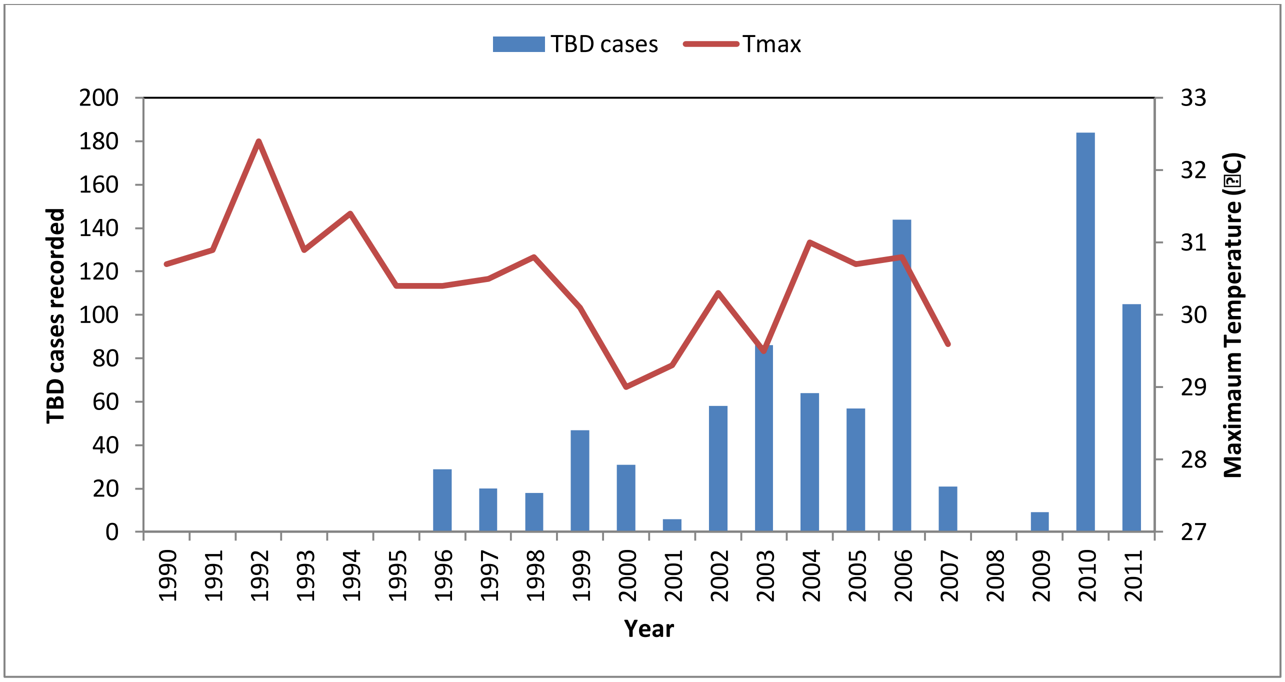

Figure 4.8 Relationship between disease incidence and average maximum temperature

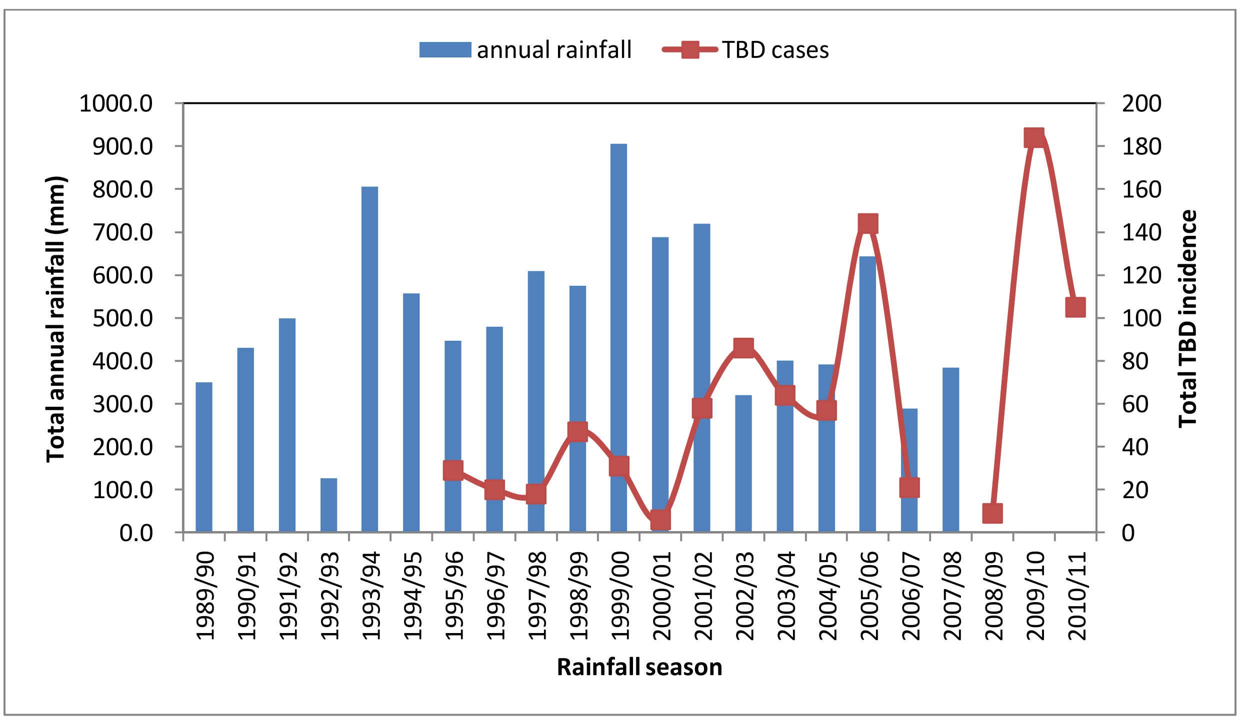

Figure 4.9 Relationship between total rainfall and total disease incidence recorded in Chiredzi District

Figure 4.9 shows that an increase in total amount of rainfall received corresponds to an increase in tickborne disease incidence. This is shown by the high disease incidence recorded between 2000/01 and 2001/02 seasons. The highest rainfall recorded in 1999/2000 corresponds to low tickborne diseases. This might be because of the floods experienced during this season might have washed away the tick eggs before hatching hence the low disease incidence may be attributed to low vector density.

4.4 Evaluation of the Epidemic risk model

The results from the use of the epidemic risk model were used to make several conclusions about the use of the model in predicting tick borne disease risk.

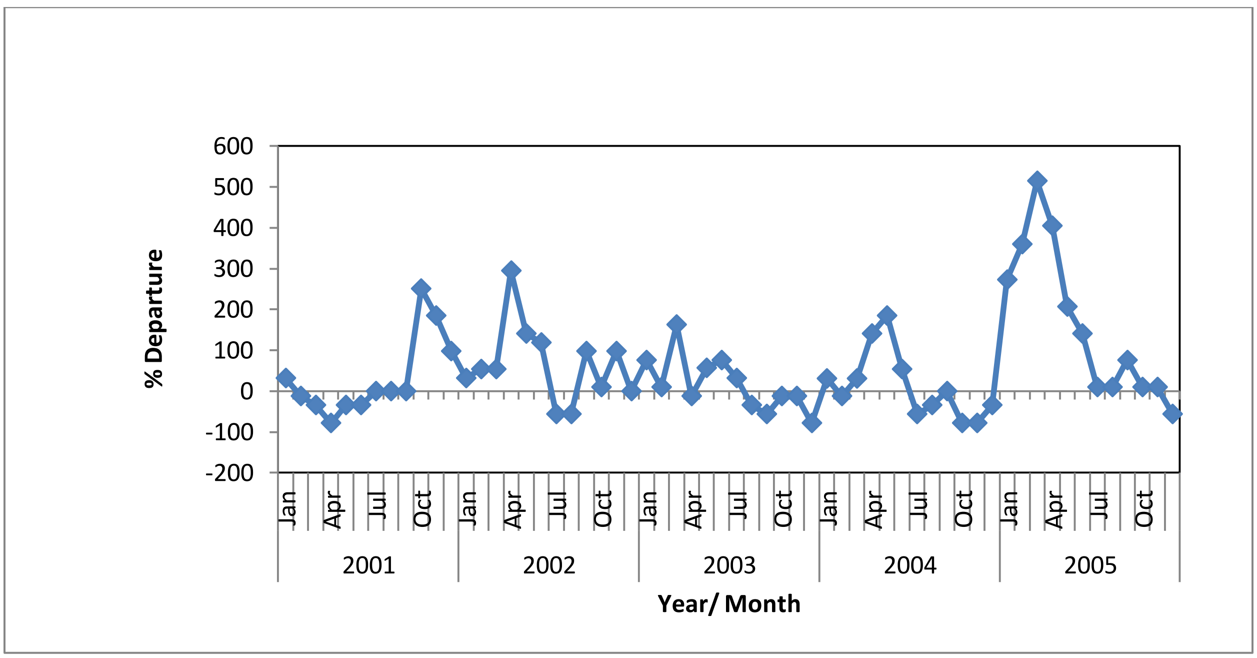

Figure 4.10 Percentage departure from long term disease incidence mean from 2001 to 2005

The graph above shows general departure from the mean in an upward direction. This confirms that tick borne diseases are increasing in Chiredzi district as most results lie above 0. Figure 4.11 shows that an increase in temperature anomaly results in an increase in the disease percentage departure from the mean as well as the total number of diseases recorded. Figure 4.11

also shows that a low total temperature anomaly is followed by a percentage departure below the 0 line, meaning low temperature anomaly results in a below normal disease occurrence.

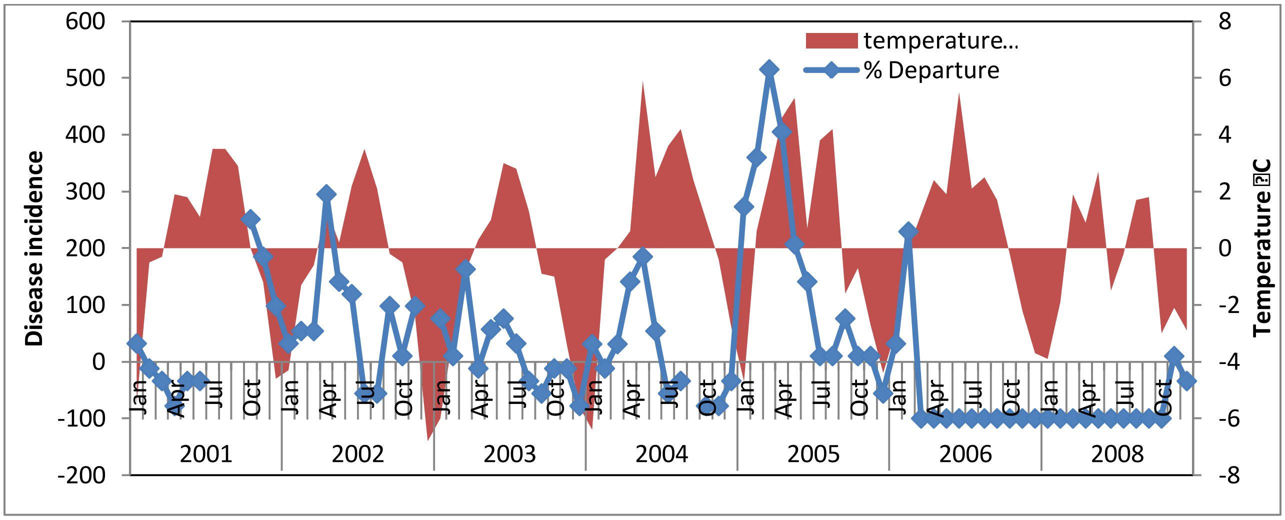

Figure 4.11 Relationship between monthly TBD departure from long term disease mean and temperature anomaly

The percentage epidemic risk was calculated using the equation shown in 3.3.4 and the results from the equation was plotted against time. The trendline shows an increase in percentage risk which translates to an increase in tickborne diseases.

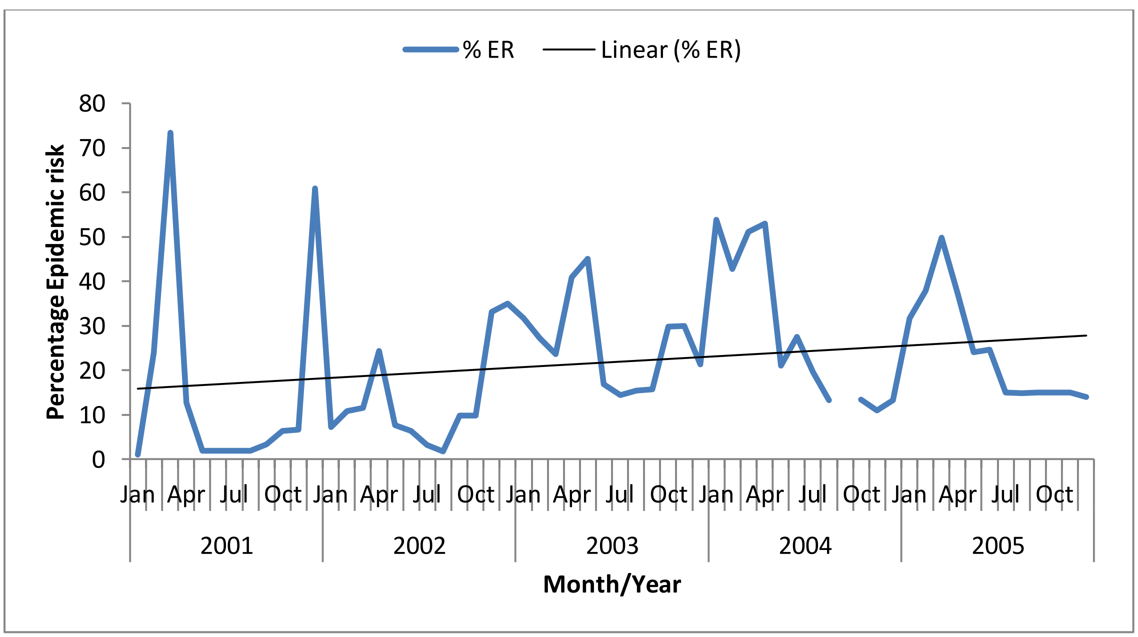

Figure 4.12 The percentage epidemic risk over time

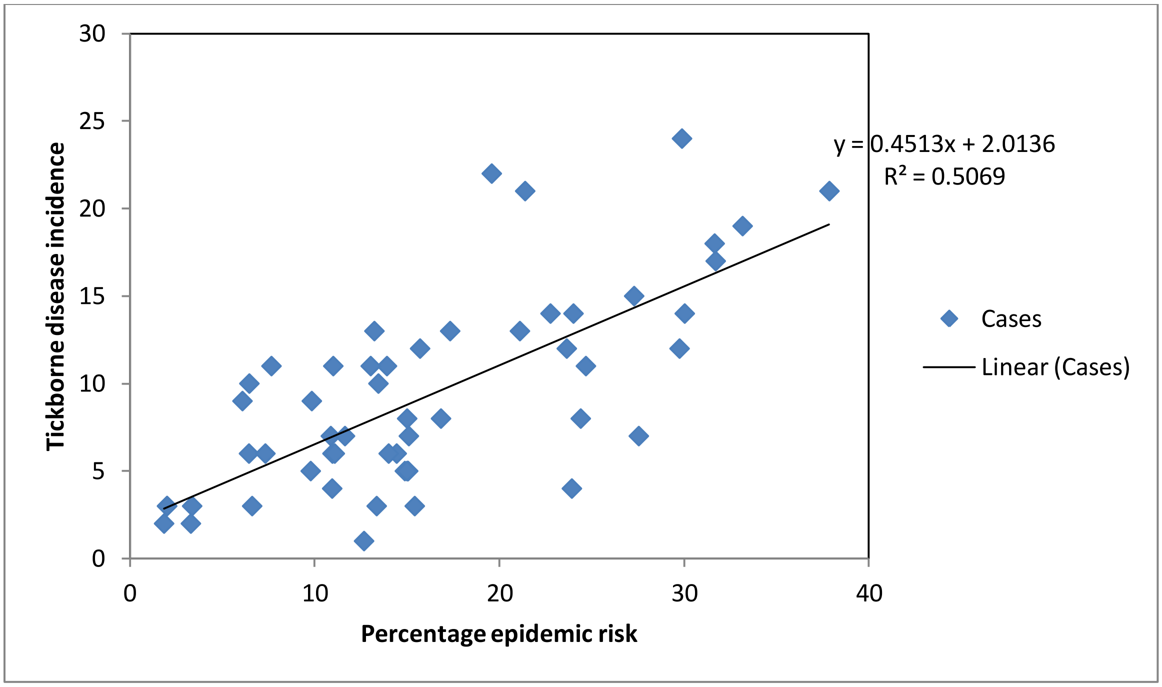

Figure 4.13 Relationship between percentage epidemic risk and tick borne disease incidence

In Figure 4.13 Disease incidence was plotted against epidemic risk in order to get a linear relationship between the two that can be used in the forecasting of tick borne diseases. The equation derived is

(6)

y is the tick borne disease case incidence and x is the percentage epidemic risk. x is equal to the percentage Epidemic Risk in equation 2. Equation 5 can then be worked backwards using the forecasted temperature and rainfall values and ER value will then be used in equation 6 to find the y value as shown in Figure 4.14 where recorded and simulated disease cases are illustrated.

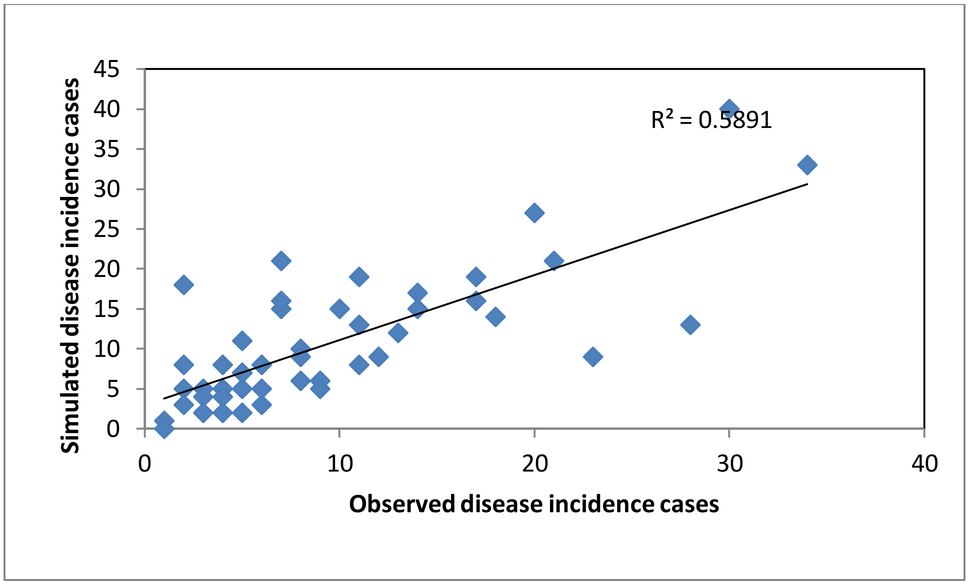

Figure 4.14 Relationship between observed (recorded) and simulated tickborne disease incidence

Table 4.1 Statistical analysis of epidemic risk model performance

Statistic	Epidemic risk model performance
R^2	0.583
RMSE	15.65

Regression analysis of Observed and simulated disease incidence values was performed. The relationship is fair showing that the model can be reliable in forecasting disease incidence in Chiredzi district. The RMSE was also calculated using the predicted and observed percentage epidemic values and it gave a value of 15.65.

Figure 4.15 shows the observed and predicted (using the equation) and observed monthly percentage epidemic risk of tick borne disease occurrence from January 2001 to December 2005. The graph was then used to create the contingency table for calculation of statistical scores of observed and predicted tick borne disease outbreak occurrence (after Wilks, 2005).

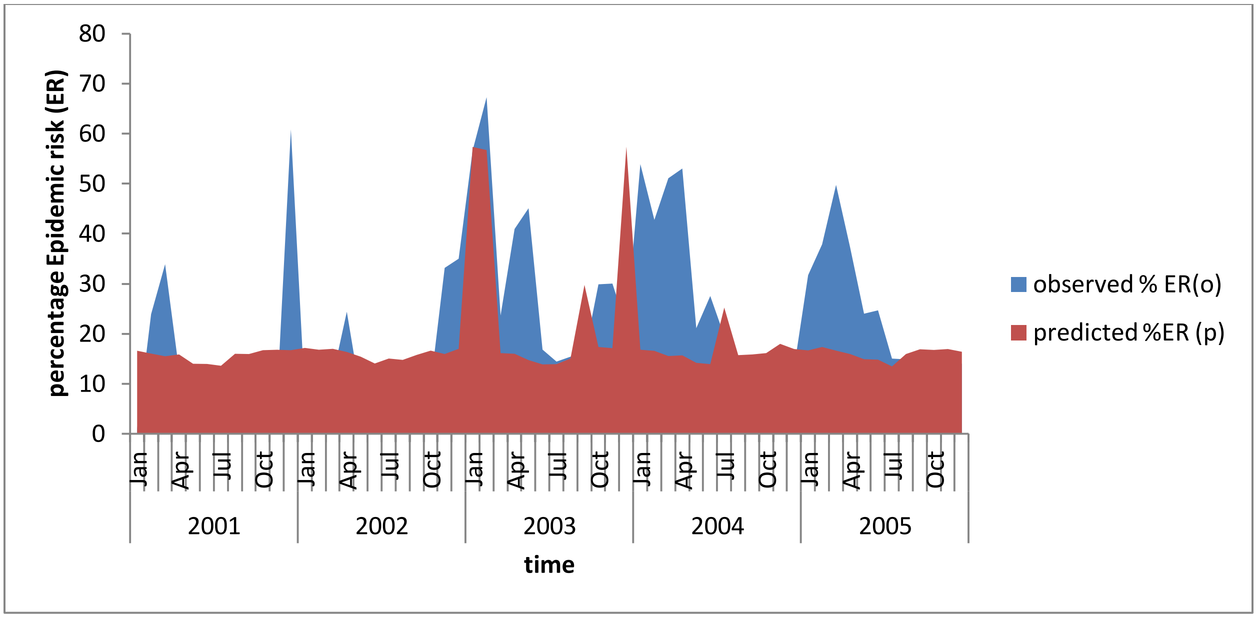

Figure 4.15 Observed and predicted percentage Epidemic occurrence from Jan 2001-Dec 2005

Table 4.2 Contingency table for calculation of statistical scores for observed and predicted tick borne disease epidemic risk

	Observed	
	Yes	No
Predicted		
Yes	(A) 3	(B) 1
No	(C) 8	(D) 48

Model performance was then evaluated using the following statistical scores,

i. Fraction of correct estimates (F_c)

$F_c = \overline{\qquad}$

=0.85

ii. Correct Success index (CSI)

$C_{SI} = \overline{}$

= 0.25

iii. False Alarm ratio,

$F_{AR} = \overline{}$

= **0.25**

4.5 Analysis of the global climate model output

Downloaded climate data from CSAG portal was loaded into Climate change explorer tool. The five GCM produced downscaled predictions for minimum temperature, maximum temperature and rainfall. A comparison was made between the observed and predicted data.

4.5.1 Quantitative measures of different climate models in simulating rainfall

The regression graphs showing observed data against simulated data are shown in the Appendix

Table 4.3 Performance of the GCMs in simulating rainfall of Chiredzi District.

MODEL	**R^2**	**RMSE (mm)**
CCMA CGCM3_1	0.314	75.46
CSIRO MK3_5	0.321	72.36
GFDL CM2_0	0.218	76.85
GISS MODEL ER	0.238	76.99
MPI_ECHAM 5	0.311	75.09

The regression analysis shows that GCM are very poor at predicting rainfall. The analysis shows very low correlation between observed and simulated values. This statement was eluded by

Hansen *et.al*, (2007) who gave the reason that this may be due to spatial variations that occur in rainfall distribution. The graphs below show the rainfall anomalies for each model the mean being the observed data. The graphs therefore show how the other models deviate from the observed data. Though GCM are poor at predicting rainfall amounts they can be used to show the trend in rainfall received.

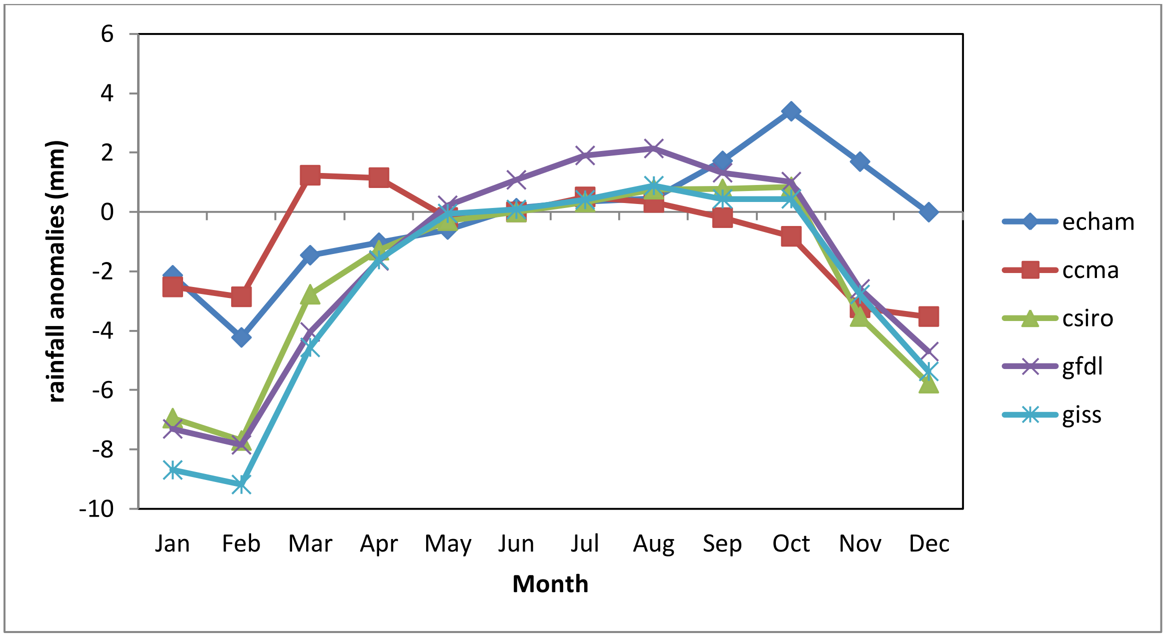

Figure 4.16 Deviation of simulated monthly rainfall totals

Figure 4.15 shows that model CCMA CCCM3_1 and MPI ECHAM 5 simulate the observed rainfall better than the other models as they show little deviation from the mean mark.

4.5.2 Quantitative measures of different climate models in simulating minimum temperature

The regression graphs illustrating observed minimum temperature data against each model output are sown in the appendix

Table 4.4 Performance of GCM in simulating minimum temperature

MODEL	R^2	**RMSE (°C)**
CCMA CGCM3_1	0.896	1.25
CSIRO MK3_5	0.725	2.18
GFDL CM2_0	0.627	2.52

GISS MODEL ER	0.845	1.97
MPI_ECHAM 5	0.855	1.5

Regression analysis was very effective in predicting minimum temperature values for the study site. All the models showed very strong correlation with CCMA CGCM3_1, MPI_ECHAM 5 and GISS MODEL ER had very high values of all above 80%.

4.5.3 Quantitative measures of different climate models in simulating maximum temperature

The regression graphs illustrating observed minimum temperature data against each model output are shown in the appendix.

Table 4.5 Performance of GCM in simulating maximum temperature

MODEL	**R^2**	**RMSE (°C)**
CCMA CGCM3_1	0.659	1.8
CSIRO MK3_5	0.551	1.84
GFDL CM2_0	0.492	1.95
GISS MODEL ER	0.565	1.76
MPI_ECHAM 5	0.523	1.92

The models show relatively high correlation in simulating maximum temperature. CCMA CGCM3_1 showed the strongest correlation out of the five models while GFDL CM2_0 showed the weakest correlation.

4.6 Analyzing the performance of the global climate models

The graph shows the behavior of the different models in simulating future rainfall trends for the period 2046-2065

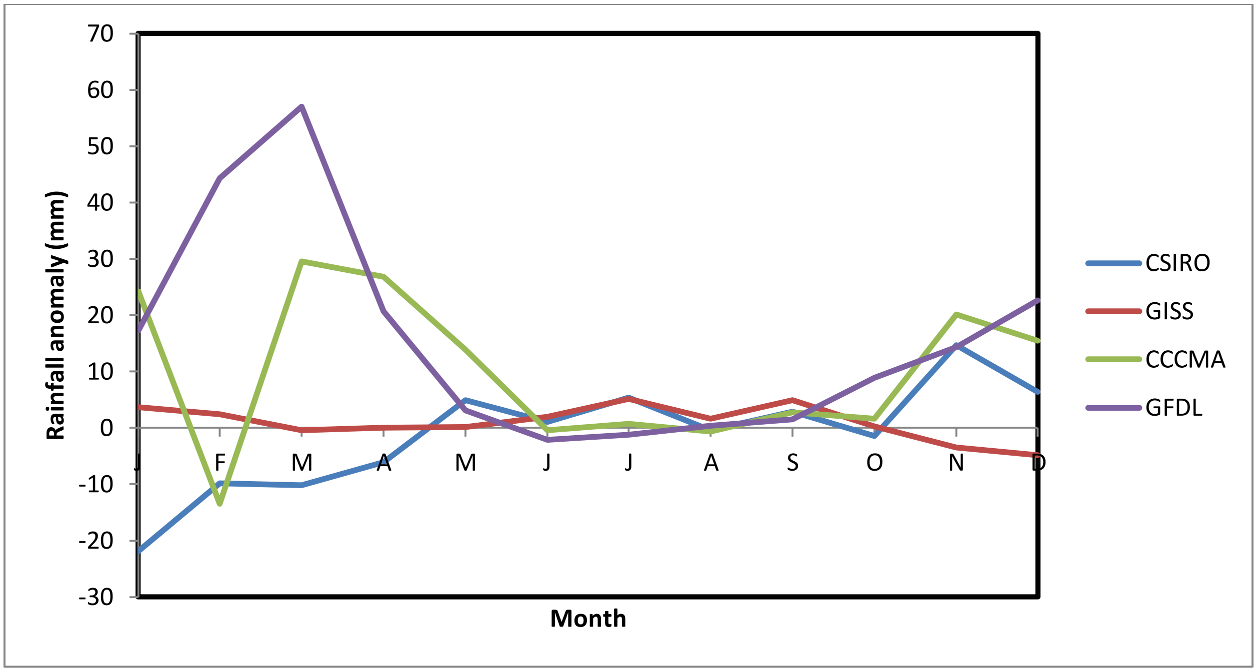

Figure 4.17 Predicted rainfall changes for the period 2046-2065

The graph shows that rainfall will increase for the best case scenario and will decrease in the worst case scenario and these changes are mostly to be experienced during the first months of the year mostly in February whose rainfall amount is expected to increase. This increase may mean longer wet conditions hence the population of ticks will increase into the coming year from the onset of the rainy season. This may mean an increase in the frequency of the dipping regime into the months of May and June especially where the increase in moisture is accompanied by an increase in temperature.

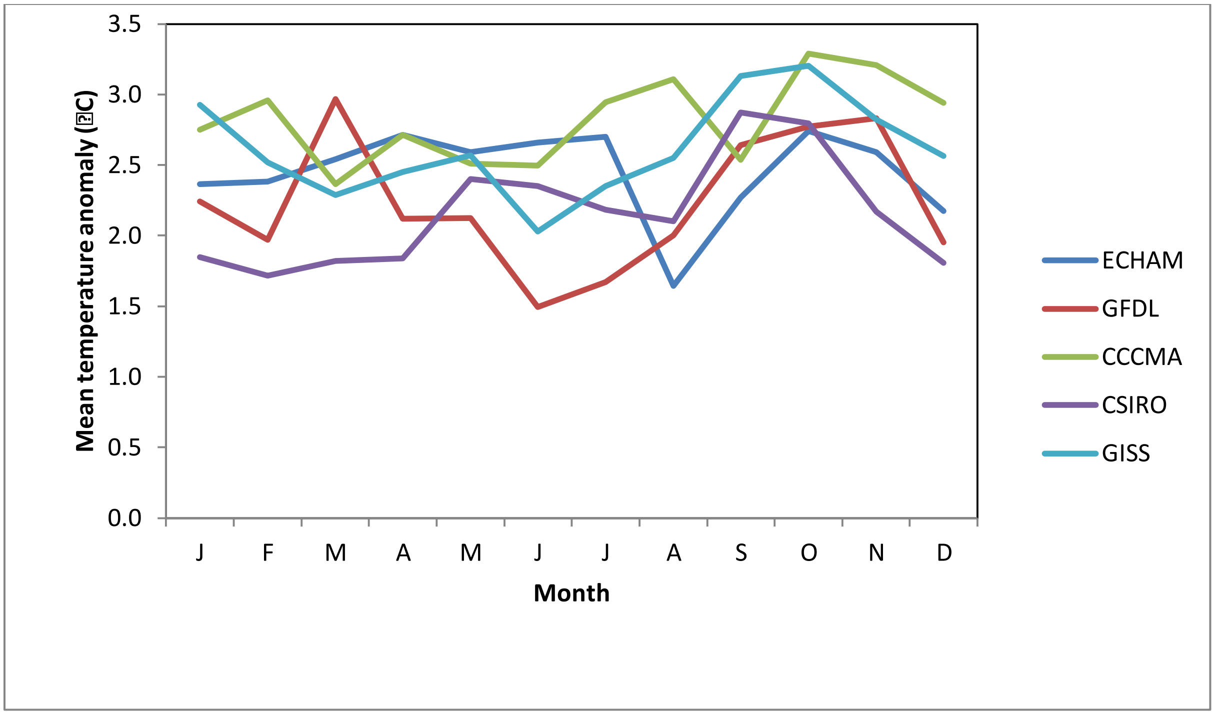

Figure 4.18 Predicted mean temperature anomalies for Chiredzi District for the period 2046-2065

The models above show that the temperature of Chiredzi will increase by between 1.5 to 3.5 ?C between the years 2046- 2065. The increase will be experienced mostly in June- July and also around October. All the models used are in agreement with each other that the temperatures of Chiredzi will increase.

From the regression analysis of the temperature model the GCM which showed the best results was CCMA CGCM 3_1. This model was used to compare predicted current trends (control) and near future climate (future a) and the result is shown in Figure 4.9. The comparison shows an increase of about 0.3?C. This is comparable to the study carried out by Unganai in 2008 (figure 4.10) that shows a temperature increase in mean temperature in the best case simulation scenario for Chiredzi district.

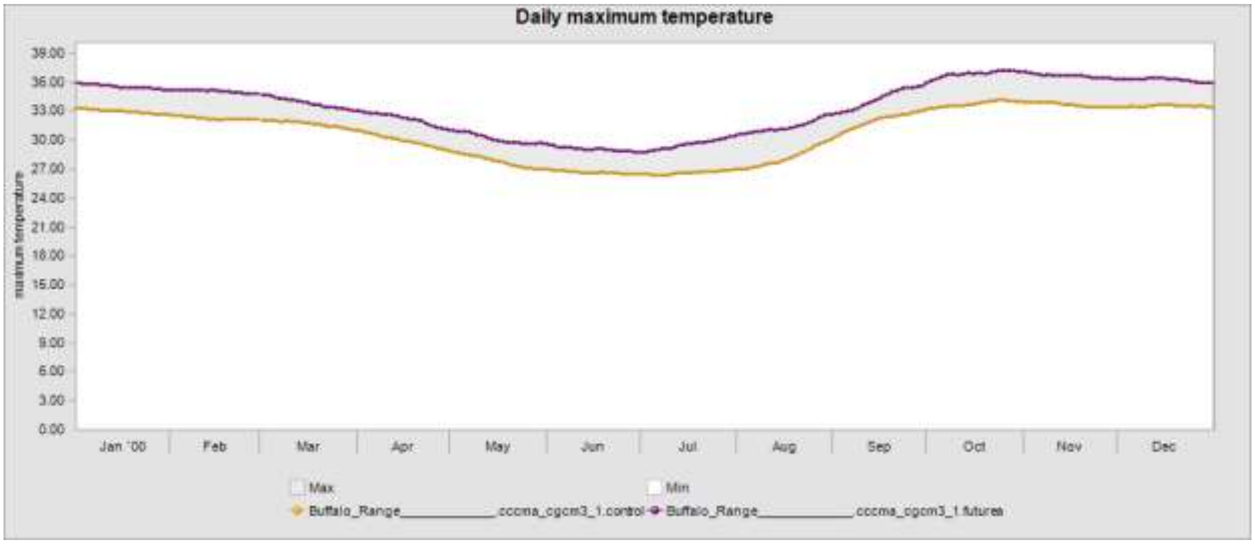

Figure 4.19 A comparison of current (control) and future maximum temperature based on CCCMA_CGCM3_1 model

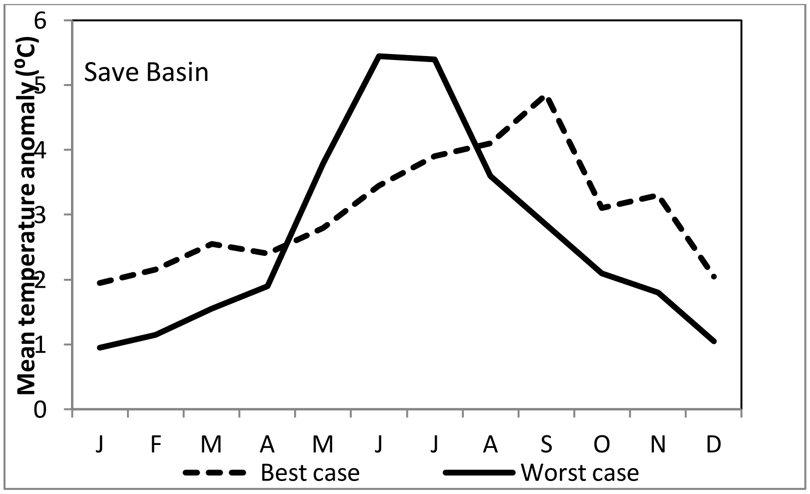

Figure 4.20 Predicted temperature anomalies for best and worst case scenarios

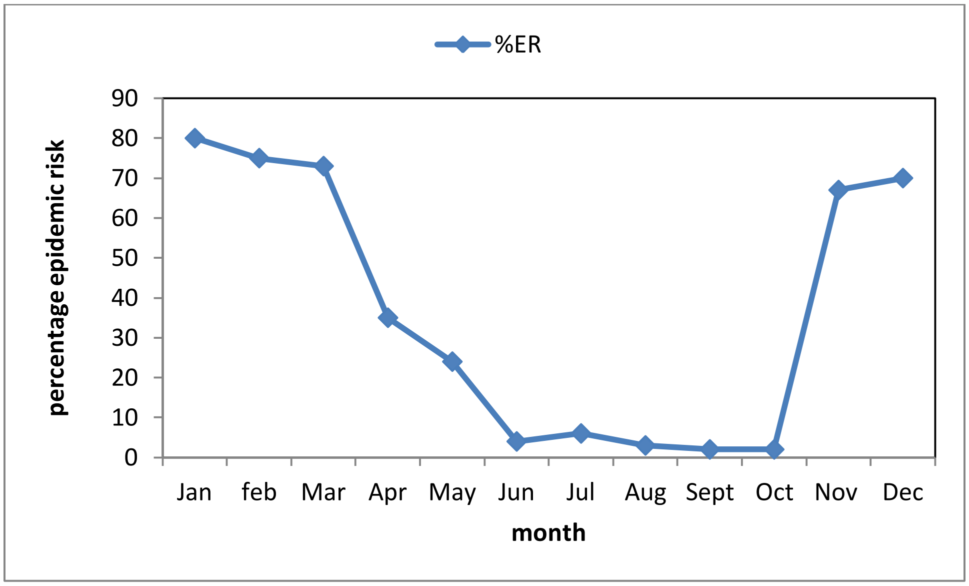

Figure 4.21 Predicted percentage epidemic risk of tickborne diseases in Chiredzi District for the period 2046-2065

Figure 4.21 shows the projected epidemic risk using monthly projected average values of temperature and rainfall downloaded from near future projection on CCE tool. The result shows a significant increase in tickborne disease epidemic risk for the wet months.

CHAPTER 5

5. Conclusions and recommendations

From the analysis it can be concluded that climate variability and change have an impact on tick borne diseases. Time series analyses show that there is a general increase in temperature in Chiredzi district and a reduction in total amount of annual rainfall. Increased monthly rainfall variability was also observed. The current shift in the climatic conditions of Chiredzi District will result in the increase in tick borne diseases. Downscaled GCM proved useful in making future climate predictions for temperature, however low correlation was observed in simulating rainfall data. The use of GCM may also be coupled with synoptic forecasting methods especially for rainfall. The combined methods may be used to predict the epidemic risk a few months before an epidemic occurs using seasonal forecasts.

5.1 Application of the epidemic risk model

The epidemic model is a good way of predicting future disease incidence. Figure 5.1 shows the type of data input into the epidemic risk model, the process and how the final variables are derived before they can be used in the model, and when interventions can be implemented (Githeko and Ndegwa, 2002). The framework can be used in early warning system in order to avoid reduce the impacts of tick borne disease outbreak.

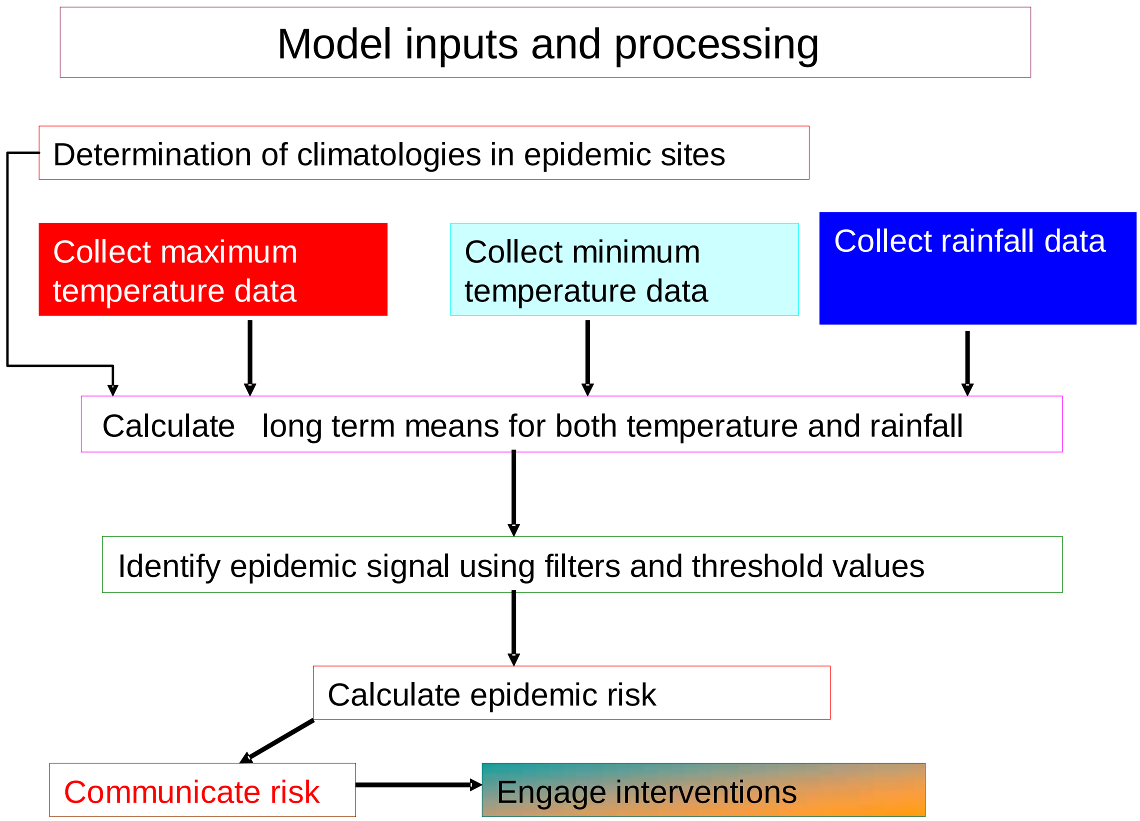

Figure 5.1 Framework for proposed early warning system (Githeko and Ndengwa, 2002)

5.1.1 Determination of climatologies in epidemic sites

This process involves collecting past climatology data of rainfall and both maximum and minimum temperatures. The past data can then be used to calculate temperature and rainfall long term means which form the baseline meteorological variables for the particular site. When past meteorological data is plotted n the same graph with disease occurrence the epidemic signal can be determined, that is, from the graph one can determine how disease occurrence and meteorological variables react with each other and also one can determine which of the variables has a greater influence in causing proliferation of diseases. In this particular study rainfall and maximum temperature has more effect on vector development than minimum temperatures. Monthly rainfall and average monthly temperature became the inputs of the epidemic risk model.

5.1.2 Communicating risks and engaging interventions

The process of predicting the disease situation of a particular season can be a collaborated effort between the ZMSD and Ministry of Agriculture. Once an outbreak has been identified the early warning message can them be conveyed to farmers through extension services of Agritex. The appropriate measures can then be employed for example availing acarides to the farmers at affordable prices, making broad spectrum antibacterial accessible to farmers in order to treat secondary infections.

The epidemic model is a good way of predicting future disease incidence. However the reason the reason for the fair relationship between simulated and observed values may be attributed to the several missing data within the DVS Zimbabwe database as seen by most months that had no records. The use of the epidemic model may be improved in further studies where an individual collects their own disease incidence data at a local scale and apply the modeling technique and make future predictions.

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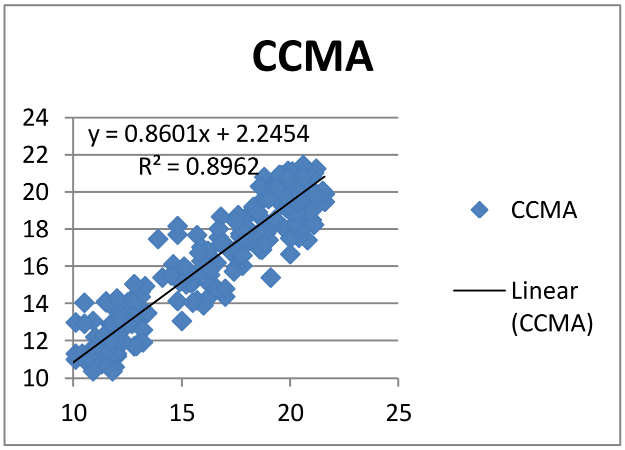
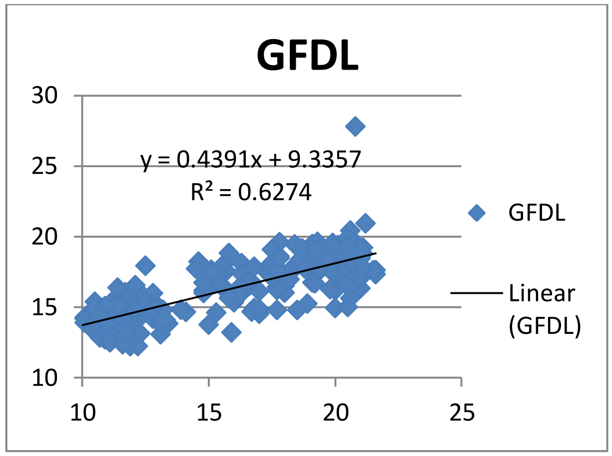
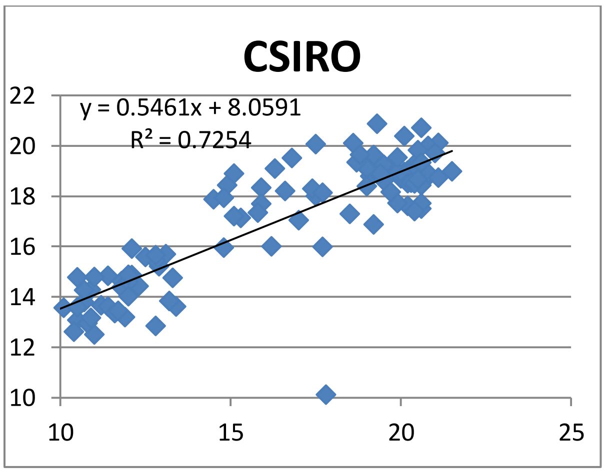
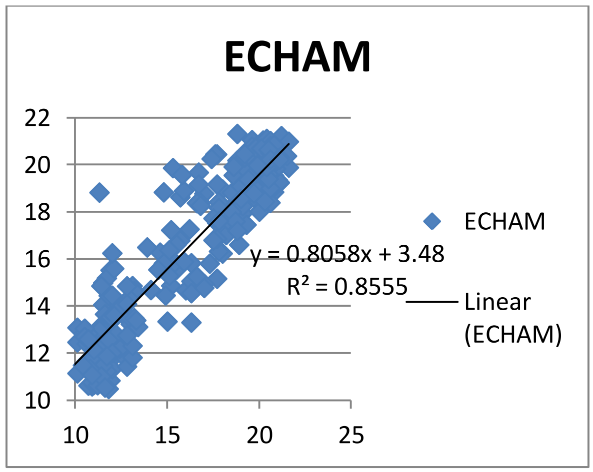
Appendices

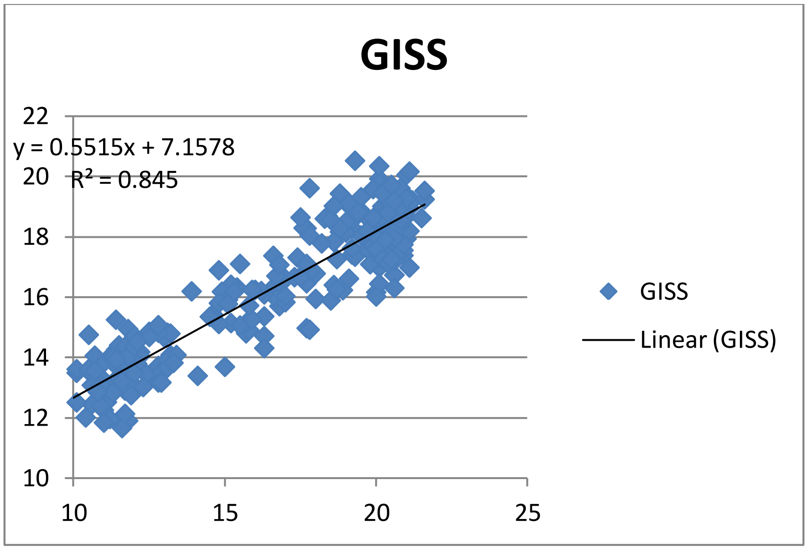
Minimum Temperature



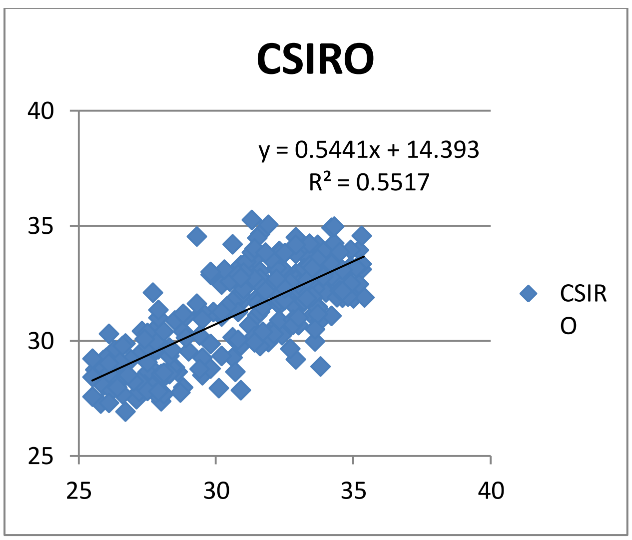


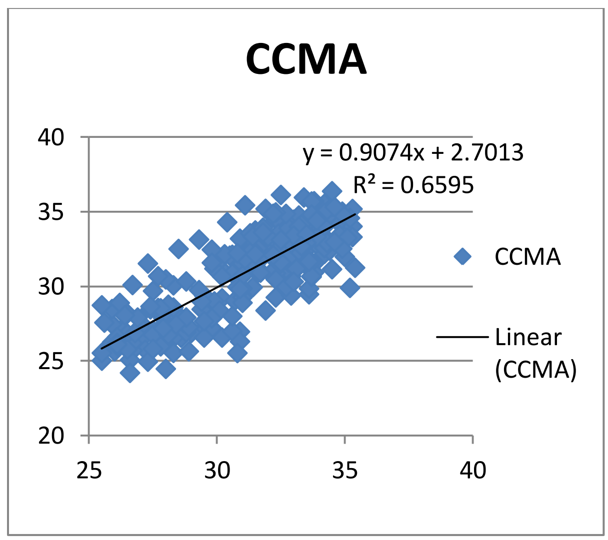


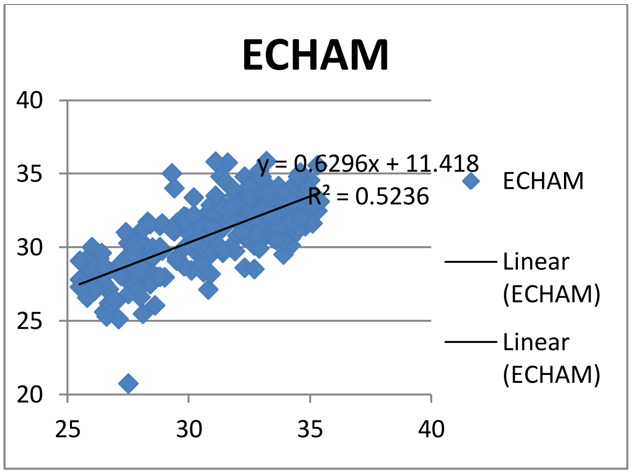


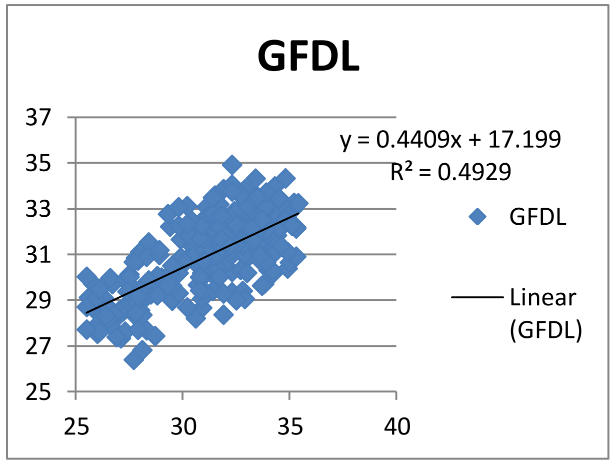


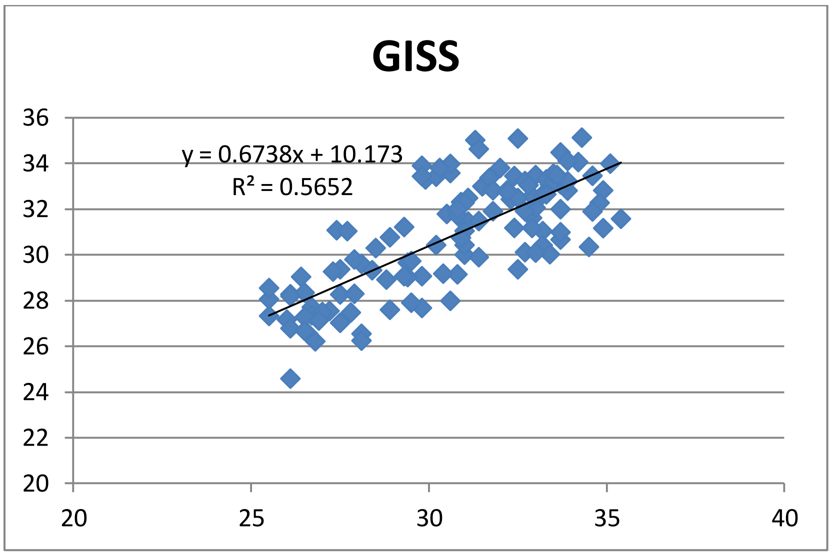
Maximum temperature






ECHAM
y = 0.6296x + 11.418
R² = 0.5236
ECHAM
Linear (ECHAM)
Linear (ECHAM)
40
35
30
25
20
25
30
35
40


GFDL
y = 0.4409x + 17.199
R² = 0.4929
GFDL
Linear (GFDL)
37
35
33
31
29
27
25
25
30
35
40


GISS
y = 0.6738x + 10.173
R² = 0.5652
36
34
32
30
28
26
24
22
20
20
25
30
35
40