# Spatio-temporal analysis of bovine theileriosis (*Theileria parva*) in Zimbabwe from 1995 to 2018

By

**Musaemura Manyenyeka**

Submitted in partial fulfilment of the requirements for the degree

**Master of Science in Tropical Animal Health**

in the Department of Veterinary Tropical Disease,
Faculty of Veterinary Science, University of Pretoria

September 2020

## Declaration

I, Musaemura Manyenyeka, declare that the research presented in this Dissertation, was conceived and executed by myself, and apart from the normal guidance from my supervisors, I have not received any assistance. I declare that this Dissertation contains my own work, except where acknowledged.

Neither the substance, nor any part of this dissertation has been submitted in the past, or is to be submitted for a degree at this University or any other University.

I hereby grant the University of Pretoria free license to reproduce this dissertation in part or as a whole, for the purpose of research or continuing education.

___________M.M________________ ____28/10/2020________

**Musaemura Manyenyeka (19394994)** **Date**

**October 2020**

# List of Abbreviations

| | |
|---|---|
| **asl** | Above sea level |
| **CFSPH** | Centre for Food Security and Public Health |
| **DGD** | Belgian Development Cooperation |
| **DLVSZ** | Department of Livestock and Veterinary Services of Zimbabwe |
| **ECF** | East Coast fever |
| **FAO** | Food and Agriculture Organisation of the United Nations |
| **ITM** | Infection and Treatment Method |
| **MSDZ** | Zimbabwe Meteorological Services Department |
| **TBD** | Tick-borne disease |
| **UP** | University of Pretoria |

# Abstract

## Spatio-temporal analysis of bovine theileriosis (*Theileria parva*) in Zimbabwe from 1995 to 2018

By

Musaemura Manyenyeka

Study leader(s): Dr C Marufu and Dr W. Tagwireyi

Degree: MSc Tropical Animal Health

Department: Veterinary Tropical Diseases

Bovine theileriosis is a serious veterinary challenge that is responsible for high cattle mortalities and thus limiting cattle production and improvement in the smallholder farming sector of Zimbabwe (Lawrence, 1994). Despite its huge impact on the cattle industry, the spatial and temporal distribution dynamics of bovine theileriosis in the country remain scant and outdated. A retrospective study was therefore conducted to investigate the spatial and temporal patterns of bovine theileriosis in Zimbabwe in the period 1995 to 2018 to improve understanding of the disease's dynamics. It was hypothesised that spatial and temporal patterns of bovine theileriosis in Zimbabwe were unchanged during this period. Data on bovine theileriosis cases were obtained from the Department of Livestock and Veterinary Services of Zimbabwe (DLVSZ) bovine theileriosis database for the period 1995 to 2018. The data were collated in Microsoft Excel and analysed using SatScan® version 9.4.6 for spatio-temporal clustering so as to detect high-risk areas for bovine theileriosis and Studio R® version 11.0 for evaluation of potential risk factors associated with disease occurrence.

A total of 4 540 deaths and 8 728 cases of bovine theileriosis were recorded during the study period (1995 – 2018). Adult cattle (2 496; 29%), the hot wet season (3 627; 42%) and communal areas (6266; 72%) had the highest number of cases recorded. One-year and one-month aggregates detected five and four high risk clusters of bovine theileriosis respectively, all within the last seven years of the study period (2011 – 2018). The multivariate model detected all the six tested variables (province, sex, farming system, season, year and age) to be associated with bovine theileriosis occurrence ($P < 0.2$) in the univariate model. The hypothesis that spatial and temporal patterns of bovine theileriosis were constant from year to year between 1995 and 2018 in Zimbabwe was rejected as it was shown that the spatial and temporal patterns of Zimbabwe bovine theileriosis were not the same over the study period.

The results showed bovine theileriosis cases in relation to the identified potential risk factors, risk areas and risk clusters over time and space and thus, the null hypothesis was rejected. Findings support the fact that there is proliferation of bovine theileriosis during the hot wet season, especially in the communal grazing areas. Recommendations for control and prevention strategies especially in high-risk areas and seasons revolve around better farmer awareness and improved knowledge about the disease, correct and consistent use of acaricides, cattle immunization with the correct vaccine, cattle movement control and improved disease surveillance.

# Acknowledgement

I would like to give thanks and praise to the Almighty God, for the gift of life and the wonderful opportunity and strength to be able to accomplish my studies according to His will and grace. My profound gratitude goes to my supervisor Dr. Chris Marufu, for his unwavering support, guidance and encouragement during the entire thesis period. A special mention goes to my co –supervisors Dr. Tagwireyi and Prof. Etter for their assistance with the necessary statistical analysis of the project. I would also like to express gratitude to the support received from Dr. Spargo on bovine theileriosis data used in this study and his continued listening ear despite my continued pestering. I would like to thank the Belgian Development Cooperation (DGD), Framework Agreement 4 DGD-ITM 2017-2021(FA4) for awarding me the opportunity to undertake my studies through their scholarship.

Many thanks to the University of Pretoria (UP), Faculty of Veterinary Science and the Institute of Tropical Medicine Antwerp, Belgium for awarding me the opportunity to undertake my studies. Special thanks go to Rina Serfontein from University of Pretoria (UP) for her assistance and support throughout the whole study period.

To my beautiful wife Emily, my daughter Michelle and the boys, I would like to mention their tremendous support and love throughout the duration of my studies, my prolonged mental absence as I devoted my thoughts towards the demands of the study.

## Dedication

To my wife Emily, Michelle and the boys, you are my everything.

## Table of Contents

## List of Tables

## List of Figures

# 1. GENERAL INTRODUCTION

## 1.1 Background

Bovine theileriosis is a lymphoproliferative, extremely debilitating and fatal tick-borne disease of cattle caused by protozoan parasites which belong to the genus *Theileria* (Coetzer et al., 1994). *Theileria parva* and *Theileria annulata* are the most pathogenic and economically important *Theileria* species (Fayyaz, 2017). *Theileria parva* is responsible for bovine theileriosis whilst *Theileria annulata* is responsible for tropical (Mediterranean) theileriosis (Nambota et al., 1994). In Zimbabwe, three forms of bovine theileriosis are recognised namely, East Coast fever (ECF), Zimbabwe theileriosis (January disease) and Corridor disease (Stoltsz, 2005). The responsible pathogen is cattle-derived *T. parva* for the former two and buffalo-derived *T. parva* for the latter, respectively (Latif and Hove, 2011). These are distinguished on clinical and epidemiological grounds (Norval et al., 1992).

East Coast fever has been eradicated from Zimbabwe; however Zimbabwe theileriosis and Corridor disease remain a challenge to cattle production (Lawrence, 1991). Zimbabwe theileriosis is an acute and frequently fatal disease of cattle occurring in Zimbabwe, which resembles ECF but is less virulent and follows a seasonal pattern in occurrence (Bishop et al., 2009). Corridor disease also affects cattle, and is usually a more acute and fatal disease than ECF or Zimbabwe theileriosis, often spreading from buffaloes to cattle (Ganaie et al., 2019, Latif and Hove, 2011). McLeod and Kristjanson (1999) reported that globally bovine theileriosis kills approximately 1 million cattle annually with yearly economic losses of up to USD300 million. It is likely that the losses have significantly increased in recent times (Nene et al., 2016). In Zimbabwe, the vectors of bovine theileriosis are *Rhipicephalus appendiculatus* in the cooler parts of the country and *Rhipicephalus zambeziensis* in the more arid parts of the country (Sungirai et al., 2016[a]).

Bovine theileriosis has been reported to occur sporadically in the Highveld and Middleveld of Zimbabwe mirroring the distribution of *R. appendiculatus* in these high rainfall areas (Lawrence et al., 1994). Other authors reported the occurrence of sporadic cases in the Lowveld where conditions are drier and the main vector is *R. zambeziensis* (Madzima and Mutugi, 1996). The distribution and occurrence of bovine theileriosis has recently been reported to have changed affecting a more widespread region than that reported by previous authors (Moyo et al., 2017). These recent reports suggest that there are changes in spatial and temporal patterns of bovine theileriosis in Zimbabwe and an understanding of these patterns is important for the control of the disease in the country.

## 1.2 Problem statement

Bovine theileriosis is considered the most important tick-borne disease of cattle in sub–Saharan Africa (Thompson, 2007). It presents a serious veterinary challenge and a huge economic threat to cattle production-oriented communities in Zimbabwe (Nyahangare et al., 2015). The disease is a major constraint limiting livestock production and improvement through cattle mortalities and widespread morbidities (Coetzer and Tustin, 2004). Despite the huge threat posed on the Zimbabwean cattle industry, bovine theileriosis remains a disease with scant and outdated research publications on its spatial and temporal distribution, hence its continued impact on the country's cattle industry. Increased understanding of the bovine theileriosis scourge will assist decision makers in allocating scarce resources to fighting the disease as well as formulating strategies for its surveillance and control.

## 1.3 Justification

Livestock and livestock products make a significant contribution to the Zimbabwean economy, with cattle alone contributing between 35-38% of the Gross Domestic Product (GDP) attributed to the Agricultural Sector (FAO, 2016[a]). This contribution is, however, threatened by the wanton spread of bovine theileriosis whose temporal and spatial patterns remain scant and outdated. Generating data on spatial and temporal distribution and transmission patterns of bovine theileriosis based on retrospective spatial and temporal data will enable the identification of high-risk areas and significant risk factors associated with bovine theileriosis. Understanding the risk factors will assist in the formulation of national disease surveillance and control strategies in light of limited resources. A retrospective study over a 23-year period will enable the identification of trends and patterns which would otherwise be missed in cross-sectional studies over a shorter period of time. The trends and patterns that may be exhibited by bovine theileriosis will be useful in informing decision makers on strategies to currently deal with the disease.

## 1.4 Aim

The aim of the study was to explore bovine theileriosis with reference to changes in Zimbabwean endemic conditions in order to offer new insights and increase understanding of the epidemiology of the disease.

### 1.4.1 Objectives

1. To analyse historical data on bovine theileriosis cases in Zimbabwe from 1 January 1995 to 31 December 2018
2. To describe the spatio-temporal patterns and identify the high-risk areas of bovine theileriosis in Zimbabwe between 1 January 1995 and 31 December 2018.
3. To evaluate the significance of potential risk factors associated with the occurrence of bovine theileriosis between 1 January 1995 and 31 December 2018.

## 1.5 Hypotheses

1. $H_0$: Spatial and temporal patterns of bovine theileriosis were constant from year to year between 1995 and 2018 in Zimbabwe.

2. $H_0$: The bovine theileriosis control areas have been defined as areas where most of the outbreaks have been reported and form clusters over time and space, more than would be expected by chance alone because of their association to potential risk factors.

# 2. LITERATURE REVIEW

## 2.1 Introduction

Bovine theileriosisis is a major constraint limiting beef cattle production and improvement in Zimbabwe (Thompson, 2007). The disease causes cattle mortality and poses a very serious threat to the cattle industry particularly for the smallholder farmers (CFSPH, 2019). Despite the huge challenge posed to the beef industry in Zimbabwe information on the spatial and temporal patterns of bovine theileriosis in the country is lacking. Retrospective data on the occurrence of bovine theileriosis cases can be useful in determining the spatial and temporal trends of the disease for use in various intervention strategies. The current review aims to highlight the state of affairs of the beef sector in Zimbabwe in the face of the bovine theileriosis threat**.** It discusses the agro- climatic features, describes the beef production systems in Zimbabwe and looks at the history of bovine theileriosis outbreaks. Bovine theileriosis is discussed in detail including its spatial and temporal patterns. A Detailed description of areas where bovine theileriosis is so far known to be prevalent is given, including the distribution of its vector. The review culminates in the analysis of current literature in order to identify bovine theileriosis clusters or high-risk areas in space and time.

## 2.2 Main climatic and geographical features of Zimbabwe

Zimbabwe is a landlocked country in the Southern part of Africa, lying between the $15^0$ 37' S and $22^0$ 24' S latitudes and $25^0$ 14' E and $33^0$ 04' E longitudes and covering an area of 390 580 $km^2$ (FAO, 2004; Mugandani et al., 2012). It has a subtropical climate with four overlapping seasons, namely hot dry season (September – October), hot wet season (November – February), post-rain season (March – May) and cool dry season (June – August) (FAO, 2004) as shown in Table 1 below.

**Table 1: Seasons in Zimbabwe**

| SEASON | TIME PERIOD | TEMPERATURE RANGE |
|---|---|---|
| Hot dry | September – October | 26-36 $^0$C |
| Hot wet | November – March | 26 – 36 $^0$C |
| Post-rain | April – May | 23-31 $^0$C |
| Cool dry | June – August | 20-29 $^0$C |

Adapted from FAO (2004).

Zimbabwe was divided into five (5) agro-ecological natural regions (NR) by Vincent and Thomas (1960) on the basis of mean annual rainfall, temperature and other agro-ecological factors (Svinurai et al., 2017). An agro-ecological region is a land resource mapping unit, with specific climate, landform and soils, land cover and having a specific range of potentials and constraints for land use (Chikodzi et al., 2013). This is achieved through the use of several techniques, with climate taking the centre stage ahead of vegetation, soil type, water resources and ultimately human activities (FAO, 2004).

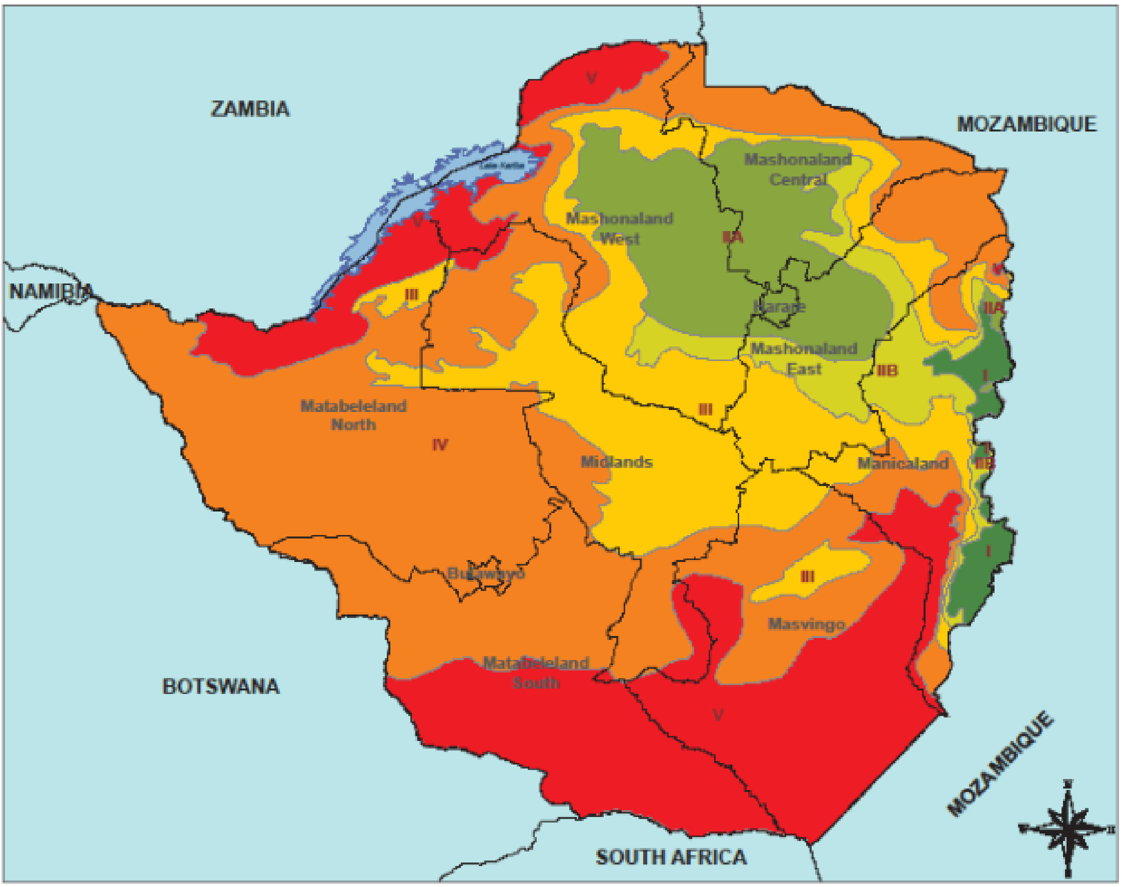
Mugandani et al. (2012) pushed forward the need for reclassification of the current NRs arguing that the current classification has become redundant, outdated and cannot be used to plan sustainable agriculture. According to Chikodzi et al. (2013) climate change and variability has shifted previously derived NRs and, the development of new tools and technologies that are more effective in agro-ecological zonation have necessitated the alteration of the current NRs boundaries. This proposed reclassification resulted in the same number of NRs (5) but with altered size per NR (Mugandani et al., 2012). The findings by Mugandani et al. (2012) point to an increase in the size of NRs I, IV and V by 106 %, 5.6 % and 22.5 %, respectively while NRs II and III recorded a decrease in size of 49 % and 13.9%, respectively. The shrinking of Natural Regions II and III, which are the main food producing areas in Zimbabwe, point to possible reduction in carrying capacities for the regions and thus problems of food insecurity (Chikodzi et al., 2013). The acceptance of these changes remains limited despite the presentation of reports on the decline in land areas under NR II and III in favour of the relatively dry NRs IV and V (Mugandani et al., 2012). The current study will be based on Vincent and Thomas' (1960) classification of the five NRs. The current NRs are characterised in Table 2 below and their sizes are compared to the proposed reclassifications.

**Table 2: Natural Regions and farming systems in Zimbabwe**

| Natural region | Land Area (%) | Reclassification sizes (%) | Mean Annual Rainfall (mm) | Mean Annual Temperature ($^0$C) | Altitude (m) | Farming System | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | **Communal System (%)** | **Partially Commercial (%)** | **Fully commercial (%)** |
| **I** | 1.8 | 4 | >1000 | <15$^0$C | Highveld (1200) | 1 | 18 | 64 |
| **II** | 15 | 7.6 | 750-1000 | 20.5-30$^0$C | Highveld | 8 | 13 | 77 |
| **III** | 18.7 | 16.1 | 650-750 | 20.5-30$^0$C | Highveld | 17 | 22 | 52 |
| **IV** | 37.8 | 39.9 | 450-650 | 30.5-35$^0$C | Lowveld (< 900) | 45 | 5 | 29 |
| **V** | 26.7 | 32.5 | <450 | >35$^0$C | Lowveld | 29 | 17 | 36 |

Adapted from Sungirai et al. (2016); Mugandani et al. (2012) and Chiremba and Masters (2003).

Figure 1 below is a map depicting how the NRs are distributed across the country. NRs IV and V which cover up to 65% of the country's total land area are suitable for semi-extensive and extensive livestock production due to palatable, sweet grass (Svinurai et al., 2017). NRs I and II are the high grain producing regions of the country covering 17% of the country's total land area and are suitable for intensive livestock production (ZIMSTAT, 2015). About 18% of the country's land area falls under NR III which is suitable for semi-intensive livestock production. Beef cattle are raised on natural pastures in all the NRs though predominantly in NRs III, IV and V (Svinurai et al., 2017).

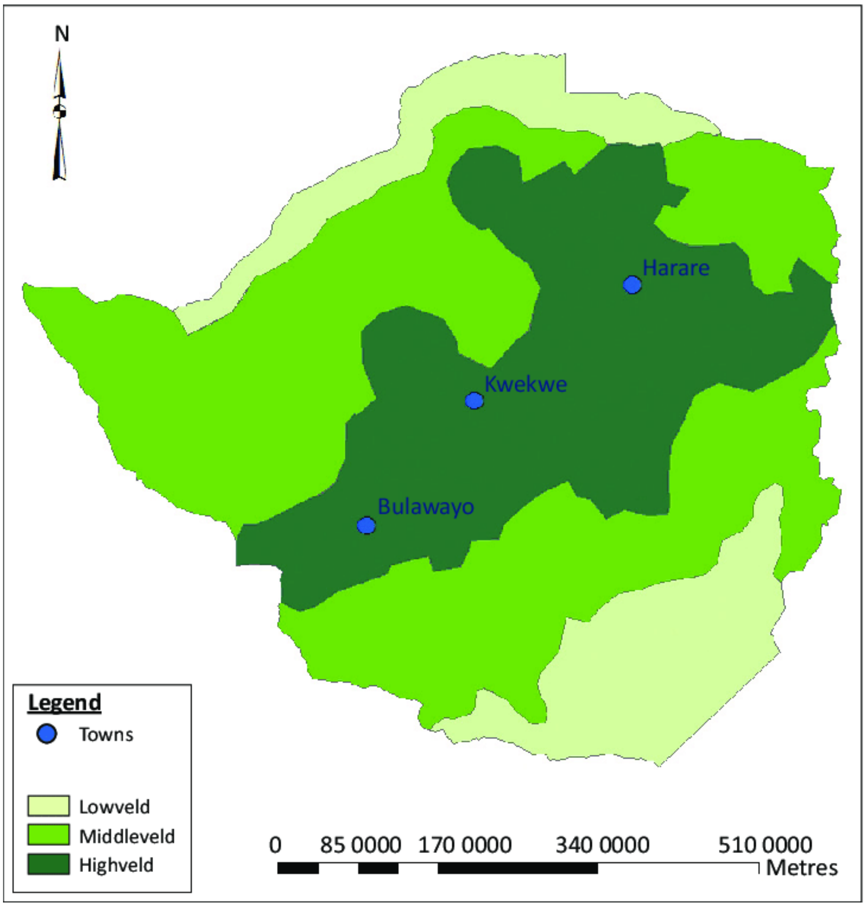


Source: FAO (2004)

**Figure 1: Provinces and Natural Regions of Zimbabwe**

Zimbabwe has an undulating landscape with mountain ranges in the eastern parts and low plains in the Zambezi valley and the Limpopo-Sabi basins where the altitude is below 600 m (FAO, 2004). Using altitude, Zimbabwe can be categorised into 3 distinct relief regions which are the Highveld, Middleveld and the Lowveld (FAO, 2016[b]). The Highveld represents area with altitude greater than 1200 m above sea level (asl), the Middleveld lies between

900m and 1199 m asl and the Lowveld represents the area below 900 m asl (Sungirai et al., 2016[a]). Highveld is NRs I, II and III, Middleveld covers NRIV and Lowveld covers regions V (FAO, 2016[b] ). Figure 2 below shows the 3 relief regions of Zimbabwe.



Source: Gordon et al. (2017)

**Figure 2 : The three relief regions of Zimbabwe**

### 2.3 Beef farming systems in Zimbabwe

The beef sector in Zimbabwe has historically gone through various developmental phases which each had a different focus depending on the prevailing circumstances in the country (Bennet et al., 2019). The colonial and post-colonial period focused on intensive commercial production and exploitation of new emerging market opportunities (Bennet et al., 2019). This was followed by the fast track land reform programme which saw the significant transfer of ownership, shift in use and management of livestock, with repercussions for disease management, marketing and production (Tavirimirwa et al., 2013). The fast-track land reform programme saw the large-scale transfer of land from the commercial (white) to small-scale (black) farmers (Bennet et al., 2019). Bennet et al. (2019) pointed out that the rapidness of the land reform programme resulted in poor data collection and availability which complicated the definition of the beef production systems in Zimbabwe.

The beef sector in Zimbabwe can be categorised into partially-commercial, commercial, partially-communal and the communal systems (Sungirai et al., 2016). These are categorised on the level of technology in use, management level, output and income level, herd size, cattle breed, resources invested and land holding (Tavirimirwa et al., 2013). The farming systems represent different farmer types i.e. communal system represents communal farmers, partially-commercial system represents the old resettlement beneficiaries, partially-communal system represents beneficiaries of the fast-track land reform programme (A1 farms and small A2 farms) and commercial system represents large A2 and the former large commercial farms (Bennet et al., 2019).

Zimbabwe's total cattle population is estimated to be between 5.3 and 5.5 million with 84% of these being found in the smallholder sector (Tavirimirwa et al., 2013). Smallholder farming is the dominant type of farming in Zimbabwe and is undertaken in communal, partially-communal, and partially-commercial farming areas (Sungirai et al., 2016[a]). This highlights the significant role played by the smallholder farmers in the cattle sector in Zimbabwe. Communal farmers own approximately 69%, partially-communal farmers 11%, partially-commercial farmers 10%, and commercial farmers 10% of the national herd (Mujeyi et al., 2015).

Chiremba and Masters (2003) noted the skewed distribution of land between the different cattle production systems, pointing out that the commercial farmers have the majority of their land in the higher potential areas (NRs 1 and II), while communal farmers and partially-commercial farmers are concentrated in the lower agro-potential regions IV and V. About 74% of communal lands are in the semi-arid NRs IV and V (ZIMSTAT, 2015). Table 2 above illustrates land allocations in the NRs for the different farming systems. This has a bearing on the type of vegetation present and consequently tick habitat and challenge in these different farming systems (Moyo et al., 2017).

### 2.3.1 Communal system

The communal system comprises of farmers in a rural setting with small land holdings which average 2.1 ha of arable land, managing cattle herds of up to 10 animals and sharing grazing land (Mutami, 2015). Communal areas are characterised by generally low agricultural potential, erratic rainfall, recurrent droughts, poor soil fertility, poor veld and low cattle herd sizes per farmer (Svinurai et al., 2017). The indigenous breeds or non-descript crossbreds of predominantly indigenous blood adapted to the local environment constitute the majority of cattle in the communal areas (Marufu, 2008). Some of the breeds found in the communal system include Mashona, Nguni, Nkone, Afrikander and their crosses (Tavirimirwa et al., 2013).

Most communal farmers have relatively small herds (<10), lack alternative sources of income and have limited resources to invest in livestock production (Svinurai et al., 2017). Communal cattle are rarely supplemented with commercial feeds or improved fodder crops or legumes (Mapiye, 2006). This limits productivity and results in low beef off-take from the communal areas, reported to be at 5% by Bennet et al. (2019). Group herding and grazing is the common production practice in the communal areas. Cattle are herded by day and penned at night during the hot wet season (Mkuhlani et al., 2018). During the cool dry season, until the beginning of the hot wet season, cattle are let to feed on crop residues following crop harvesting (Nkomboni et al., 2014).

Diseases and parasites are major perennial constraints to communal cattle production in Zimbabwe (Sungirai et al., 2016[b]). The majority of communal farmers are incapacitated to institute their own tick control measures (Mkuhlani et al., 2018). As a result communal farmers' herds are prone to attack by tick-borne diseases (TBD) with very serious negative financial and productivity implications, accounting for 60% of herd mortality in communal cattle (Tavirimirwa et al., 2013). The most common diseases reported by farmers are bovine theileriosis (January disease), blackleg, heartwater, redwater, anthrax and gallsickness (Masikati, 2010). Most of the communal farmers rely on the government-run communal plunge dip tanks which are not very reliable due to erratic supply of acaricides and unavailability of replenishment water (Nkomboni et al., 2014). This is despite the fact that most of Zimbabwean beef cattle are produced by the small holder farmers in the communal areas (Bennet et al., 2019).

### 2.3.2 Partially-communal system

This category represents the A1 and small A2 farmers. These are the beneficiaries of the fast-track land reform programme. Farmers in this category have land holding averaging 6 ha for A1 and 15 ha for small A2 farmers. The partially-communal system provides for farms that are relatively small but adequate to sustain a family and produce a surplus for sale. Farmers have more grazing areas but have limited access to technical support and health services (Bennet et al., 2019). They produce high quality animals but may be constrained by not getting credit and difficulty in marketing their produce. There is a mixture of both the indigenous breeds and the improved breeds inherited from the former white farmers (Bennet et al., 2019). The bulk of farmers in this category rely on government-run dip tanks within close reach to their locality and the remainder use both their own initiative and the government dip tanks (Chiremba and Masters, 2003).

### 2.3.3 Commercial system

This category comprises of former white commercial farmers and the large A2 farmers. Commercial agriculture is practiced on farms formerly owned by white commercial farmers and on A2 farms that are on average 250 ha in NR II and 2000 ha in NR V in size (Bennet et al., 2019). These A2 farms were subdivided into smaller pieces of land and were redistributed during the fast-track land reform programme. The commercial farming system is much more market-oriented contributing up to 80% of all commercial beef sales (Chiremba and Masters, 2003). Livestock are kept in paddocks, grazing is controlled, commercial feed supplements are used and improved forage species are sometimes introduced. Exotic high performing cattle breeds are found in the commercial system e.g. Hereford, Sussex, Simmental and Limousin (Tavirimirwa et al., 2013). Tick-borne diseases are not a major challenge in these areas as the farmers have the finance to institute effective dipping programmes to protect their herds from TBDs in order to curb any economic loss that may occur in the event of a disease outbreak (Chiremba and Masters, 2003).

### 2.3.4 Partially-commercial system

This category represents the beneficiaries of the old resettlement scheme, each farmer with land-holding averaging 3.5 ha (Bennet et al., 2019). Farmers in this category are involved in intensive cattle production for profit. They use a graze and kraal system combining home farm and communal grazing (Svinurai et al., 2017). Tick control in this category is dependent on farmer's initiatives to secure the chemicals for their animals (Sungirai et al., 2016$^{a}$). Some farmers in this group also depend on government-run communal dip tanks for control of ticks on their cattle (Bennet et al., 2019).

## 2.4 Bovine theileriosis

### 2.4.1 History of bovine theileriosis in Zimbabwe

It is reported that *T. parva* was introduced into Zimbabwe in 1901 by cattle imported from Tanzania and spread rapidly causing severe cattle losses (Latif and Hove, 2011). The disease was initially named Rhodesian redwater, but later referred to as African Coast fever, before the name was subsequently modified to East Coast fever (Stoltsz, 2005). Compulsory and strict acaricidal tick control coupled with quarantine, slaughter and tight control over cattle movement introduced 10 years later, led to the eradication of the disease in 1954 (Mcleod and Kristjanson, 1999). In 1936 a buffalo-associated bovine theileriosis characterised by low parasitaemia compared to ECF was reported (Nene et al., 2016). Outbreaks of this disease were common mostly in the hot wet season and the disease was locally known as Zimbabwe theileriosis or January disease (Latif et al., 2001). Zimbabwe theileriosis continues to be a problem in cattle to this day and as such the Zimbabwean government is slowly loosening its policy of rigid tick control measures in order to establish a state of endemic stability to ticks and the diseases they transmit (Latif and Hove, 2011).

### 2.4.2 The aetiology

Bovine theileriosis is an acute and often fatal disease of both wild and domestic bovids caused by infection with protozoa of the genus *Theileria* in the order *Piroplasmida* and suborder Piroplasmarina (OIE, 2018). *Theileria parva* is an obligate intracellular parasite that has a complex life cycle involving morphologically distinct phases in two hosts (vertebrate and invertebrate hosts) (Coetzer et al., 1994). Sporogony and merogony take place in the bovine host while zygotes and kinetes are formed in ticks (Morrison, 2015).

Based on differences in the epidemiology, clinical signs and parasitological parameters in cattle associated with different *T. parva* infections, 3 forms of *T. parva* have been identified (Table 4) (Nene et al., 2016). These are now described as cattle-derived or buffalo-derived, giving rise to three forms of bovine theileriosis, namely, ECF caused by cattle-derived *T. parva* and is very virulent, Corridor disease (Buffalo disease) caused by buffalo-derived *T.*

*parva* and is usually more acute than ECF, and Zimbabwe theileriosis (January disease) associated with another cattle-derived *T. parva* and being less virulent than ECF or Corridor disease (Latif and Hove, 2011).

**Table 4: Distinct epidemiological variants of disease caused by *T. parva***

| Disease | Pathogen | Transmission | Seasonality | Virulence |
|---|---|---|---|---|
| **ECF** | Cattle-derived *T. parva* | Cattle-Cattle | Non-seasonal | Mild infection |
| **Corridor disease** | Buffalo-derived *T. parva* | Buffalo-Cattle | Non-seasonal | Very virulent |
| **Zimbabwe theileriosis** | Cattle-derived *T. parva* | Cattle-Cattle | Rain-season | Less virulent |

Adapted from Stoltsz (2005)

### 2.4.3 Clinical signs

Bovine theileriosis is characterised by high fever (>40$^{o}$C), depression, listlessness, legs standing apart, generalised enlargement of lymph glands such as the parotid, prescapular and prefemoral lymph nodes ,a gradually increasing respiratory rate, dyspnoea, anorexia, low body temperature, diarrhoea, hypothermia, lacrimation and corneal opacity (Abdela and Bekele, 2016[a], Stoltsz, 2005, OIE, 2018). Zimbabwe theileriosis occurs seasonally with disease incidence coinciding with the flush of adult *R. appendiculatus* activity during the hot wet season (i.e. November until March) (Uilenberg et al., 1993). The disease is controlled through good and effective control of its tick vectors by effective and consistent dipping with acaricides (Moyo et al., 2017).

### 2.4.4 Transmission

#### 2.4.4.1 Tick vector

Bovine theileriosis is a complex syndrome related to changes in population dynamics of its vectors *Rhipicephalus appendiculatus* and *Rhipicephalus zambeziensis* (Coetzer et al., 1994).

**a) *Rhipicephalus appendiculatus***

Commonly known as the African brown ear tick, *R. appendiculatus* is widely distributed in the country especially throughout the central and eastern parts of Zimbabwe (Sungirai et al., 2016$^{b}$). The tick's occurrence is influenced by several factors, the most important of which are climate, vegetation and host availability (Norval, et al., 1992). This species is largely restricted to the Highveld region where the climatic conditions of high rainfall, cooler temperatures and host availability provide a suitable environment for the proliferation of *R. appendiculatus* in this region (Sungirai et al., 2016$^{a}$). The species *R. appendiculatus* is absent from areas receiving a mean annual rainfall of less than 500 mm and occurs most commonly in areas receiving 700-2000 mm (Minjauw and Mcleod, 2003). The tick occurs in the cooler parts of the country and is absent from all areas where the mean annual temperature exceeds 22.5 $^{0}$C. It is, however, found in only a few districts where the mean temperature exceeds 20$^{o}$C such as Chiredzi, Bulawayo and Victoria Falls (Sungirai et al., 2016$^{b}$). *Rhipicephalus appendiculatus* is associated with *Brachystegia* woodland (Lawrence, 1992).

### b) *Rhipicephalus zambeziensis*

This species is largely found in the low-lying areas of northern, north-western and southern Zimbabwe (Morrison, 2015). The tick is thus commonly referred to as the Lowveld brown ear tick (Norval et al., 1992). The species *R. zambeziensis* occurs in the drier parts of the country where the mean annual rainfall ranges from 400 to 700 mm with relative humidity of less than 70%. *R. zambeziensis* is restricted to the hotter parts of Zimbabwe where the mean annual temperature is higher than 20°C (Latif et al., 2001). The tick is frequently associated with *Colophospermum mopane* woodland (Lawrence, 1992). Adults of *R. zambeziensis* feed on ears whilst the larvae and nymphs feed on the legs of their hosts (Sonenshine et al., 2002). Nymphs of this tick are very efficient vectors of *T. parva* (Latif and Hove, 2011). *R. zambeziensis* is known to be responsible for transmission of ECF especially during winter in the Southern Province of Zambia and is thus likely to be responsible for winter transmission of bovine theileriosis in Zimbabwe (Norval et al., 1992; Nambota et al., 1994).

Vegetation cover has an influence on the distribution of ticks due to its influence on the microclimate of the tick habitat (Bishop et al., 2004). However both *R. appendiculatus* and *R. zambeziensis* do occur in other vegetation types and there is not a strict association between either species or vegetation type (Lawrence, 1992). Activities such as overgrazing have a marked adverse effect on the tick population (Moyo et al., 2017). Unlike *R. appendiculatus, R zambeziensis* never occurs on hosts or vegetation in high numbers and in the absence of tick control *R. zambeziensis* does not appear to achieve the same high levels of abundance that are characteristic of *R. appendiculatus* (Nambota et al., 1994). *R. appendiculatus* has thus been identified as the main vector for bovine theileriosis (Worthington and Bigalke, 2001). *R. appendiculatus* has also been identified in large numbers in many cattle producing areas on which wild ungulates exist, while similar high levels of *R zambeziensis* have not been recorded either in wildlife reserves or on cattle ranches (Norval et al., 1992). Ecological studies have shown that *R. appendiculatus and R. zambeziensis* need the presence of alternative hosts in order to maintain tick population (Abdela and Bekele, 2016$^{a}$). This explains the increased occurrence of the ticks and the disease in areas where there is interaction between cattle and wildlife (Latif et al., 2001). Spatial distribution of *R. appendiculatus* has also been shown to be determined by the spatial distribution of its hosts (Latif et al., 2001).

The two brown ear tick species, *R. appendiculatus* and *R. zambeziensis* exhibit a strict pattern of seasonal occurrence (Abdela and Bekele, 2016$^{b}$). The pattern of seasonal occurrence of *R. appendiculatus* and *R. zambeziensis* is determined by photophase (Latif et al., 2001). The seasonal cycle is determined by the adults, which are only active under warm, wet conditions when photophase (day length) exceeds approximately 11 hours (Nambota et al., 1994). Adult ticks are most active and abundant during the hot wet season (mid-November – early March), larvae in the cool dry season (April- June) and the nymphs in the dry months of July to October (Latif et al., 2001). More than 95% of Zimbabwe theileriosis outbreaks recorded in the country have been recorded during the period of the adult tick activity (Latif and Hove, 2011). Table 5 below illustrates the various tick stages and the months when they are most active and abundant.

**Table 5: Life cycle stages of *R. appendiculatus* and *R. zambeziensis*, and time when in abundance**

| Life cycle stage | Months when most active and abundant | Season |
|---|---|---|
| Adult | January-March | Hot wet season |
| Larvae | April- June | Dry cold season |
| Nymph | July-October | Dry hot season |
| Diapause (No ticks) | October-December | Hot dry season |

Adapted from Latif and Hove (2011)

Developmental stages of *T. parva* occur in the tick and are transstadially passed through the larva, nymph and adult tick stages, but there is no transovarial transmission (Sonenshine et al, 2002; Minjauw and McLeod, 2003). Larvae or nymphs become infected and transmit infection as nymphs or adults, respectively. Of the two stages, adult ticks are more efficient vectors than nymphs. The ticks acquire infection by ingesting piroplasm-infected erythrocytes during feeding on cattle with circulating piroplasms (Jongejan and Uilenberg, 2004). Infective cattle may be clinically ill, recently recovered, or persistent carriers of the parasite (Abdela and Bekele, 2016[a]). The severity of disease a tick is able to transmit is parasite dose-dependent (Bishop et al., 2004). A tick will receive a higher infective parasite dose from clinically affected animals than from recovered cases and carriers (Abdela and Bekele, 2016[b]).

Data on tick distribution need constant updating due to spatial and temporal changes which have an effect on tick distribution (Sungirai et al., 2016[b]). The land reform programme in Zimbabwe resulted in changes in land-use patterns (Chiremba and Masters, 2003). This had a cascading effect on tick distribution as some ticks are now being found in areas where they were previously not known to occur, due to uncontrolled livestock movement (Sungirai et al., 2016[b]). Introduction of a tick species into an area has important implications for the epidemiology of the infections that they transmit, hence the spatial distribution of disease cases (Sungirai et al., 2016[b]). Theft of fencing from conservancies led to the wildlife (buffaloes) straying into cattle-grazing areas and *vice versa* (Chiremba and Masters, 2003). This led to the spread of the ticks, and by association the pathogens they harbour, into areas where they were not usually found.

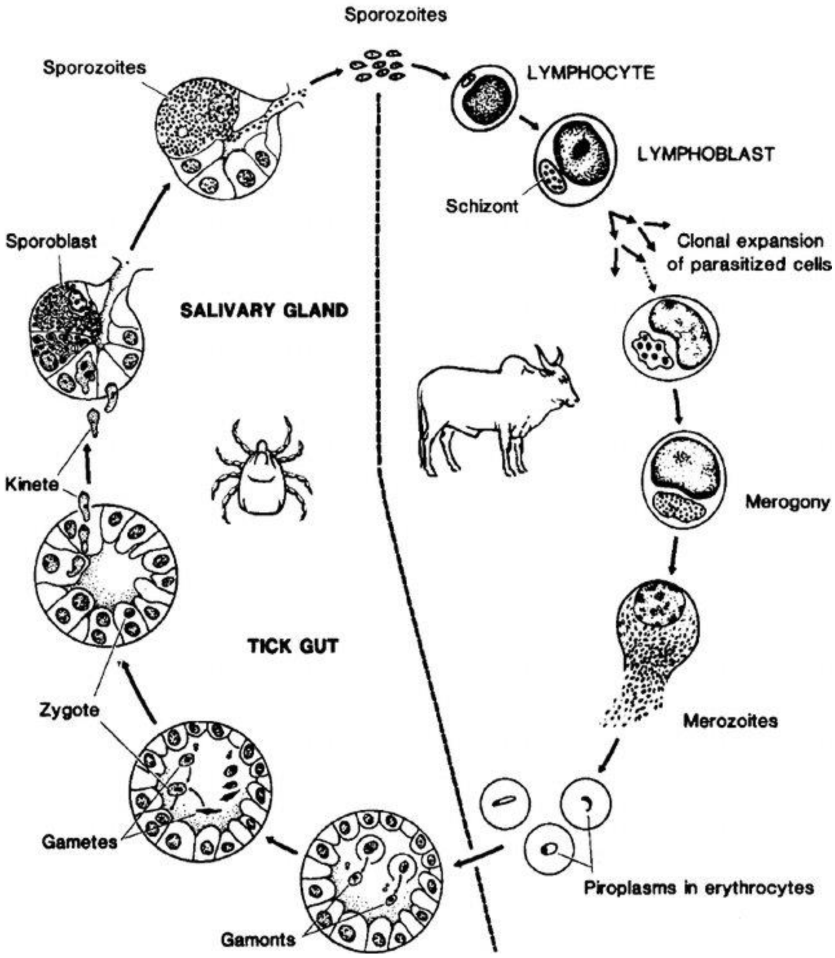
#### 2.4.4.2 Iatrogenic transmission

Bovine theileriosis can also be transmitted through human contact with animals. Humans may aid in the transmission of *T. parva* between infected hosts and susceptible hosts through blood transfusion (Abdela and Bekele, 2016[a]).

### 2.4.5 *Theileria parva* life cycle

Understanding the life cycle of *Theileria parva* is important as it provides information that may be essential for improvement of disease control strategies, and for identifying novel targets of intervention (Nene et al., 2016). *Theileria parva* undergoes a series of sequential developmental changes in the tick and bovine host (Sungirai et al., 2015). *Theileria* sporozoites are transmitted to susceptible bovine hosts through the infected saliva of the feeding adult tick (Abdela and Bekele, 2016[a]). The sporozoites rapidly invade lymphocytes where they mature into macroschizonts and induce the infected host cell to acquire a metastatic, cancer-like phenotype which is the major cause of pathology (Sungirai et al., 2015). Microschizonts undergo merogony to ultimately produce merozoites, which are released from lymphocytes by cell rapture (Nene et al., 2016). The merozoites then invade the erythrocytes (red blood cells- RBC) where they develop into piroplasms (Abdela and Bekele, 2016 [a]).

During the next feeding the larval or nymphal tick ingest the piroplasms and the fusion of the micro and macro gametes produces zygotes which enter cells of the tick gut and develop into motile kinetes that infect the tick gut epithelial cells and migrate to the haemolymph and subsequently infect the salivary glands (Nene et al., 2016). Sporogony occurs in the salivary gland resulting in the multiplication and production of almost 30,000 to 50,000 non-motile sporozoites in each infected acinar cell (Abdela and Bekele, 2016[b]). The sporozoites are injected into the feeding site on the bovine host by nymphs or adult ticks (Nene et al., 2016).
Under normal conditions sporogony is only initiated and sporozoites come to saliva on commencement of feeding on the host. Usually, a tick must be attached for 48–72 hours before it becomes infective (Abdela and Bekele, 2016[b]). If environmental temperatures are high, infective sporozoites can develop in ticks on the ground and may enter the host within hours of attachment. Ticks can remain infected on the pasture for not more than 6 months depending on climatic conditions. Disease is not maintained in the absence of these field vectors (Abdela and Bekele, 2016[a]).



Source Bishop et al (2004)

**Figure 3: Life Cycle of *Theileria parva***

### 2.4.6 Prevention and control

The expensive nature of antitheilerial drugs, the high prevalence of the carrier state infection and the high cost of treatment makes prevention the best option to control theilerial infections. Prevention is achieved by two means; control of the vector tick and control of the theilerial parasite (Abdela and Bekele, 2016[a]).

#### 2.4.6.1 Control of the vector

According to OIE (2018), the most practical and widely used method for the control of bovine theileriosis is the chemical control of ticks with acaricides. Acaricides may be used to control both free living as well as parasitic stages of the ticks (Nambota et al., 1994). Acaricides are applied by spraying, spot-on, injection, acaricide-impregnated ear-tags and bands, and dipping (Jongejan and Uilenberg, 1994). Dipping is considered the most effective of these methods. In Zimbabwe plunge dip is the primary method of tick control in communal and resettled farm communities. Farmers bring their cattle to a centrally located dip tank where they are submerged in the dip wash (Sungirai et al., 2016[a]). A reduction in government subsidy for tick control has resulted in a change of attitude and perception by the farmers with regards to tick control programmes (Nyahangare et al., 2015). However, chemical tick control has its share of challenges which include the high costs of acaricides, lack of dipping infrastructure, lack of funding for dipping infrastructure maintenance, inconsistent or erratic provision of acaricides, inadequate water supply, tick resistance to acaricides and environmental pollution from acaricides (Jongejan and Uilenberg, 1994).

New methods for disease control are required because the reliance on intensive acaricidal tick control has proved to be inefficient and unsustainable, with cattle reared under tick free conditions being highly susceptible to all tick-borne diseases and prone to huge losses when tick control breaks down (Uilenberg et al., 1993). In Zimbabwe huge losses of cattle have been observed in some areas following the breakdown of government-controlled dip tanks which serve the bulk of the communal sector (Moyo et al., 2014). There has also been a shift of the government of Zimbabwe away from strict tick control to one of selective control and establishment of endemic stability in cattle ((Latif et al., 2001).

Tick control can also be achieved through other options e.g. ecological and biological control methods. Ecological method is used for habitat and host linked treatment e.g. removal of vegetation that shelters ticks. Biological control involves the use of tick predators like rodents, birds and ants (Abdela and Bekele, 2016[b]). In the Zimbabwean context these are, however impractical when compared to acaricide use (Jongejan and Uilenberg, 1994).

#### 2.4.6.2 Chemotherapy

Chemotherapeutic agents such as parvaquone, buparvaquone and halofuginone are available to treat *T. parva* infections (OIE, 2018). The hydroxynaphtoquinones are the best antitheilerial drugs (Abdela and Bekele, 2016[a]). These naphthoquinone compounds are effective for treating clinical bovine theileriosis as well as providing a remarkable prophylactic measure against the disease (Uilenberg et al., 1993). Treatments with chemotherapeutic agents do not completely eradicate theilerial infections, thus leading to the development of carrier states in their hosts. These drugs are highly effective when administered during the early clinical stages of the disease and are less effective in the advanced stages in which there is extensive destruction of lymphoid and hematopoietic tissues (Morrison, 2015). Parvaquone is mainly active against schizonts while buparvaquone is active against both schizontes and piroplasms (OIE, 2018). They both should be injected intramuscularly. The cost of these medications is often beyond the capacity of smallholder farmers' resources and the lack of access to veterinary services means that these farmers fail to get antitheilerial drugs administered to their animals in time (Jongejan and Uilenberg, 1994).

#### 2.4.6.3 Vaccination

Due to the shortcomings of vector control, vaccination can also be used to control bovine theileriosis. There is solid evidence from both field observations and from laboratory-based studies that cattle acquire robust immunity to bovine theileriosis following recovery from infection (Norval et al., 1992). Low dilutions of the Boleni strain of *T. parva* from Zimbabwe can be used to immunize cattle in the absence of tetracycline treatment; however, it has been difficult to do the same with other parasite isolates (Latif and Hove, 2011). Heterologous immunity cannot be achieved for strains from different geographic sites, thus combining different isolates become important in achieving the desired protection (Nambota, 1994).

Combinations of different isolates to improve the effectiveness of vaccines has led to the introduction of the Muguga cocktail which consists of three *T. parva* isolates (Muguga, Serengeti-transformed and Kiambu-5) (Nene et al.,2016). Muguga cocktail was shown to provide broad-spectrum immunity to bovine theileriosis (Latif and Hove, 2011). The use of these vaccine cocktails, however, requires utilisation of the infection and treatment method. As the name implies, in ITM the cattle are inoculated with a subcutaneous dose of tick-derived sporozoites and immediately treated with a long acting tetracycline formulation (Morrison, 2015). The treatment results in a mild form of bovine theileriosis followed by recovery and a robust immunity which lasts for the animal's lifetime (Norval et al., 1992). This, however, provides homologous immunity as antigenic diversity prevents attainment of heterologous immunity (Uilenberg et al., 1993). The possibility of introducing live vaccine organisms into areas where the disease is not endemic has remained a concern, limiting the widespread uptake of this method for effective control of the disease (Jongejan and Uilenberg, 1994).

#### 2.4.6.4 Management

Management of the environment and livestock plays an important role in controlling bovine theileriosis. Environmental management involves erection of fencing, pasture rotation, weed and bush control and rotational grazing (Coetzer et al, 1994). Stock management involves provision of appropriate nutrition to the animal for maintenance and production, adequate water and routine health care (Nene et al., 2016). Animals in good health are better able to resist ticks and TBD (Abdela and Bekele, 2016[b]). Stock management also involves the selection of the appropriate breeds in terms of suitability to a particular environment and resistance to disease. Animal movement is also another management aspect which can be crucial in controlling bovine theileriosis. Restrictive movement of infected animals or quarantine measures can be applied locally or at national level to prevent the spread of disease to non-endemic areas (Kotze et al., 1994). In Zimbabwe cattle movement is subject to issuance of movement permits by the veterinary services office. Movement within endemic areas is allowed but movement from endemic to non-endemic areas is only allowed after serious consideration from the veterinary office (Nambota et al., 1994). However, movement control faces many hurdles which include illegal cattle movement (Jongejan and Uilenberg, 1994). Cattle farms can also be relocated away from bovine theileriosis endemic areas or where there is constant contact with reservoir hosts of both ticks and disease e.g. areas near game reserves (Kotze et al., 1994).

## 2.5 Spatial and temporal patterns of bovine theileriosis

### 2.5.1 Spatial and temporal trends

Spatial and temporal patterns of disease define the disease in terms of the defined area it affects i.e. district, province and natural regions and over the time period it is occurring i.e. seasons, months and years (Thrusfied, 2007). Analysis of the spatial and temporal patterns indicates the clustering of disease cases over space and time. Spatial and temporal clustering can assist in the identification of the cause of disease and help in indicating areas for further research (Kulldorff et al., 2005).

Temporal patterns in disease occurrence can be classified into 3 trends, i.e. short-term, cyclical (including seasonal) and long-term (secular) (Thrusfield, 2007). Short-term trends occur within a short space of time in the form of an outbreak, cyclical trends are associated with regular, periodic, cyclical and predictable fluctuations in the level of disease occurrence.

Seasonal trends are a special type of cyclical trend where periodic disease incidences are associated with particular seasons (Kulldorff et al., 2005). Most cases of Zimbabwe theileriosis occur between January and March and coincide with the period of adult tick activity (Latif et al., 2001; Latif and Hove, 2011). Primary outbreaks occur in herds with moderate to heavy infestation of ticks. Occasional outbreaks occur during the winter months and coincide with the nymphal activity of the vector (Uilenberg et al., 1993). Secular trend occurs over a long period of time and represent a long-term interaction between host and parasite. Temporal trends (short term, cyclical and secular) can occur simultaneously and may be mixed with random variation. In such circumstances there will be a need for a statistical analysis in order to identify the various trends/changes. One method which can be used is the regression analysis, a technique for investigating the relationship between two or more variables (Thrusfield, 2007).

The temporal patterns that occur in recorded morbidity and mortality rates may be either true or false (Chikerema et al., 2012). Recording of mortality rates in veterinary medicine is not compulsory thus; details of trends in mortality in animals are usually unavailable (Thrusfield, 2007). In Zimbabwe not all deaths of cattle are captured on official records. Farmers are not obliged to report their dead animals to the veterinary officials and some deaths may go unreported (Chikerema et al., 2012).

### 2.5.2 Spatial distribution of *Theileria parva*

In Zimbabwe it has been reported that theileriosis occurs sporadically in the Highveld and usually during the period December to May (Latif et al., 2001). Theileriosis has devastated Midlands, Manicaland and the three Mashonaland Provinces (East, West and Central) of Zimbabwe (Moyo et al., 2017). There is a need to identify characteristics which may be common in all these areas and ways to manage these characteristics so that proper strategies in managing theileriosis are identified. Spatial and temporal patterns of theileriosis enables the identification of areas worst affected. It also enables the analysis and identification of any trends and characteristics which may be enabling in the spread of theileriosis or proliferation of theileriosis vectors. Cattle production in Zimbabwe has undergone tremendous transformation with the introduction of the agrarian land reform in the year 2000 (Moyo et al., 2017). The agrarian land reform resulted in removal of boundary fences, uncontrolled animal movements and breakdown in national dipping programme whose impact on the distribution dynamics of bovine theileriosis needs to be investigated.

Many risk factors can be identified for bovine theileriosis. Bovine theileriosis prevalence is dependent on geographic region, tick density, climatic conditions, age, gender, management practice, immunity and cattle breed (Abdela and Bekele, 2016[b]). The disease occurs when there is high tick activity mainly during summer season, presence of ticks on animals, e.g. *R. appendiculatus* is most active at onset of rain, increased age of animal high ambient temperatures during the hot dry season promote *R. appendiculatus* activity (Nene et al., 2016). The risk factors associated with bovine theileriosis in Zimbabwe remain poorly understood and need to be elucidated, particularly in identified high-risk areas.

### 2.5.3 Methods of determining spatial and temporal patterns

Time series analysis is one of the methods which can be used to detect temporal patterns of disease (Thrusfield, 2007). A time series records events that occur over a period of time e.g. cases of disease. The disease cases are plotted on a graph with time on the horizontal axis of the graph (Kulldorff et al., 2005). The trend is then detected through either free-hand drawing; calculation of rolling (moving) averages and regression analysis. Free-hand drawing the joining of points by eye indicating a trend, a rolling average is the arithmetic average of consecutive groups of measurements. To construct a rolling 3-month average of the monthly data, sequential sets of three adjacent values are averaged (Thrusfield, 2007). Regression analysis is a statistical technique for investigating relationships between two or more variables.

Retrospective study is one of the methods used to determine the spatial and temporal patterns of a disease. The current study used retrospective bovine theileriosis data compiled by the Department of Livestock and Veterinary Services of Zimbabwe (DLVSZ) to determine the spatial and temporal patterns of the disease over the 23-year period.

## 2.6 Conclusion

Bovine theileriosis has been a leading TBD causing high cattle mortalities in Zimbabwe especially for the smallholder farmers. The disease is thus a threat and a constraint for the improvement of cattle productivity in Zimbabwe. The continued prevalence of the disease in cattle producing regions of the country threatens to diminish the existing cattle herds. Bovine theileriosis hinders the introduction of improved cattle breeds into the regions where it is endemic, thus limiting productivity. There is, however, a lack of comprehensive studies on the spatial and temporal patterns of theileriosis in Zimbabwe in order to enable policy makers to effectively and efficiently formulate policies to control the continued threat from theileriosis on the cattle industry in the country. A detailed study of the spatial and temporal patterns of theileriosis is essential to fully understanding the characteristics of the diseases and the factors which may be contributing to the incidence and prevalence of the disease in Zimbabwe.

# 3. MATERIALS AND METHOD

## 3.1 Ethical clearance

Ethical clearance to undertake the research was obtained from the Faculty of Veterinary Science Research Ethics Committee (Appendix 2). Permission to access and use the national database on bovine theileriosis was also obtained from the Department of Livestock and Veterinary Services: Division of Veterinary Services in Zimbabwe (Appendix 3).

## 3.2 Study area

Zimbabwe is a landlocked country located in southern Africa, covering 390 757 km$^2$ and bordered by four countries, namely South Africa to the south, Botswana and Namibia to the west, Zambia to the north and Mozambique to the east. It is divided administratively into ten provinces with 59 districts. The country has a tropical climate characterized by four seasons, namely the hot dry season (September - October), hot wet season (November - February), post-rain season (March - May) and cool dry season (June - August) (Chikerema et al., 2012; Moyo et al., 2017). The average cattle population in Zimbabwe has been around 5 million animals for the past 10 years and the sector accounts for a significant proportion of agricultural activities and greatly contributes to the livelihood of the communal communities (Nkomboni et al., 2014).

## 3.3 Data collection

Retrospective data were obtained from the Epidemiology and Disease Control Unit of the Department of Livestock and Veterinary Services in Zimbabwe (DLVSZ). The DLVSZ has the mandate to detect and report bovine theileriosis cases and outbreaks in the country. Bovine theileriosis cases were confirmed based on clinical signs, post-mortem findings and laboratory tests.

Data entered in excel was collected from monthly and annual reports from the DLVSZ over the 23-year period between 1 January 1995 and 31 December 2018. The database consisted of cases that had confirmation of diagnosis by laboratory tests and were captured on the national database. The data were captured, sorted, cleaned, validated and verified to enable generation of descriptive statistics of bovine theileriosis cases on Microsoft Excel spreadsheet. Replicated entries were identified and deleted leaving one entry per case; incomplete records were identified and verified for completeness. Data captured included affected districts and provinces, grid references for the dip tanks where cattle are dipped, number of cases and farm type.

## 3.4 Data analysis

### 3.4.1 Descriptive statistics

Analysis of bovine theileriosis cases and deaths reported over the study period was done to generate descriptive statistics in order to describe temporal (annual, monthly and seasonal) and spatial (district and province) distribution of the disease. The statistics described included the total number of cases and deaths from bovine theileriosis, distribution of the cases and deaths over the study period, number of cases as compared to the age of the animal affected and recorded over the study period.

### 3.4.2 Space-time analysis

To detect high rates of bovine theileriosis or space-time clusters that compare disease occurrence risk within and outside the scanning areas (windows) was done using a space-time permutation model incorporated in SaTScan. The method involved the detection of clusters of bovine theileriosis outbreaks that were significantly different in cases where the space-time interaction was considered and provided their delimitations by the use of cylindrical scanning windows with a circular base of variable location and radius representing geographical space (Kulldorff et al., 2005). A time aggregate of one year and a location setting that included location identification in the scanning window, if at least one set of coordinates is included, was used in the analysis. The test used the number of bovine theileriosis cases per outbreak at each point and the number of susceptible animals provided by the DLVSZ census database to determine high risk regions and their number. The groups with high values of log likelihood ratio (LLR) were considered the most likely clusters and a maximum window size of 50% of the population at risk was set (Kulldorff et al., 2005).

### 3.4.3 Regression analysis

Association between the number of theileriosis outbreaks and the risk factors was assessed using a generalized linear model with Poisson distribution for count data (number of outbreaks). Variables assessed were age, sex, year, province, farming system and season. The goodness of fit of the model was tested using the deviance goodness of fit test (Faraway, 2016). In the case of significant test ($p<0.05$) it means a significant difference between the model fits and the data that could be due to the missing of important factors in the model or to over-dispersion of the data. In order to deal with over-dispersed data we used a quasi-Poisson model (Verhoef and Boyeng, 2007). The final model was determined by assessing the validity of the removal of variables in the model by the analysis of deviance which compared the model with the variable and without the variable. We applied the parsimony rule by retaining the model with the lowest number of explanatory variables which did not differ significantly with the model with more variables. The model outcome is related to count data (number of cases) and relative risk (RR) with 95% confidence intervals (95% CI) of fixed effects were estimated for each. Once the model was chosen we used an analysis of deviance for generalized linear model fits using the F test which is more appropriate for the model where the dispersion is estimated by moments such as the quasi-Poisson model. This analysis of deviance allowed us to test for the global significance of each of the risk factors retained in the model (Hastie and Pregibon, 1992). The regression analysis was carried out using the R 3.5.0 software (R Development Core Team., 2018).

# 4. RESULTS

## 4.1 Descriptive analysis

### 4.1.1 Bovine theileriosis cases in Zimbabwe from January 1995 to December 2018

A total of 8 728 cases (4 188 live cases and 4 540 mortalities) were detected and recorded during the period 1 January 1995 to 31 December 2018. The annual distribution of bovine theileriosis cases recorded over the duration of the study period is shown in Figure 4. There were variations in the number of cases which started very low from 1995 (93 cases) peaking in 1997 (279 cases) before dropping in 1999 (43 cases). The cases remained relatively stable from 1999 until a slight peak in 2011 (577 cases) followed by another wave of increments from 2012, peaking in 2016 (756 cases). There was a slight drop in cases in 2017 followed by an exponential increase in 2018. The highest number of cases (5 221) was recorded in 2018 accounting for 60% of reported cases over the entire study period.

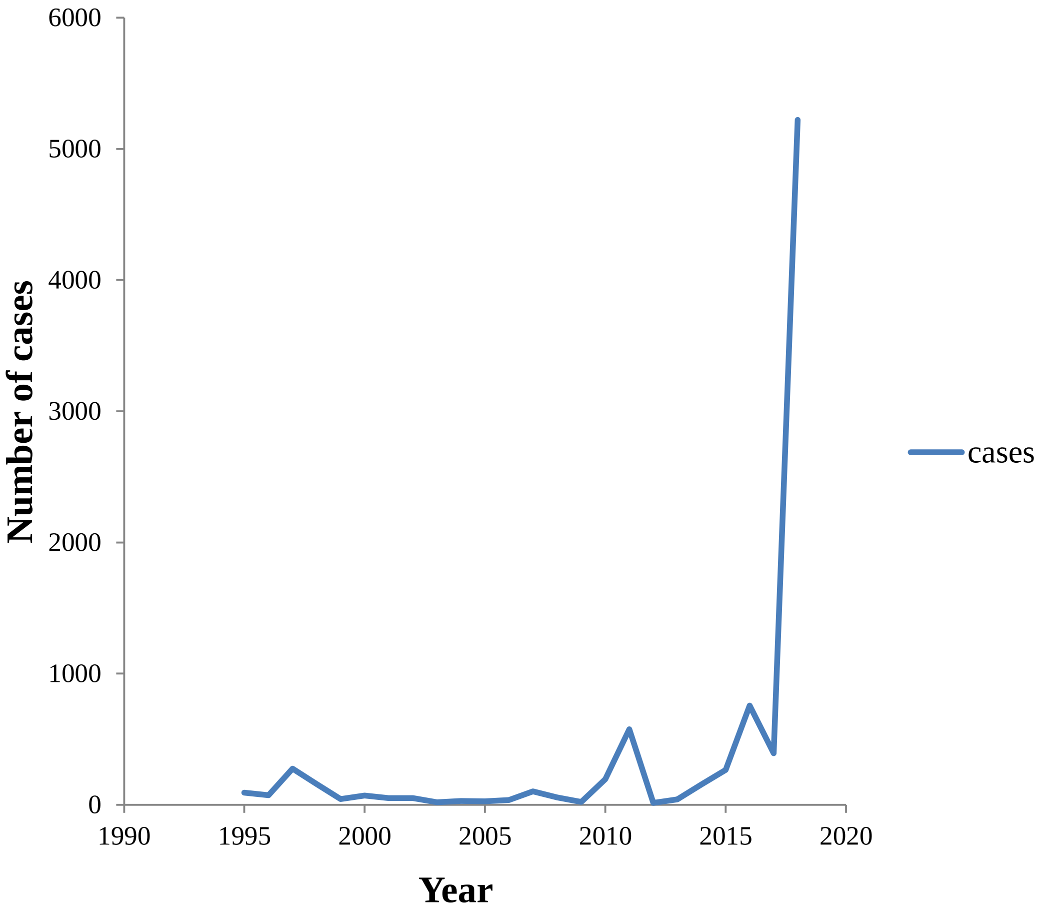


**Figure 4:Yearly distribution of bovine theileriosis cases in Zimbabwe from January 1995 to December 2018**

### 4.1.2 Bovine theileriosis and different age groups

Adult cattle (2 496 cases; 29%) were the most severely affected age group followed by sub-adults (197 cases; 5%), juveniles (94 cases; 3%) and lastly neonates (45 cases; 0.5%) as shown in Figure 5 below (Refer to Appendix 1 for the cattle age groups segregation). More deaths from bovine theileriosis were recorded in adult cattle (1 028 deaths; 23%) followed by sub-adults (197 deaths; 4%), juveniles (94 deaths; 2%) and neonates (12 deaths; 0.3%).

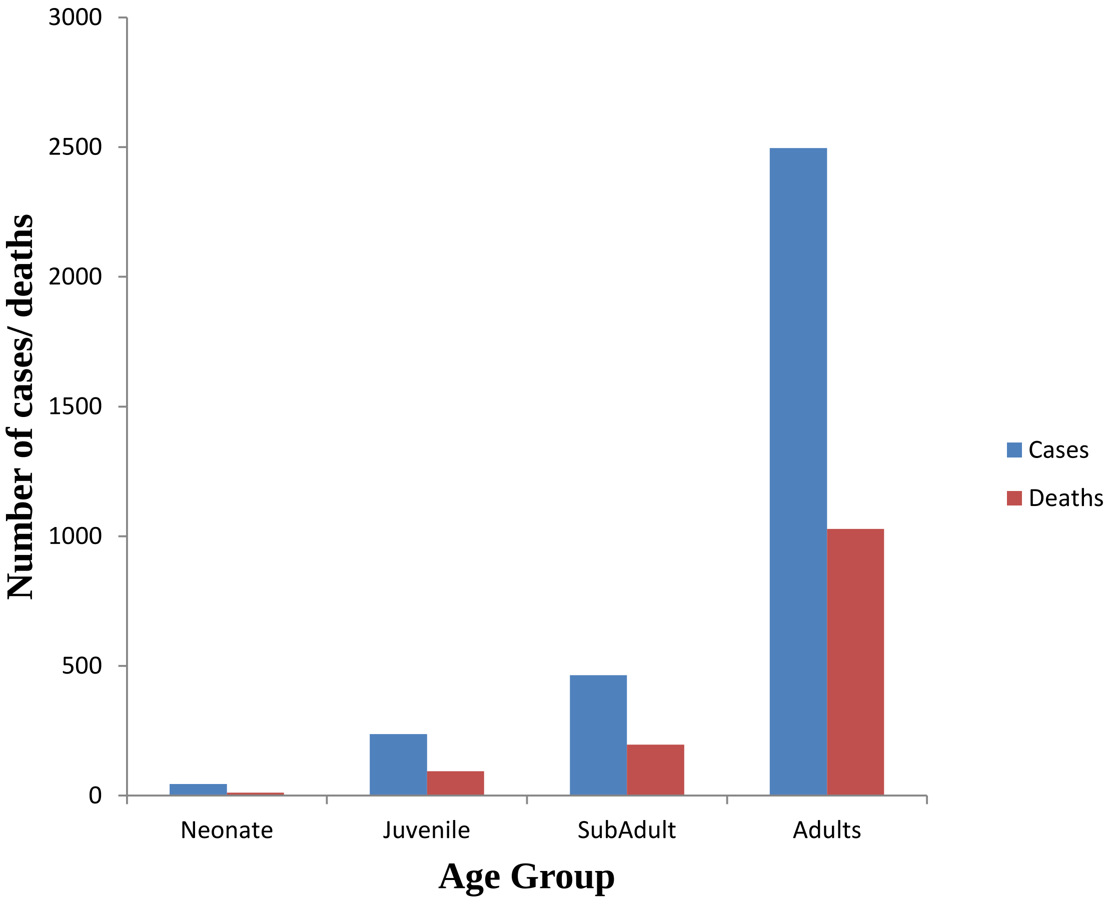


**Figure 5: Bovine theileriosis cases and deaths in relation to age of animal**

### 4.2 Spatio-temporal clustering

Bovine theileriosis outbreaks are thought to be clustered and this study tried to identify significant spatio-temporal clusters based on the chosen aggregation time. For this study 2 units of measurement were chosen, taking into consideration the epidemiology of bovine theileriosis and the objectives of the study. These are one-year aggregation time and one-month aggregation time. Hence the total length of the study period was divided by the length of time interval aggregation.

### 4.2.1 Clustering using one year aggregation time

A total of five high rate clusters were identified using one-year aggregation time (Figure 6). Cluster 1 covered an area with a radius of 92.81 km spanning from Makoni district in Manicaland Province to Wedza, Marondera, Murehwa and Goromonzi districts in Mashonaland East Province. Cluster 1 was under NRII and lasted from 01 January 2011 to 31 December 2018. Cluster 2 was located around Mwenezi district in Masvingo Province under NR V, covering an area with a radius of 39.13 km and lasted from 01 January 2016 to 31 December 2016. Cluster 3 was located around Chegutu and Kadoma area in Mashonaland West Province under NR III covering an area with a radius of 41.33 km radius and lasting from 01 January 2018 to 31 December 2018. Cluster 4 was located around Bindura area in Mashonaland West province under NR II, covering an area with a radius of 0.001 km and lasted from 01 January 2018 to 31 December 2018. Cluster 5 was located around Chikomba, Chirumhanzu, Kwekwe, Kadoma and Chegutu covering an area of 31.74 km radius and lasted from 01 January 2018 to 31 December 2018. Cluster 1 (3 580 cases) contained the bulk of the cases followed by Cluster 5 (1 220 cases), Cluster 3 (640 cases), Cluster 2 (457 cases) and lastly Cluster 4 (257cases).

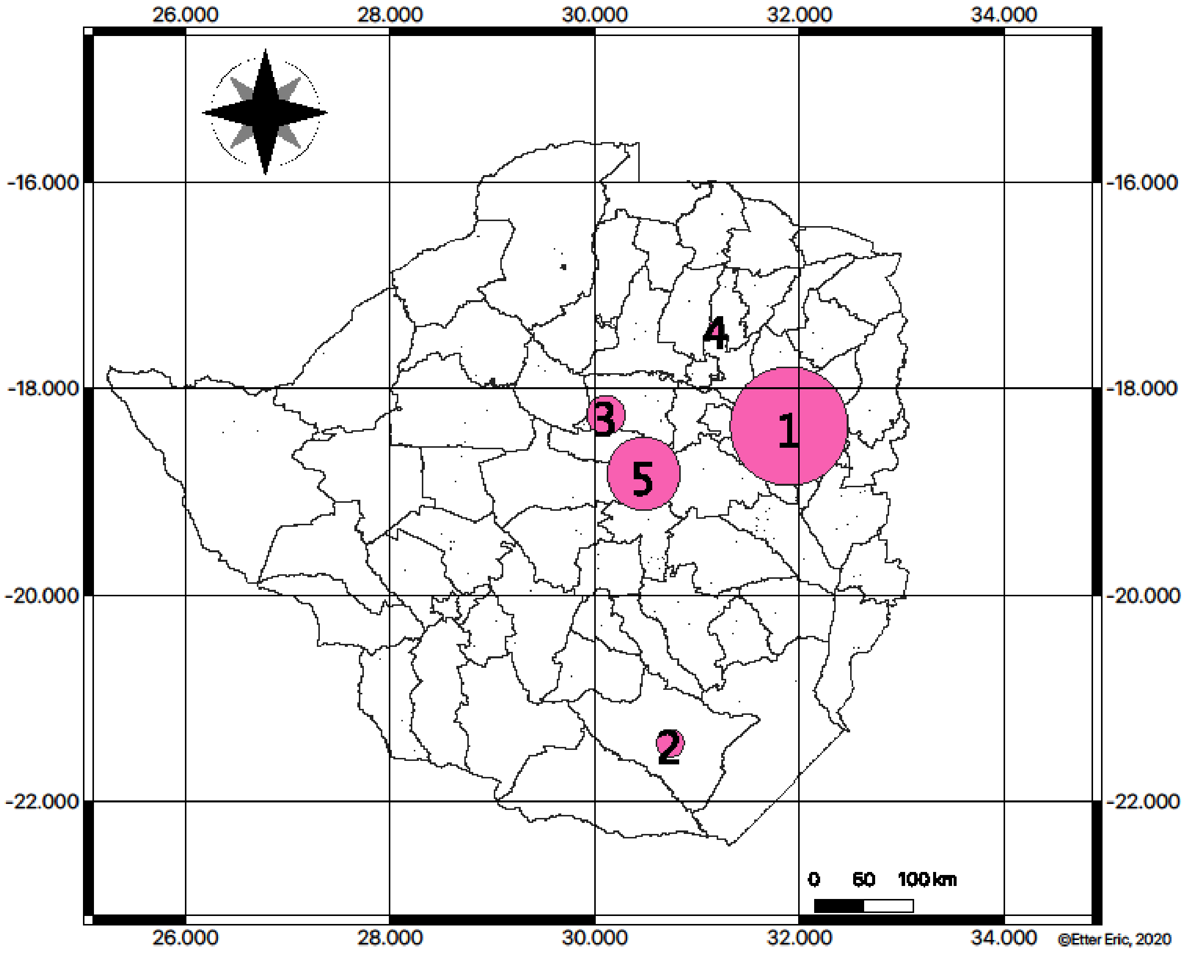


**Figure 6: Spatio-temporal clusters of bovine theileriosis in Zimbabwe with a one-year aggregation time**

**Table 3: Summary of spatio-temporal cluster analysis of bovine theileriosis in Zimbabwe using the one year time aggregation**

| Cluster | Timeframe | Observed | Expected | RR | p-value |
|---|---|---|---|---|---|
| 1 | 2011/1/1- 2018/12/31 | 1981 | 288.40 | 8.31 | < 0.001 |
| 2 | 2016/1/1- 2016/12/31 | 457 | 7.92 | 60.40 | < 0.001 |
| 3 | 2018/1/1- 2018/12/31 | 640 | 45.20 | 15.05 | < 0.001 |
| 4 | 2018/1/1-2018/12/31 | 257 | 5.58 | 47.44 | < 0.001 |
| 5 | 2018/1/1- 2018/12/31 | 1220 | 482.39 | 2.74 | < 0.001 |

### 4.2.2 Clustering using one-month aggregation time

Considering one-month as aggregation time, four high rate clusters were identified as illustrated in the map below (Figure 7). Cluster 1 was much broader covering an area with a radius of 78.79 km located around Makoni, Wedza, Chikomba, Seke, Murehwa and Marondera districts which are under NR II and lasted from 01 February 2011 to 31 December 2018 (Table 4). Cluster 2 was located around Mwenezi area in Masvingo Province which is under NR V. It covered an area with 39.13 km radius and lasted from 01 March 2016 to 31 March 2016. The third cluster was located around Chinhoyi, Makonde and Zvimba districts which are in Mashonaland West Province under NR II. Cluster 3 covered an area with 106.6 km radius and lasted from 01 June 2018 to 31 December 2018. Cluster 4 was located around Chirumhanzu, Kwekwe and Kadoma area in the Midlands province under NR III. Cluster 4 covered an area with 46.77 km radius and lasted from 01 January 2018 to 30 September 2018. Cluster 1 recorded (1579) the bulk of the cases followed by Cluster 4 (1227) then Cluster 3(872) and lastly Cluster 2 (440).

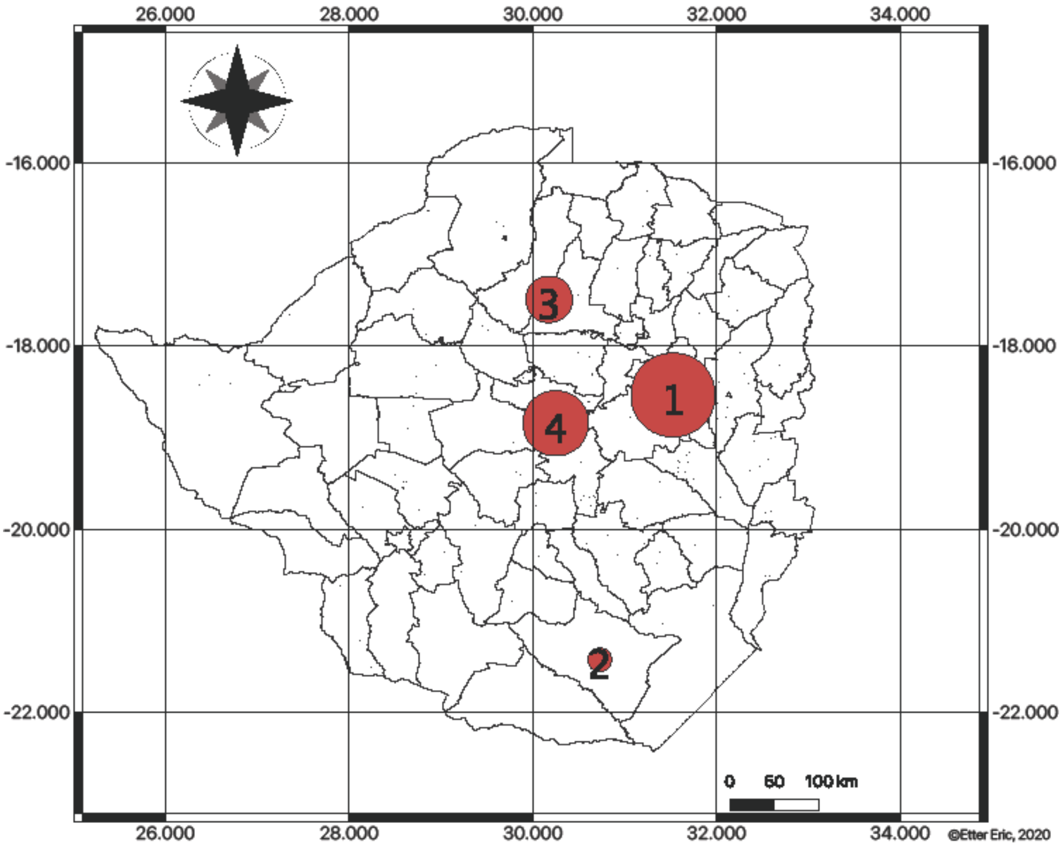


**Figure 7: Spatio-temporal clusters of bovine theileriosis in Zimbabwe with a one-month aggregation time**

**Table 4: Month on month spatio-temporal cluster analysis of bovine theileriosis cases in Zimbabwe from 1995 to 2018**

| Cluster | Timeframe | Observed | Expected | RR | p-value |
|---|---|---|---|---|---|
| 1 | 2011/2/1-2018/12/31 | 1579 | 180.89 | 10.17 | < 0.001 |
| 2 | 2016/3/1- 2016/3/31 | 440 | 3.95 | 116.53 | < 0.001 |
| 3 | 2018/6/1- 2018/12/31 | 872 | 60.95 | 15.57 | < 0.001 |
| 4 | 2018/1/1/- 2018/9/30 | 1227 | 426.68 | 3.14 | < 0.001 |

### 4.2.3 Common high-risk areas between the two time aggregates

Makoni, Marondera, Wedza and Murehwa districts were common for Cluster 1 and Mwenezi district was common for Cluster 2. These five districts were identified as the common high-risk areas on the different aggregation times. Makoni district is in Manicaland province, while Marondera, Wedza and Murehwa are in Mashonaland East Province and Mwenezi district is in Masvingo Province. Chirumhanzu, Kwekwe and Kadoma appeared in Cluster 5 for the one-year aggregation time and in Cluster 4 for the one-month aggregation. The three districts were common in these two clusters and the two clusters occupied almost the same position on the Zimbabwean map.

Cluster 1 had a slightly bigger radius (92.81 km) in one-year aggregation time as compared to the one-month aggregation time; however its timeframe in both aggregation times lasted from 2011 to 2018. Cluster 2 had the same radius (39.13 km) and similar timeframe (2016) for both aggregation times. For one-year aggregation time Cluster 3 had a radius of 41.33 km while for one-month aggregation time Cluster 3 was much bigger with a radius of 106.6 km, however, it had a similar timeframe (2018) in both aggregation times. Cluster 4 had a very small radius (0.001 km) for one-year aggregation time than for one-month aggregation time (46.7 km) with a similar timeframe (2018) in both aggregation times. One month-aggregation time did not have a fifth cluster while one-year aggregation time had Cluster 5 with a radius of 31.74 occurring in 2018.

Makoni district had the highest number (1273) of bovine theileriosis cases and was common in both clustering hence indicating that it’s a high risk area for bovine theileriosis. Seke district had the second highest bovine theileriosis cases with 1086 cases, followed by Gutu district with 806 cases. Makoni, Seke and Gutu were as a result identified as high risk areas for bovine theileriosis. The three districts accounted for 36% of all the reported bovine theileriosis cases over the study period.

### 4.3 Distribution of bovine theileriosis in different farming system in Zimbabwe

Communal system (6266 cases; 72%) had the highest number of bovine theileriosis cases followed by the commercial system (1569 cases; 18%), partially-commercial system (819 cases; 9%) and lastly the partially-communal system (74 cases; 1%) (Figure 8).

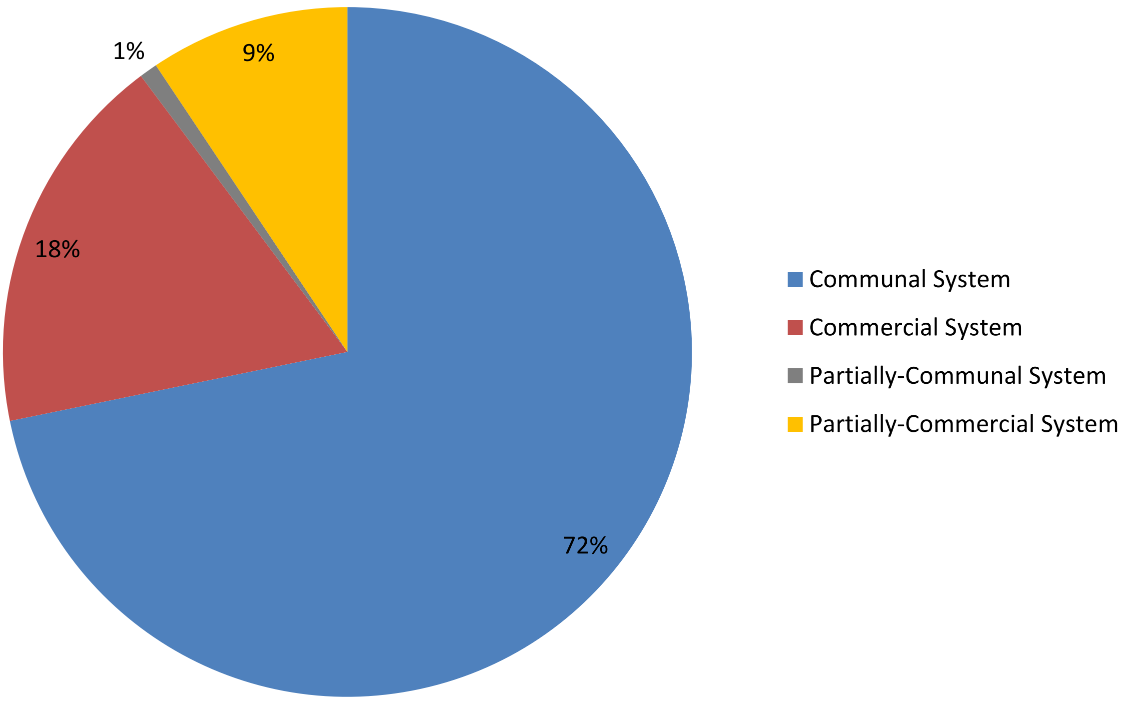


**Figure 8: Distribution of bovine theileriosis cases in the different farming systems**

### 4.4 Distribution of bovine theileriosis in Natural Regions (NRs) of Zimbabwe

Bovine theileriosis was recorded in seven of the country's 10 provinces and in 36 districts out of the country's 59 districts. The affected provinces were Manicaland (NRI, II, III, IV, V), Mashonaland Central (NRII, III, IV), Mashonaland East (NRII, III, IV), Mashonaland West (NRII, III, IV, V), Matabeleland North (NRIII, IV, V), Masvingo (NR III, IV, V) and Midlands (NR III, IV). Manicaland Province recorded the highest number of cases with 2443 cases accounting for 28% of all the recorded cases. Mashonaland East (2153 cases; 25%) had the second highest number of cases followed by Masvingo (2057 cases; 24%), Mashonaland Central (1208 cases; 14%), Mashonaland West (583 cases; 7%), Midlands (246 cases; 3 %) and lastly Matabeleland North (38 cases; 0.5%). The results thus reveal that more cases were recorded in NR I to III and fewer cases in NR IV and V.

The province with the highest number of cattle mortalities was Mashonaland East (1406 deaths; 31%) followed by Masvingo (947 deaths; 21%), Mashonaland Central (915 deaths; 20%), Manicaland (614 deaths; 14%), Midlands (215 deaths; 5%) and lastly Matabeleland North (14 deaths; 0.3%). Figure 9 below shows the cases and deaths per province.

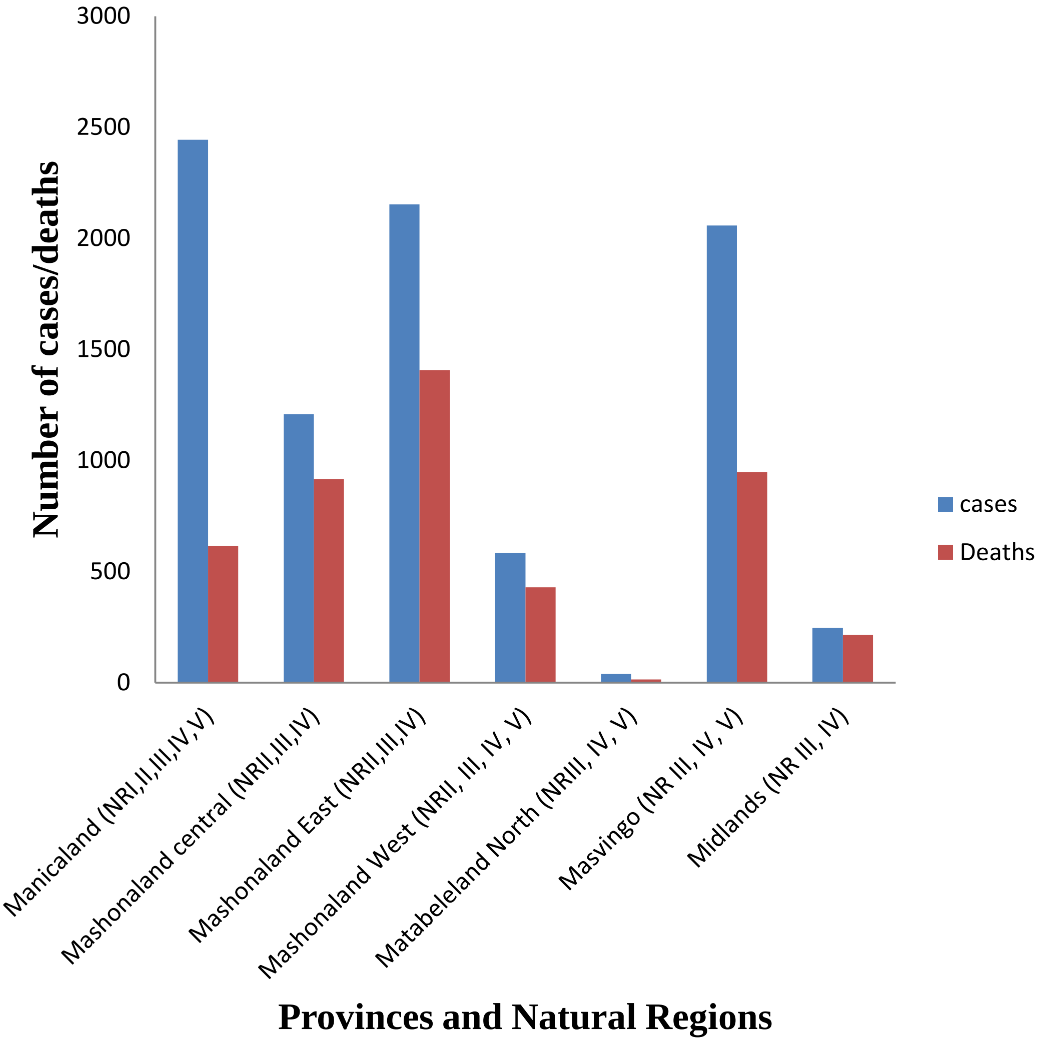


**Figure 9: Distribution of bovine theileriosis cases and deaths in the different provinces/ natural regions in Zimbabwe (1995-2018)**

### 4.5 Districts with reported cases of bovine theileriosis 1995-2018

The year 1995 had the least number (2) of districts affected with bovine theileriosis while 2018 had the highest number of districts, recording a total of 30, accounting for 81% of the districts affected by bovine theileriosis. The number of districts affected by bovine theileriosis started very low at the beginning of the study period in 1995 (2 districts) before a spike occurred in 2000 (6 districts). The number of districts dropped to 4 in 2001 and stabilised up to 2007. This was followed by a spike in 2008 which had 15 districts affected. 2009 saw the number of districts dropping again to 3 with the number steadily fluctuating between 3 and 5 districts till 2014 when there was a sudden sustained increase of the number of districts from until 2018. From this analysis it can be concluded that there was a five-year interval between 1995 and 2000 when there was a first peak and then an eight-year interval between 2000 and 2008 when there was a second peak. This is followed by a six-year gap before another peak in 2014 followed by a sustained increase from 2015 onwards to 2018 when the last peak occurred. Figure 10 represents the number of districts that recorded bovine theileriosis against each year over the period under review.

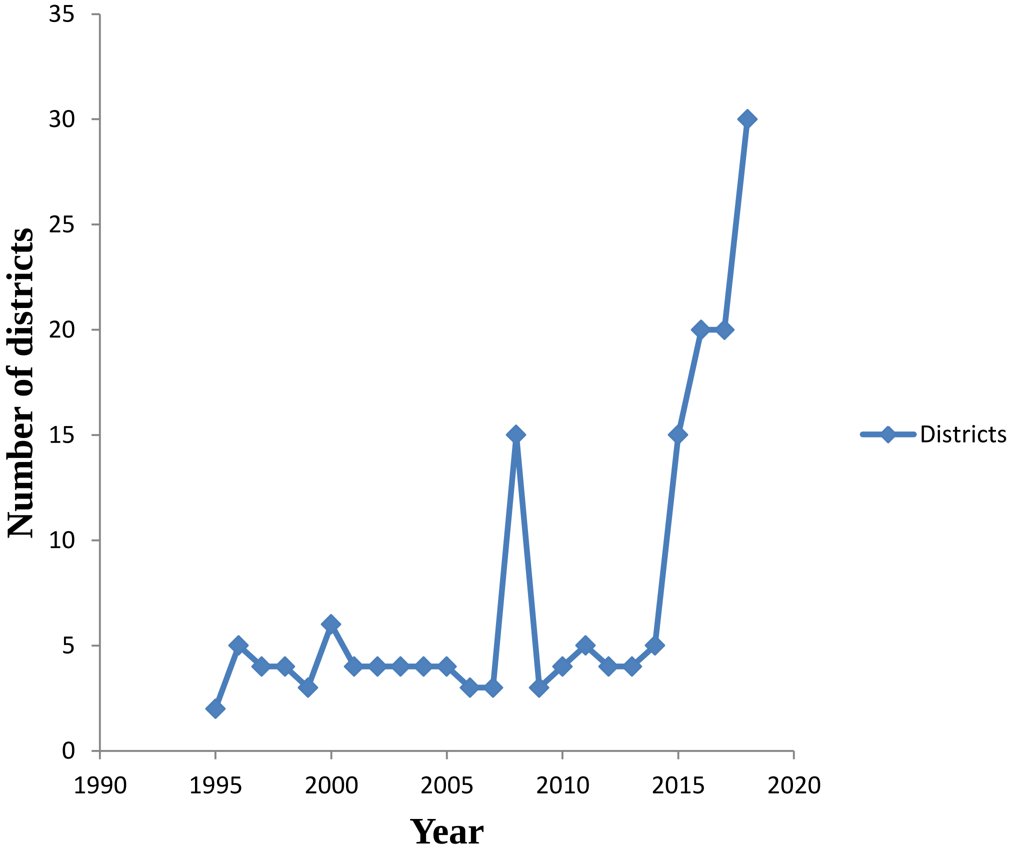


**Figure 10: Number of districts with reported bovine theileriosis cases from 1995 to 2018**

Bovine theileriosis was recorded in 36 districts distributed across 7 provinces. Affected districts were predominantly distributed in the eastern half of the country up to the Midlands Province with a few cases in the western parts. Figure 11 below shows the map with districts affected by bovine theileriosis over the study period.

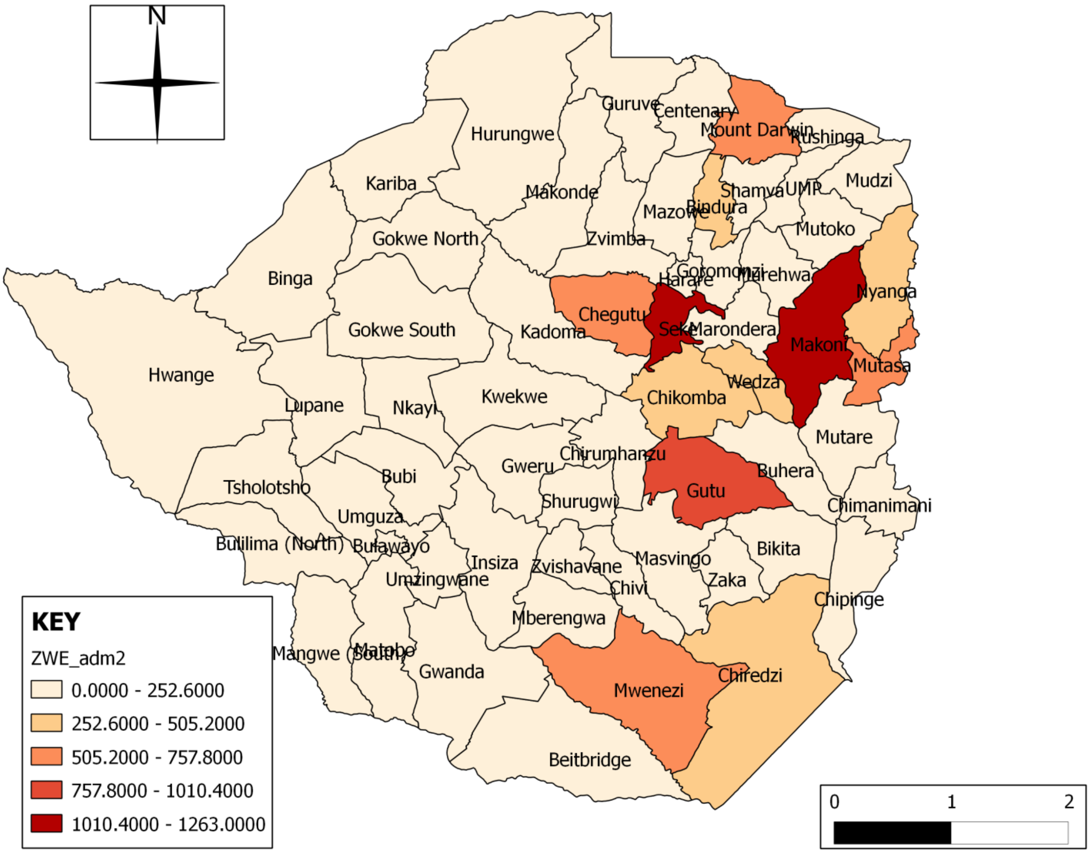


**Figure 11: Number of bovine theileriosis cases per district over the study period**

Mashonaland East had the highest number of affected districts per province with 8 districts followed by Manicaland with 7 districts, followed by Mashonaland Central and Masvingo with 5 districts each, Midlands and Mashonaland West with 4 districts each then lastly Matabeleland North with 3 districts. Makoni district in Manicaland Province recorded the highest number of cases with 1263 cases accounting for 14.5% of all the recorded cases followed by Seke district in Mashonaland East Province with 1086 cases accounting for 12% of all the recorded cases. Of the 1263 bovine theileriosis cases reported in Makoni district 521 were from the commercial sector, 390 were from the communal sector and 352 were from the partially commercial sector. The least number of cases were recorded in Mudzi, Sanyati and Umguza districts with each accounting for 0.01% of all the recorded cases.

### 4.6 Temporal distribution of bovine theileriosis in Zimbabwe from January 1995 to December 2018

The hot wet season (3627 cases; 42%) had the highest number of cases of bovine theileriosis followed by the cool dry (1928 cases; 22%), the hot dry (1741 cases; 20%) and lastly the post-rain (1433 cases; 16%) seasons (Figure 12). The hot wet season (1418 deaths; 31%) also had the highest number of cattle mortalities followed by the hot dry (1281 deaths; 28%), the cool dry (1222 deaths; 27%) and lastly the post-rain season (620 deaths; 14%).

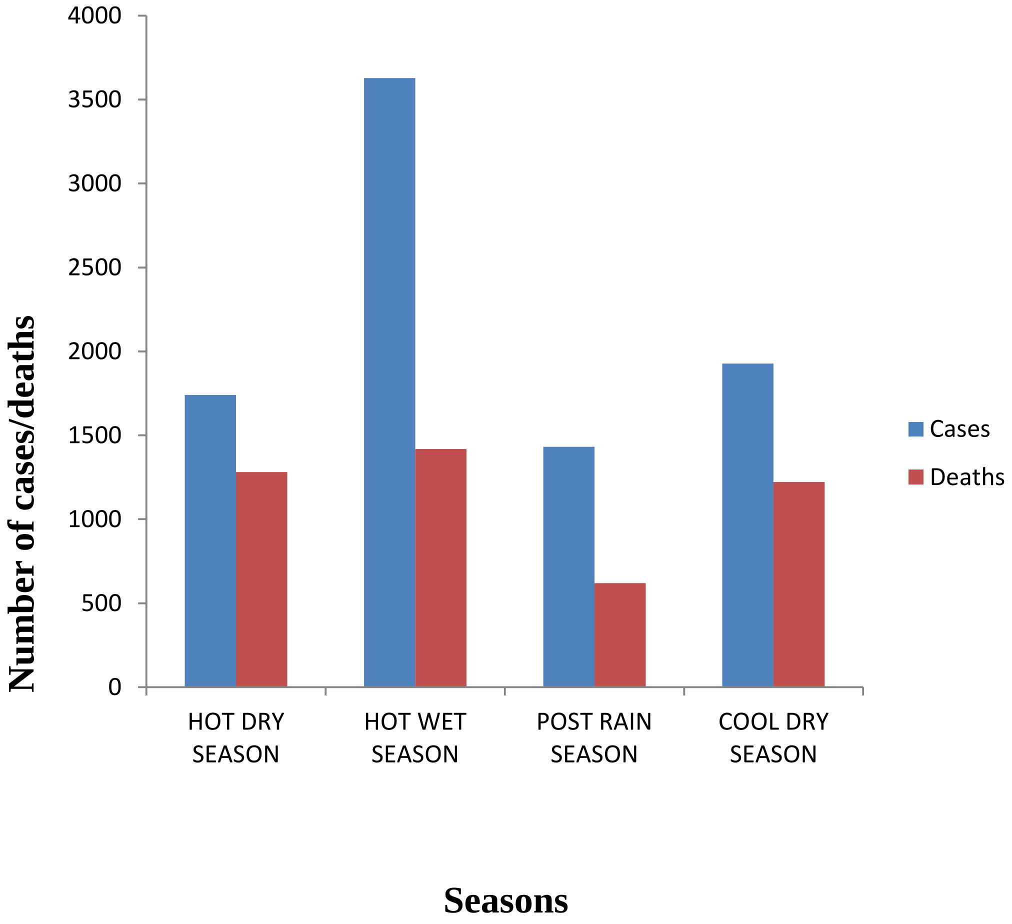


**Figure 12: Seasonal distribution of bovine theileriosis from 1995 to 2018**

### 4.7 Monthly distribution of Zimbabwe theileriosis

The months of February and March had the highest number of cases on a per month basis (1485 cases; 17%) and consistently over the period under review. January (966 cases) recorded the second highest number of cases, followed by May (880), June (826), September (823), August (554), November (525), July (385), April (250) and lastly December (171). Figure 13 below illustrates the monthly distribution of bovine theileriosis over the study period.

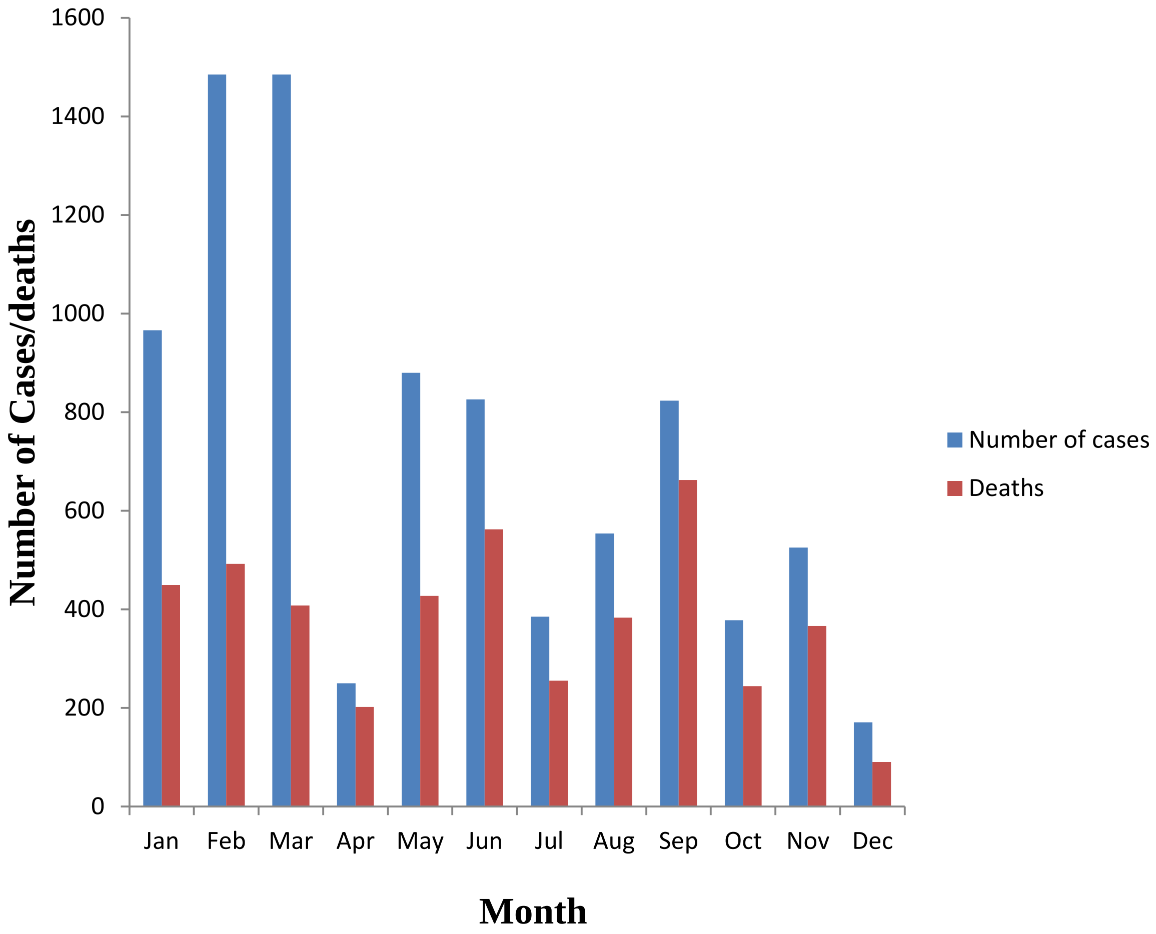


**Figure 13: Monthly distribution of bovine theileriosis cases and mortalities from 1995 to 2018**

From the study, it is evident that the months of February and March are the dominant months over the study period, with more years recording the highest number of cases during these months. The exception was in 2018 when June (733) had the highest number of cases.

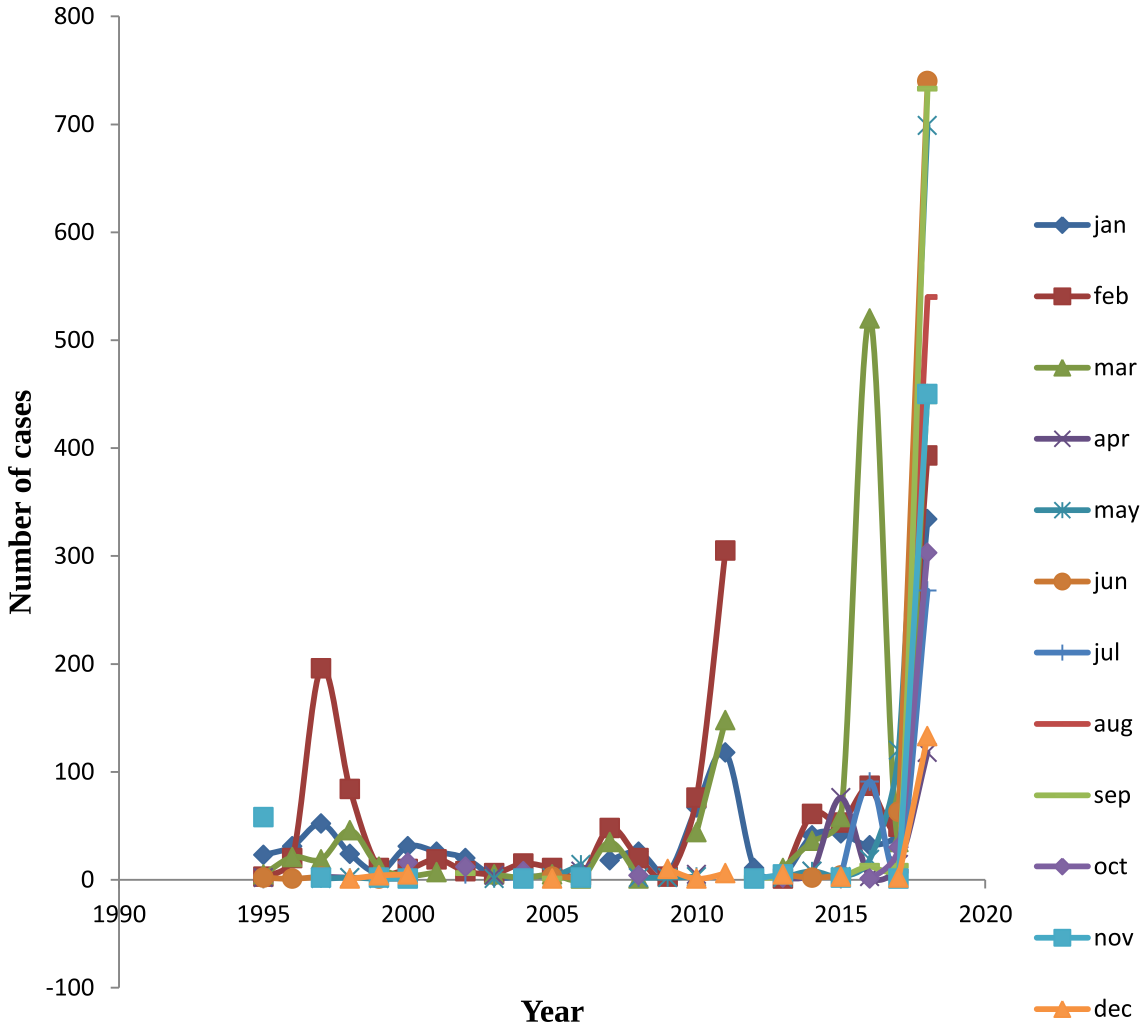


**Figure 14 : Monthly distrubition of bovine theileriosis cases over the study period**

### 4.8 Regression analysis

All the six variables tested were found to be associated with bovine theileriosis occurrence in the univariate model according to the assumed cut-off ($p \leq 0.20$) at this step. These variables were included in the multivariate model and again all the variables were found to be statistically significant and associated with bovine theileriosis occurrence. Table 5 below summaries the results for the variables.

**Table 5: Risk factors identification for bovine theileriosis outbreaks in Zimbabwe(1995-2018)**

| | **Risk Ratios (RR)** | **LL** | **UL** | **Pr(>\|z\|)** | **Analysis of Deviance: Pr(>F)** |
|---|---|---|---|---|---|
| **(Intercept)** | 2.65 | 1.86 | 3.78 | **0.000** | |
| **PROVINCE (reference Manicaland)** | | | | | |
| Mashonaland Central | 0.93 | 0.67 | 1.29 | 0.657 | <2.2 10-16 |
| Mashonaland East | 0.77 | 0.57 | 1.05 | 0.102 | |
| Mashonaland West | 3.01 | 2.22 | 4.09 | **0.000** | |
| Masvingo | 1.42 | 1.05 | 1.93 | **0.023** | |
| Matabeleland North | 0.58 | 0.17 | 2.00 | 0.385 | |
| Midlands | 2.08 | 1.28 | 3.38 | **0.003** | |
| **SEX (reference: Male)** | | | | | |
| Female | 1.17 | 0.85 | 1.61 | 0.346 | 1.09 10-9 |
| **FARMING SYSTEM (reference: Commercial)** | | | | | |
| A1 farm | 0.99 | 0.34 | 2.83 | 0.978 | 5.05 10-10 |
| A2 farm | 2.09 | 1.27 | 3.44 | **0.004** | |
| Communal | 0.63 | 0.47 | 0.86 | **0.004** | |
| Small scale | 0.004 | 1.05 | 2.35 | **0.026** | |
| **AGE (reference adult)** | | | | | |
| Juvenile | 0.75 | 0.44 | 1.28 | 0.285 | 3.06 10-7 |
| Neonate | 0.47 | 0.13 | 1.68 | 0.246 | |
| Subadult | 0.89 | 0.58 | 1.36 | 0.579 | |

# 5. DISCUSSION

## 5.1 Bovine theileriosis cases in Zimbabwe from January 1995 to December 2018

A retrospective study on data gathered by the DLVSZ on bovine theileriosis over the study period was undertaken so as to understand the context in which the disease outbreaks occur in cattle. Relying on such data is known to have drawbacks which cannot be ignored. Underestimation of the severity of the disease cannot be ruled out as the data only records reported cases (Maravanyika et al., 2012). Overestimation may also have occurred due to misdiagnosis of bovine theileriosis (Moyo et al., 2014). Considering that the study focused only on reported cases confirmed by laboratory tests, the study managed to analyse a total of 8728 reported cases which could be an underestimate of the extent of the disease at national level given the length of the study period. Error in compiling the data at national level also further complicated issues. Critical data cleaning and further verification with the relevant authorities were done in order to make sure that errors were kept to a minimum. Nevertheless, useful epidemiological information to improve decision making related to bovine theileriosis was revealed by the study.

The relatively low number of cases observed from 1995 to 2011 can be attributed to the general lack of awareness of the disease amongst the cattle producers, coupled with good veterinary control and management of disease during this time period. From 1995 to 2000, before the land reform programme, the country had efficient veterinary services with tight controls on cattle movements within the country (Thomson et al., 2012). The fences to control cattle and wildlife movements were also still intact around high-risk areas e.g. around game reserves. A number of cases may have gone unreported which could have resulted in the low number of cases over this period. The sustained increase in the number of cases, especially during the last 3 years of the study period, and the huge peak in bovine theileriosis cases in 2018 may be attributed to compromised control activities due to escalating costs of acaricides in face of the economic meltdown which plagued the country following the fast-track land reform programme (Bennet et al., 2019). Furthermore, the indiscriminate destruction of fences as a result of the land reform programme from the year 2000 onwards may have resulted in uncontrolled cattle movement and straying of wildlife into cattle grazing lands and *vice versa*, likely contributing towards the increase in bovine theileriosis cases (Thomson et al., 2012). Improved awareness and educational campaigns about the disease due to its increased occurrence and mortalities in cattle may likely have led to better surveillance and reporting by farmers.

Zimbabwe had severe drought episodes in the following farming seasons: 1991/92, 1994/95, 2001/02, 2002/03, 2006/07, 2011/12, 2015/16 and 2018/19 (Frischen et al., 2020; FAO, 2016[b]). Drought is a product of climate-related factors such as rainfall, moisture deficiency and temperature. These factors resulted in an increased burden on the already economically challenged government due to the economic downturn over the preceding years (Frischen et al., 2020). Droughts are not good for animal production as they deprive animals of adequate grazing and water (Nkomboni and Beekman, 2015). Drought-affected animals are prone to attack by diseases due to impaired immunity and may become emaciated due to limited pastures (Nkomboni et al., 2014). Farmers may be forced to move cattle across vast lands in search of pastures and drinking water for their animals, inadvertently spreading the disease and its vectors (Fayyaz, 2017). All these factors associated with drought have the potential to cause an increase in the disease challenge and may likely help to explain the peaks in bovine theileriosis that were recorded from 2016 onwards.

### 5.2 Bovine theileriosis cases and cattle age groups

The higher number of cases recorded in adult animals and low numbers in neonates concurs with the known fact that bovine theileriosis usually affects cattle that are older than 1 year and is rarely seen in calves (Nkomboni and Beekman, 2015). Lower occurrence in calves may have been as a result of maternal immunity from maternally-derived antibodies (Billiouw et al., 2002). Calves also carry fewer ticks than adult cattle and may thus receive a lesser infective pathogen dose than that required to cause disease (Koch et al., 1990). Maternal antibodies to *T. parva* wane at about 6 months of age making cattle that are more than one year of age more susceptible to *T. parva* infection (Muhanguzi et al., 2014). The maternal immunity most likely also protected the calves from death. The higher mortalities in adult cattle and lower mortalities in calves observed in the current study corroborates reports in the literature that mortality may exceed 90% in adult animals but is usually much lower in calves (Soneshine et al., 2002).

### 5.3 Spatio-temporal clustering and high-risk areas

The high-risk clusters for bovine theileriosis observed throughout Zimbabwe is an interesting result, as outbreaks of the disease were traditionally restricted to the high rainfall areas of the country, namely the Highveld and the Middleveld (Lawrence et al., 1994). The current study revealed five high risk clusters using the one-year aggregation which represent high-risk bovine theileriosis areas in Zimbabwe. The highest number of cases recorded in Cluster 1 may be attributed to the prevailing climatic conditions and vegetation cover characteristic of the NR II which experienced warm temperatures and high rainfall, hence good grass and herbage cover giving rise to proliferation of the tick vector *R. appendiculatus* (Moyo et al., 2014). Cluster five recorded the second highest number of cases. Outbreaks in this area can be attributed not only to the high rainfall and favourable temperatures in the region but its proximity to the main highway and the presence of a good road network, which creates new opportunities for invasive vectors (Medlock and Leach, 2015). The trade of live animals can be a significant factor in the dissemination of disease or its vectors (Nkomboni and Beekman, 2015). The least number of cases in Cluster 4 may be due to the lack of grass cover in the area caused by overgrazing in the locality (Norval et al., 1992). Overgrazing is not conducive for the tick vector, thereby resulting in a reduced number of cattle at risk of contracting bovine theileriosis. Vegetation cover affects the microclimate which is essential for the survival of the free-living stages of the tick vector. Without vegetation cover *R. appendiculatus* disappears (Norval et al., 1992).

Of the 4 clusters which were identified using one-month aggregation time, Cluster 1 had a larger radius which could likely be attributed to the conducive agro-ecological conditions (warm temperatures and high rainfall) for the proliferation of the tick vector for bovine theileriosis (Latif et al., 2001). Cluster 2 had the smallest number of cases which could most likely be attributed to the prevailing conditions which are prohibitive to the proliferation of the tick vector. Since Cluster 2 which covered Mwenezi district is in Masvingo Province, outbreaks of bovine theileriosis are historically not common in this Lowveld area as it has low rainfall and high temperatures which are not conducive for proliferation of the tick vector (Lawrence et al., 1994). The presence of a cluster in such an area could be attributed to the fact that the farming area is adjacent to the Gonarezhou National Park and, due to the indiscriminate destruction of fences as a result of the land reform programme, this has resulted in increased uncontrolled cattle movement and straying of wildlife into cattle grazing areas and *vice versa* (Thomson et al., 2012). This constantly exposes cattle to reservoir hosts, their ticks and the diseases they transmit (Abdela and Bekele, 2016[b]).

The temporal pattern of the clusters is also quite interesting with Cluster 1 lasting from 2011 to 2018 for both the one month and the one year aggregation times, which could be attributed to the economic challenges which befell the country resulting in a breakdown in the government-run dipping system for the cattle (Frischen et al., 2020). Cluster 2 lasted only in 2016 for both one month and one year aggregation times. Clusters 3, 4 and 5 lasted only in 2018 for one month aggregation time and for one year aggregation time which could strongly be attributed to the economic meltdown in the preceding years which had a peak in 2017 and resulted in the breakdown of national tick control programmes hence increased bovine theileriosis cases (Bennet et al., 2019).

The spatio-temporal distribution of bovine theileriosis has been shown to be very diverse with some areas being identified as high-risk. Knowledge of high risk areas enables the formulation of effective contingency plans for the different risk areas, hence development of a differentiated strategy of vaccination and other control strategies (Chikerema et al., 2011). Prior knowledge of bovine theileriosis risk areas before any control measure is implemented would be very important in knowing which areas to prioritise (Olwoch et al., 2008).

Makoni district in Manicaland Province was identified as a high-risk area for bovine theileriosis due to the occurrence of high number of cases. Surprisingly, Makoni district recorded more cases from the commercial sector (521) as compared to the communal sector (390) in contrast to all the other districts which had more cases in the communal sector. The commercial sector is known to prefer exotic breeds to local breeds with maximisation of profits in mind (Mpofu, 2002). Exotic breeds tend to be more susceptible to ticks and hence to bovine theileriosis if inadequate tick control is instituted, which may have caused the rise in bovine theileriosis cases in Makoni district (Thompson, 2007). The generally high number of cases in Makoni district may also be attributed to the optimal environmental conditions for maintaining the existence of the tick vector *R. appendiculatus* i.e. wet conditions and adequate temperature (Norval et al., 1992).

Seke district in Mashonaland East Province and Gutu district in Masvingo Province were also identified as high-risk areas. It is important to note that in these districts, a large communal and resettled farmer population exists and this may have likely contributed to poor tick control measures and resultant spikes in theileriosis cases (Chiremba and Masters, 2003). Furthermore, Gutu is in the lowveld where *R. zambeziensis* is the main tick vector and cattle are often grazed close to game reserves, further increasing their risk of exposure to wildlife which harbour\ the vector and the disease (Nambota et al., 1994). There is a need for further epidemiological investigations in these identified high-risk areas to establish the risk factors for bovine theileriosis which may be contributing to the high occurrence of the disease in these areas.

### 5.4 Spatial distribution of bovine theileriosis in different farming sectors

The finding that the majority of the bovine theileriosis cases were recorded in the communal sector as compared to the other farming sectors was expected, given that the communal areas demographically carry the bulk of the cattle population (69%) in Zimbabwe (Mujeyi et al., 2015). Communal areas are overstocked, share poorly managed pastures and practice communal herding which increases the risk to exposure and disease transmission amongst the cattle (Chikerema et al., 2011). The communal system is characterised by poor accessibility to public and private veterinary services, lack of knowledge and awareness of animal diseases (bovine theileriosis) and poor access to veterinary drugs and chemicals e.g. acaricides, most of which may have contributed to the increased number of disease cases from this system (Mutami, 2015). Most communal farmers rely on government-run dip tanks, which may have increased disease occurrence due to deterioration of tick control measures as a result of failure to buy replenishment chemicals due to the economic crisis which crippled the government in the period under review (Nyahangare et al., 2015). The failure of the dipping system may also have exposed how vulnerable the communal sector’s cattle are to TBDs having been overly dependent on acaricides for protection, given the many challenges associated with acaricides usage including the cost of the acaricides, development of acaricides resistance and environmental threat posed by continued use of acaricides (Uilenberg et al., 1993).

The lowest number of cases was recorded in the partially-communal sector. According to Bennet et al. (2019), the newly resettled farmers (A1 and small A2) have limited access to technical support and hence lack knowledge and awareness of animal diseases. Limited technical support provision most likely resulted in underreporting of cases by the A1 and small A2 farmers (Madzima and Mutugi, 1996). Lack of accessibility into the A1 and small A2 resettlement areas during the implementation of the fast-track land programme by government technical teams, especially during the period 2000 to 2005, most likely resulted in the underestimation of the extent of the problem, as many cases may have gone undiagnosed and unreported resulting in limited data from the A1 and small A2 sectors (Svinurai et al., 2017).

About 18% of the reported cases were in the commercial sector of Zimbabwe. Unlike the communal sector which has cases of overgrazing thus negatively impacting the microclimate for tick proliferation, the commercial sector usually has adequate grass cover for tick proliferation (Norval et al., 1992). Commercial farmers, however, counteract the abundance of ticks through excellent standards of tick control, thereby keeping the introduction and subsequent spread of bovine theileriosis to a minimum as long as the management practices do not deteriorate (Uilenberg et al., 1993).

The DLVSZ should promote rearing of cattle breeds that are bovine theileriosis resistant, especially by communal farmers (De castro and Newson, 1993). Cattle breeds such as Mashona, Nguni and Tuli have been known to be more resistant to the TBDs and adaptive to local production conditions for the majority of the communal farmers e.g. low standard of management and no supplementary feed as compared to exotic breeds such as Hereford, Limousin and Simmental (Marandure et al., 2020). Rearing disease-resistant cattle breeds plays a significant role in reducing disease impact and may be a sustainable approach for controlling bovine theileriosis in Zimbabwe (De castro and Newson, 1993).

### 5.5 Distribution of bovine theileriosis in Natural Regions of Zimbabwe

The high number of cases observed in Natural regions I, II and III may be attributed to high rainfall and cooler temperature, and availability of hosts which are characteristic of these regions and are favourable for proliferation of *R. appendiculatus* (Sungirai et al., 2016[a]). High rainfall promotes good grass cover for the survival of the ticks (Moyo et al, 2014). With good grass cover *R. appendiculatus* larvae and nymphs have been known to proliferate to very large numbers which increase the chances for tick/ host interaction, hence the spread of the disease (Coetzer and Tustin, 2004).

The high number of cases recorded in Manicaland Province which is predominantly under NR I could be attributed to the prevailing climatic conditions in the province, which are conducive to the proliferation of the tick vector for bovine theileriosis (Norval et al., 1992). The low number of cases recorded in Matabeleland North Province, which is predominantly under NR IV and V may likely be attributed to the low rainfall received and the semi-arid climatic conditions in these regions which are not conducive for the proliferation of *R. appendiculatus* the more efficient vector for bovine theileriosis (Latif and Hove, 2011; Bishop et al., 2004). In these regions *R. zambeziensis* is more prevalent; however it has not been recorded at high levels of abundance on either the host or vegetation, which is characteristic of *R. appendiculatus* (Uilenberg et al., 1993). This may result in reduced tick/host interaction, hence reduced disease spread. The semi-arid conditions may also be contributing due to the reduced grass cover for the ticks to proliferate in and quest for hosts (Norval et al., 1992).

### 5.6 Districts with reported cases of bovine theileriosis 1995-2018

The study indicated that there is an increase in the number of districts affected by bovine theileriosis over the study period. There was a spike in the number of districts affected in 2000 which may be attributed to the uncontrolled movement of cattle during the fast-track land reform programme (Moyo et al., 2014). A breakdown in the government-supported dipping programme due to the economic recession that followed the land reform programme could also have contributed to the peak in the number of affected districts during this year. Another peak was to follow in 2008 and in 2018, coinciding with massive economic recessions in the country, hence the incapacitation of the government to continue to support the cattle dipping programmes across the country (Mkuhlani et al., 2018).

The sudden sustained increase in the number of affected districts observed in the last three years of the study is in agreement with reports that bovine theileriosis is on the increase in the country in recent years (Lawrence and Waniwa, 2020). The increase in bovine theileriosis cases can be attributed to rampant and uncontrolled sale of cattle across the country, hence movement of cattle from high-risk into unaffected districts or *vice versa* (Mujeyi et al., 2015).

Climate could also most likely be contributing to this increase (Lawrence and Waniwa, 2020). Zimbabwe experienced drought in the seasons 2015/16 and 2018/19 which saw many farmers being forced to sell their cattle as a mitigating strategy for the impact of the drought (Frischen et al., 2020). Drought periods saw some farmers failing to take their cattle to the dip tanks due to the emaciated state of the cattle and given the distances which they have to travel to the nearest dip tanks (Sungirai et al., 2016[a]).

The predominance of affected districts in the eastern half of the country may likely be due to the good rainfall and temperature which favours growth of tall grass in these parts of the country, hence good grass cover for the proliferation and questing of the tick vector (Latif et al., 2001). The eastern parts of the country are home to *R. appendiculatus* which occurs in abundance on vegetation as well as on cattle, whereas the western parts of the country are home to *R zambeziensis,* which does not occur in such abundance as the former (Uilenberg et al., 1993). The good grass cover and forestry could also offer shelter for other livestock species which may be alternative hosts for the tick vector, hence hindering the success of control programmes (Sungirai et al., 2016[a]). The country shares a border to the east with Mozambique which is a well-known ECF territory (Abdela and Bekele, 2016[a]). Cases of cattle straying from Mozambique into Zimbabwe and *vice versa* are very rampant which could be exposing susceptible cattle to infection by bovine theileriosis (Perry et al., 1991). There is also rampant movement of wildlife across the board between the two countries which may be contributing to increased cases of bovine theileriosis in the eastern districts. With that in mind, effective and efficient control of bovine theileriosis can thus be easily achieved through the implementation of a regional strategy which recognises the true epidemiological situation and is holistically formulated (Stoltsz, 2005).

The observed spike in cases in the western parts of the country, particularly in Hwange district of Matabeleland North Province, could likely be attributed to proximity to Hwange National Park in the province, where the fence barrier is regularly compromised, thereby allowing the intrusion of wildlife such as buffalo or other small animals e.g. hares, which act as alternative hosts for *R. appendiculatus,* to stray into cattle grazing lands (Stoltsz, 2005). Movement restriction of buffalo and other wildlife through fencing and vigorous tick control in areas bordering bovine theileriosis endemic areas could have likely contributed towards preventing spread of the disease throughout the province (Stoltsz, 2005). Buffalo can harbour

*T. parva* as carriers for at least five years (Worthington and Bigalke, 2001). There is a need, therefore, for improved surveillance and control in those areas where wildlife and uncontrolled animal movement is a challenge (Thomson et al., 2012).

## 5.7 Temporal distribution of bovine theileriosis in Zimbabwe from January 1995 to 31 December 2018

Season had a significant effect on the number of bovine theileriosis outbreaks, despite their occurrence in all four identified seasons. The majority of the cases were recorded during the hot wet season (November – March) which coincides with the period of peak activity and abundance of adult ticks that are more efficient vectors of *T. parva* (Thompson, 2007). The high ambient temperature during the hot wet season provides a conducive environment for the growth and multiplication of the ticks and ultimately increases the transmission of bovine theileriosis during this season (Abdela and Bekele, 2016[a]). The months of February and March recorded the majority of the cases in this study which supports the fact that the adults of *R. appendiculatus* and *R. zambeziensis* are mostly responsible for the transmission of bovine theileriosis (Moyo et al., 2014). Adult ticks have been known to be active and abundant during the hot wet season and are responsible for more than 95% of outbreaks recorded in the country (Billiouw, et al., 2002). The result is in accord with the consistent observation from previous studies on the seasonal occurrence of bovine theileriosis outbreaks and that the disease is rife during the hot wet season (Latif et al., 2001).

Interestingly, in 2018 the highest number of bovine theileriosis cases was recorded in the cool dry season (June) which is contrary to the known seasonal pattern of the disease in Zimbabwe (Moyo et al., 2014). This is a rather surprising result given that June coincides with the period when the larvae stage of the tick vector, which is not known to transmit *T. parva*, is most active and abundant (Latif and Hove, 2011; Abdela and Bekele, 2016[b]). The rising mean monthly temperatures attributed to climate change may be becoming milder hence not low enough to inhibit adult tick activity (Olwoch et al., 2008). Alternatively, successive droughts in recent years may have resulted in inadequate crop residues to sustain the cattle through the winter season, forcing farmers to continue grazing their cattle on tick-infested pastures, hence increasing the risk of *T. parva* infection (Frischen et al., 2020).

The cool dry season is known to coincide with the immature stages of the tick vector for bovine theileriosis (Moyo et al., 2014). Nymphal transmission of bovine theileriosis in Zimbabwe has been known to occur between the months of June and December, though at a very low rate (Latif et al. 2001). It is possible that nymphs of *R. appendiculatus* may have recently become more efficient in transmitting *T. parva* and may likely have caused the distortion in seasonal patterns. This phenomenon is in line with recent reports that *T. parva* is losing its seasonality in Zimbabwe (Lawrence and Waniwa, 2020). *R. zambeziensis* was reported to transmit bovine theileriosis during winter in Zambia and may most likely be responsible for the same phenomenon in Zimbabwe (Nambota et al., 1994). It is possible that *R. zambeziensis* is extending its spatial range due to the expansion of NR IV and V, hence an increased area with suitable climatic conditions for its proliferation (Mugandani et al., 2012; Chikodzi et al., 2013). The new emerging trend of higher bovine theileriosis cases during winter, therefore, suggests the possibility of changes in the vector life cycle, vector distribution, pathogen transmission dynamics or farmer management practices which warrant further investigation (Lawrence and Waniwa, 2020).

The lower number of cases and mortalities due to bovine theileriosis during the post-rain season may be attributed to the abundance of the larval stage of the tick vector during this season, which is not known to be able to transmit *T. parva* (Latif et al. 2001). Intensification of tick control strategies by the farmers during the hot wet season when the adult ticks are in abundance most likely led to the drop in tick numbers and thus reduced the transmission and occurrence of bovine theileriosis during the subsequent post-rain season (Thompson, 2007). In addition, a lower number of cases during the post-rain and cool dry season may most likely be attributed to the movement of cattle from their normal grazing lands onto harvested crop fields which help in limiting contact between the ticks and the cattle in the grazing areas (Latif et al., 2001). This management practice most likely contributed to the restriction of animal and tick contact for periods ranging from one to four months, thereby breaking the transmission cycle and reducing the incidence of bovine theileriosis in winter (Jongejan and Uilenberg, 1994).

### 5.8 Regression Analysis

The six variables (sex, age, province, farming system, season and year) which were tested and found to be significant supported already known facts about the dependence of bovine theileriosis occurrence on these variables (Coetzer et al., 1994). Abdela and Bekele (2016$^{b}$)

stated that occurrence of bovine theileriosis is dependent upon age, sex, management practices and season. High numbers of cases of bovine theileriosis where reported during the summer season due to the high ambient temperature and the wet conditions common during this season and which provides conditions conducive for the growth and proliferation of the tick vector and ultimately increases the transmission of theileriosis (Abdela and Bekele, 2016$^{b}$).

Results of the current study demonstrated a rise in the number of bovine theileriosis cases and affected districts particularly during the last 3 years of the study with Year 2018 being most significant. The hot wet season remains a great risk factor for the occurrence of bovine theileriosis cases due to rampant *T. parva* transmission by adult ticks. This calls for strategic control mechanisms by the government e.g. strategic cattle dipping based on temporal and spatial disease trends to prevent disease spread. Acaricide usage is, however, complicated by high costs, development of acaricide resistance and potential environmental consequences (Kunz and Kemp, 1994; Olwoch et al., 2008). Intensified treatment of sick animals with antitheilerial drugs should also be implemented during the hot wet season which coincides with peak tick activity. The use of buparvaquone needs to be further investigated to establish its efficacy in controlling bovine theileriosis. Success of its use is highly dependent on administration in the very early stages of infection (Nene et al., 2016). Its use is, however, not without problems, as it often results in the development of the carrier state in recovered animals.

Given the high cost of acaricides and challenges with buparvaquone treatment, immunisation becomes an alternative option to control bovine theileriosis (OIE, 2018). Adult cattle have been shown in the current study to be most susceptible to bovine theileriosis infection. Therefore, these animals should be targeted for vaccination in order to reduce losses. There is, however, a need for extensive molecular epidemiological studies to identify the actual *T. parva* strain(s) affecting cattle in Zimbabwe to avoid introduction of a new strain into the vector tick and host population, thus giving rise to new more virulent parasite variants and upsetting the balance of endemic stability (Nene et al., 2016). This will promote better understanding of the disease and aid in formulation of risk-based surveillance, prevention and control strategies (Perry et al., 1991). Identification of the local strain also helps in formulating the appropriate vaccine for effective control of the disease.

A few high-risk areas were identified and these serve as transmission hot spots and early indicators of disease outbreaks. The DLVSZ should increase the focus on identified hot spots and high-risk seasons to target these in the development of disease control strategies (Tavirimirwa et al., 2013). Strict animal movement control and implementation of quarantine measures should be put in place to ensure that no animals are allowed to move from high-risk areas to unaffected areas in order to curb the spatial spread of the disease. Fencing at farm level will also assist with controlling animal movement and prevent contact with infected ticks. This will ensure that isolated cases are controlled and prevented from spreading and makes it possible to implement a slaughter policy in isolated disease outbreaks for the total eradication of the disease (Abdela and Bekele, 2016[a]). Movement control will ensure that tick-free and disease-susceptible cattle do not interact with tick-infested and infected cattle (Kotze et al, 1994). It will also prevent the introduction of ticks and the theilerial pathogens into ecologically suitable but currently uninfested areas (Sungirai et al., 2016[b]). Strict restriction on the movement of animals in and around wildlife conservation areas to limit wildlife-cattle interaction will aid the control of bovine theileriosis (Nene et al., 2016).

Of note is the fact that the bulk of the cattle population in Zimbabwe is kept in the communal areas which have been observed to be the most affected by bovine theileriosis. Improved control techniques which include early disease diagnosis, strict control of animal numbers and the introduction of a permit system for the movement of cattle within or outside the high-risk areas could result in the decline of bovine theileriosis cases (Stoltsz, 2005). It appears that the commonly known seasonal pattern of bovine theileriosis has recently started to change. This could signify the increased prominence of nymphs and *R. zambeziensis* in the transmission of *T. parva,* especially in the cool dry season (Lawrence and Waniwa, 2020). Further investigations on the contributing factors to the sudden recent exponential increase in cases of bovine theileriosis, especially since 2016, are required so as to match surveillance and control strategies to the new demands of the disease.

The economic recession which befall the country, notably in the years 1998, 2008 and 2018 proved to be such a heavy burden on the DLVSZ as suggested by the corresponding rise in bovine theileriosis cases in these years. Farmers have to share responsibility with the government to secure availability of acaricides when there is a disruption in the dipping programme, in order to safeguard their cattle. Veterinary officials can also formulate strategies for the development of endemic stability in the identified high risk areas as an approach to manage and control bovine theileriosis (Worthington and Bigalke, 2001). Mechanisms for improved disease surveillance should be formulated to serve as an early warning system to predict the likelihood of disease or vector abundance (Chikerema et al., 2011). Early warning systems are important in making disease management sustainable and cost effective. The suggested approaches may not be conclusive enough, therefore there is a need for further research to establish the effectiveness of these options in combating bovine theileriosis.

# 6. CONCLUSIONS AND RECOMMENDATION

## 6.1 Conclusions

The current study has revealed that bovine theileriosis cases in Zimbabwe increased in number and distribution since 1995 with an exponential increase from 2016 to 2018. The numbers of cases and mortalities have increased particularly during the hot wet seasons and in the year 2018. More districts have been affected by bovine theileriosis, especially in 2018, when compared to the preceding years. Outbreaks were most concentrated in NR I, II and III. On the basis of this evidence the null hypothesis that the spatial and temporal patterns of bovine theileriosis have remained the same in Zimbabwe over the period under review was rejected. Bovine theileriosis cluster zones were identified as well as variables (risk factors) which are significantly associated with its occurrence.

## 6.2 Recommendations

Critical analysis of the study findings led to the formulation of the following recommendations: -

1. Stakeholder engagement in the beef sector, including smallholder beef farmers should be conducted to ensure that they actively participate in capacity building programmes designed to empower them on disease recognition, reporting, management and control. This should be aimed at improving disease surveillance and reporting so that bovine theileriosis cases are promptly managed and kept to a minimum. Strict movement controls should be implemented to ensure that tick vectors and carrier animals do not spread the disease to new areas across the country.
2. Attention should be paid to the high-risk areas identified, especially NRs I-III in terms of disease surveillance and control. An effective national surveillance and control strategy should be implemented taking into consideration seasons of the year, husbandry practices, distribution and density of cattle and socio-economic aspects. Proper diagnostic techniques e.g. molecular diagnosis should be the standard for confirmation of all suspected cases.
3. Research and development should be geared towards developing an effective vaccine against bovine theileriosis in Zimbabwe. The particular strain of *T. parva* affecting cattle should be determined so that appropriate vaccines can be produced for its effective control, especially in light of the changing bovine theileriosis trends in the recent years as highlighted by this study.

## 7. REFERENCES

1. Abdela, N. and Bekele, T., 2016[a]. *Bovine Theileriosis and its Control: A Review.* School of Veterinary Medicine, College of Agriculture and Veterinary Medicine, Jimma University, Jimma, Ethiopia. Advances in Biological Research 10 (4): 200-212, 2016. Available online < https://iiste.org/Journals/index.php/JMPB/article/download/30170/30986>. [Accessed on 07/08/2020].
2. Abdela, N. and Bekele, T., 2016[b]. *Epidemiology and Control of Bovine Theileriosis in Ethiopia: Review.* Journal of Medicine, Physiology and Biophysics ISSN 2422-8427, An International Peer-reviewed Journal Vol.23, 2016. Available online< https://pdfs.semanticscholar.org/c67d/2d9f05404ac53479d06325ead1633d83ccf1.pdf>. [Accessed on 31/10/2019].
3. Bennet, B., Figure, M., Vine, M., Chikomba, C. and Katic, P. 2019. *Beef Value Chain Analysis in Zimbabwe.* Report for the European Union, DG-DEVCO. Value Chain Analysis for Development Project (VCA4D CTR 2016/375-804). Available on < http://gala.gre.ac.uk/id/eprint/23332/ >. [Accessed on 25/11/2019].
4. Billiouw M., Vercruysse J., Marcotty T., Speybroeck N., Chaka G., Berkvens D., 2002. *Theileria parva epidemics: a case study in eastern Zambia.* Veterinary Parasitology 107: 51–63).
5. Bishop, R.P., Spooner, P.R. Kanhai, G.K., Kiarie, J., 2009. *Molecular characterization of Theileria parasites: application to the epidemiology of theileriosis in Zimbabwe*. Cambridge University Press.
6. Bishop, R., Musoke, A., Mozaria, S., Gardner, M. and Nene, V., 2004. *Theileria: intracellular protozoan parasites of wild and domestic ruminants transmitted by ixodid ticks.* Parasitology (2004), 129, S271–S283. Cambridge University Press.
7. Chikerema, S.M., Pfukenyi, D.M., Matope, G. and Bhebhe, E., 2012. *Temporal and spatial distribution of cattle anthrax outbreaks in Zimbabwe between 1967 and 2006*. Trop Anim Health Prod (2012) 44:63–70. Faculty of Veterinary Science, University of Zimbabwe, Mt Pleasant. Available online < http://ir.uz.ac.zw/jspui/bitstream/10646/673/1/Matope_17.pdf >. [Accessed on 30/05/2020].

8. CFSPH, 2019. *Theileriosis in Cattle and Small Ruminants*. Available online < http://www.cfsph.iastate.edu/Factsheets/pdfs/theileriosis_theileria_parva_and_theileria_annulata.pdf>. [Accessed on 10/06/2019].
9. Chikodzi, D., Zinhiwa. H. Simba, F.M. and Murwendo, T., 2013. *Reclassification of Agro-Ecological Zones in Zimbabwe – The Rationale, Methods and Expected Benefits: The Case of Masvingo Province*. Journal of Sustainable Development in Africa (Volume 15, No.1, 2013). Available on line< https://www.researchgate.net/publication/269334500_Reclassification_of_agro-ecological_zones_in_Zimbabwe_-_The_rationale_methods_and_expected_benefits_The_case_of_Masvingo_Province> [Accessed on 25/05/2020].
10. Chiremba, S. and Masters, W., 2003. *The Experience of Resettled Farmers in Zimbabwe.* African Studies Quarterly | Volume 7, Issues 2 & 3. Available on < http://www.africa.ufl.edu/asq/v7/v7i2-3a5.pdf>. [Accessed on 10/12/2019].
11. Coetzer, J. A. W. and Tustin, R C, 2004. *Infectious diseases of livestock, 2nd edition.* Oxford University Press (SA), Cape Town, 3 volumes, 2159 pp.
12. Coetzer, J.A.W., Thomson, G.R. and Tustin, R.C., 1994. *Infectious diseases of livestock with special reference to Southern Africa.*
13. De Castro, J.J. and Newson, R.M., 1993. *Host resistance in cattle tick control. Parasitology Today*, *9*(1), pp.13-17.
14. FAO, 2016$^a$. *Economic Analysis of Animal Diseases*. Food and Agriculture Organization of the United Nations, Animal Production and Health Guidelines № 8, Rome. Available online < *http://www.fao.org/3/a-i5512e.pdf* >. [*Accessed* on 10/05/2020].
15. FAO, 2016$^b$. *AQUASTAT Country profile – Zimbabwe*. Food and Agriculture Organization of the United Nations (FAO). Rome, Italy. Available online < http://www.fao.org/3/i9842en/I9842EN.pdf>. [Accessed on 05/10/2020].
16. FAO, 2004. *Zimbabwe: Country Report on the State of The World's Animal Genetic Resources.* Food and Agriculture Organization of the United Nations, Animal Production and Health Guidelines № 8, Rome. Available online < http://www.fao.org/3/a1250e/annexes/CountryReports/Zimbabwe.pdf> [Accessed on 20/05/2020].
17. Faraway, J.J., 2016. *Extending the Linear Model with R*, 2nd Ed. CRC press, ISBN 9781584884248.

18. Fayyaz, R., 2017. *Theileriosis disease: economic threat to livestock industry and its control strategies.* Available on line < https://www.technologytimes.pk/theileriosis-disease-economic-threat-to-livestock-industry-and-its-control-strategies/ >. [Accessed on 06/03/2019].
19. Frischen, J., Meza, I., Ruppi, D., Wietler, K. and Hagenlocher, M., 2020. *Drought Risk to Agricultural Systems in Zimbabwe: A Spatial Analysis of Hazard, Exposure, and Vulnerability*. Available online < https://doi.org/10.3390/su12030752 >. [Accessed on 04/08/2020].
20. Ganaies, Z. A., Shahardar, R.A., Maqbool, K.H., Allaie, I.M. and Wani, Z.A., 2019. *An Overview of bovine theileriosis*. International Journal of Veterinary Sciences and Animal Husbandry 2019; 4(1): 09-13. Available online < http://www.veterinarypaper.com/pdf/2019/vol4issue1/PartA/3-6-8-926.pdf>. [Accessed on 16/09/2020].
21. Gordon, S.J.G., Bolwell, C., Rogers, C.W., Musuka, G., Kelly, P., Guthrie, A., Mellor, P.S. and Hamblin, C., 2017. *A serosurvey of bluetongue and epizootic haemorrhagic disease in a convenience sample of sheep and cattle herds in Zimbabwe*. Onderstepoort Journal of Veterinary Research 84(1), a1505. Available online at < https://doi. org/10.4102/ojvr.v84i1.1505 > . [Accessed on 03/10/2020].
22. Gul, N., Ayaz, S., Gul, I.,Adnan, M., Shams, S. and ul Akbar, N., 2015. *Review Article Tropical Theileriosis and East Coast Fever in Cattle: Present, Past and Future Perspective.* Int.J.Curr.Microbiol.App.Sci (2015) 4(8): 1000-1018, Khyber Pakhtunkhwa, Pakistan.
23. Hastie, T. J. and Pregibon, D., 1992. *Generalized linear models. Chapter 6 of Statistical Models in S eds* . J. M. Chambers and T. J. Hastie, Wadsworth & Brooks/Cole.
24. Jongejan, F. and Uilenberg, G., 1994. *Ticks and control methods.* Rev. sci. tech. Off. int. Epiz., 1994, 13 (4), 1201-1226. Available on line< https://www.oie.int/doc/ged/D8941.PDF>. [Accessed on 06/03/2020].
25. Jongejan, F and Uilenberg, G., 2004. *The global importance of ticks.* Parasitology (2004), 129, S3–S14. Cambridge University Press, United Kingdom.
26. Koch, H.T., Kambeva, L., Norval, R.A.I., Ocama, J.G.R., Masaka, S., Munatswa, F.C., Honhold, N. and Irvin, A.D., 1990. *Age resistance to Theileria parva bovis infection in calves.* Veterinary Parasitology, 37, 197-206.

27. Kotze, J., van Vuuren, C., Coetzee, E., Cook, L., le Roux, L., Lourens, M. and Viljoen, C., 1994. *Illegal movement of buffalo causes cattle mortalities*. In: Agricultural News. South African, Department of Agriculture, Pretoria, no 2.
28. Kulldorff, M., Heffernan, R., Hartman, J., Assunção, R. and Mostashari, F., 2005. *A Space–Time Permutation Scan Statistic for Disease Outbreak Detection*. PLoS Med 2(3): e59. Available online < https://doi.org/10.1371/journal.pmed.0020059>. [Accessed on 22/08/2019].
29. Kunz, S.E. and Kemp, D.H., 1994. *Insecticides and acaricides: resistance and environmental impact*. Rev. sci. tech. Off. int. Epiz. 1994,13 (4), 1249-1286.
30. Latif, A.A., Hove, T., Kanhai, G.K., Masaka, S. and Pegram, R.G., 2001. *Epidemiological Observations of Zimbabwean theileriosis: Disease incidence and pathogenicity in susceptible cattle during Rhipicephalus appendiculatus nymphal and adult seasonal activity*. Onderstepoort Journal of Veterinary Research. Volume 68, pg 187-195. Available online< https://www.researchgate.net/publication/11589192_Epidemiological_observations_of_Zimbabwean_theileriosis_Disease_incidence_and_pathogenicity_in_susceptible_cattle_during_Rhipicephalus_appendiculatus_nymphal_and_adult_seasonal_activity>. [Accessed 10/06/2020].
31. Latif, A.A. and Hove, T., 2011. *Historical and critical review of Theileria Parva (Boleni), The vaccine stock against Zimbabwean cattle theileriosis*. Ticks and Tick-Borne Diseases, Vol 2, pg 163-167. Available on line< https://www-sciencedirect-com.uplib.idm.oclc.org/science/article/pii/S1877959X11000422 >. [Accessed on 23/06/2019].
32. Lawrence, J.A., 1992. *History of bovine Theileriosis in Southern Africa*. London, Uk., Academic Press Limited.
33. Lawrence, J. A., De Vos, A. J., IRVIN, A. D., 1994. *East Coast Fever, January disease and Corridor disease, In: Infectious Diseases of Livestock*. Volume 1. J.A.W. Coetzer, G.R. Thompson and R.C. Tustin (Eds). Oxford University Press, pp. 309-330.
34. Lawrence, J.A. and Waniwa, E. 2020. *THEILERIOSIS TODAY: A National Crisis*. Available online <http://www.cfuzim.com/wp-content/uploads/2019/11/theileriosis.pdf>. [Accessed on 08/05/2020].
35. Madzima, W.N. and Mutugi, J. J., 1996. *Epidemiology of ticks and tick-borne diseases in Zimbabwe: future research needs and priorities*. In: Irvin, A.D., McDermott, J.J., Perry,

B.D. (Eds.), *Epidemiology of Ticks and Tick-borne Diseases in Eastern, Central and Southern Africa*. Proceedings of a workshop held in Harare, 12–13 March 1996. International Livestock Research Institute, Nairobi, Kenya, pp. 95–100. Available online< https://cgspace.cgiar.org/bitstream/handle/10568/2728/epidem.pdf?sequence=1> [Accessed on 21/07/2020].

36. Mapiye, C., Mwale1, M., Chikumba, N., Poshiwa, X., Mupangwa, J.F. and Mugabe, p.h., 2006. *A review of improved forage grasses in Zimbabwe [pastos mejorados en zimbabwe: una revisión]*. Tropical and Subtropical Agroecosystems, vol. 6, núm. 3, 2006, pp. 125-131. Universidad Autónoma de Yucatán Mérida, Yucatán, México. Available on line < http://www.redalyc.org/articulo.oa?id=93960301>. [Accessed on 27/08/2020].
37. Marandure, T., Bennett, J., Dzama, K., Makombe, G., Gwiriri, L. and Mapiye, C., 2020. *Advancing a holistic systems approach for sustainable cattle development programmemes in South Africa: insights from sustainability assessments.* Agroecology and Sustainable Food Systems. Department of Animal Sciences, Stellenbosch University, Matieland, South Africa. Available online < https://doi.org/10.1080/21683565.2020.1716130>. [Accessed on 23/11/2020)].
38. Marufu, C.M., 2008. *Prevalence of Ticks and Tick-borne Diseases in Cattle on Communal Rangelands in the Highland Areas of the Eastern Cape Province, South Africa*. Department of Livestock and Pasture Science Faculty of Science and Agriculture. University of Fort Hare, Eastern Cape, South Africa. Available online < http://libdspace.ufh.ac.za/bitstream/handle/20.500.11837/653/dissertation.pdf?sequence=1&isAllowed=y>. [Accessed on 12/07/2020].
39. Mcleod, A and Kristjanson, R., 1999. *Impact of ticks and associated diseases on cattle in Asia, Australia and Africa.* ILRI and eSYS report to ACIAR International Livestock Research Institute, Nairobi, Kenya.
40. Medlock, J.M. and Leach, S.A., 2015. *Effect of climate change on vector-borne disease risk in the UK*. The Lancet Infectious Diseases, 15(6), pp.721-730.
41. Mkuhlani, S., Mupangwa, W., MacLeod, N., Gwiriri, L., Nyagumbo, I, Manyawu, G. and Chigede, N., 2018. *Crop–livestock integration in smallholder farming systems of Goromonzi and Murehwa, Zimbabwe*. Renewable Agriculture and Food Systems 1–12. Cambridge University Press. Available online < https://doi.org/10.1017/S1742170518000558>. [Accessed on 24/08/2020].

42. Mugandani, R., Wuta, M., Makarov, A. and Chisinau, B., 2012. *Re-Classification of Agro-Ecological Regions of Zimbabwe In Conformity With Climate Variability and Change.* African Crop Science Journal, Vol. 20, Issue Supplement s2, pp. 361 – 369. Available online< https://www.researchgate.net/publication/303918743_Re-classification_of_agro-ecological_regions_of_Zimbabwe_in_conformity_with_climate_variability_and_change> [Accessed on 25/05/2020].
43. Muhanguzi, D., Picozzi, K., Hatendorf, J., Thrusfield, M., Welburn, S.C., Kabasa, J. D. and Waiswa, C. 2014. *Prevalence and spatial distribution of Theileria parva in cattle under crop-livestock farming systems in Tororo District, Eastern Uganda. Parasites Vectors 7, 91* (2014). Available online < https://doi.org/10.1186/1756-3305-7-91 > [Accessed on 02/ 07/2020].
44. Mujeyi, A., Mutenje, T., Manyawu, G. J., Gwiriri, L., Chakoma, I., 2015. *Spearheading Development Through Empowering Smallholder Farmers Along Beef Cattle Value Chains: A Case Of Goromonzi And Murehwa Districts, Zimbabwe.*ILRI. International Journal of Managing Value and Supply Chains (IJMVSC) Vol. 6, No. 4, December 2015. Available online< https://www.researchgate.net/publication/289684633_Spearheading_Development_through_Empowering_Smallholder_Farmers_Along_Beef_Cattle_Value_Chains_A_Case_of_Goromonz>. [Accessed on 11/12/2019].
45. Minjauw, B. and McLeod, A., 2003. *Tick-borne diseases and poverty: the impact of ticks and tick-borne diseases on the livelihoods of small-scale and marginal livestock owners in India and eastern and southern Africa.*
46. Mutami, C., 2015. *Smallholder Agriculture Production in Zimbabwe: A Survey.* Department of Rural and Urban Development, Great Zimbabwe University, Masvingo, Zimbabwe. Consilience: The Journal of Sustainable Development, Vol. 14, Iss. 2 (2015), Pp. 140-157.
47. Morrison, W.I., 2015. *The aetiology, pathogenesis and control of theileriosis in domestic animals. Rev. Sci. Tech. Off. Int. Epiz., 2015, 34 (2), 599-611.* Available on line < https://doc.oie.int/seam/resource/directMedia/XPbqy4kuJAOM9lpDYOjvgt0HRcjg12Ia;jsessionid=c34fe973b91178d70af3bdaf0537?binaryFileId=13057&cid=1683> [Accessed on 20/12/2020].

48. Moyo, I.A., Mudimba, T.N., Ndhlovu, D.N., Dhliwayo, S.,Chikerema, S.M. and Matope, G., 2017. *Temporal and Spatial patterns of theileriosis in Zimbabwe: 2000-2014.* Department of Clinical Veterinary Studies, University of Zimbabwe. Bull. Anim. Hlth.Prod. Afr., (2017), Vol 65, pp 569-575.
49. Mpofu, N., 2002. *Comparison of indigenous and foreign cattle for beef production at Matopos Research Station in Zimbabwe.* Available online < https://core.ac.uk/download/pdf/132634065.pdf >. [Accessed on 16/08/2020].
50. Nambota, A., Samui, K. Sugimoto, C., Kakuta, T. and Onuma, M. 1994. *Theileriosis in Zambia Etiology, Epidemiology and Control Measure.* Available on line <https://www.researchgate.net/publication/15265001_Theileriosis_in_Zambia_Etiology_epidemiology_and_control_measures> [Accessed on 05/03/2019].
51. Nene, V., Kiara, H., Lacasta, A., Pelle, R., Svitek, N. and Steinaa, L., 2016. *The biology of Theileria parva and control of East Coast Fever- Current status and Future trends.* Ticks and Tick-borne Diseases 7 (2016) 549–564. Available online< https://www.sciencedirect.com/science/article/pii/S1877959X16300152?via%3Dihub>. Accessed on [09/11/2019].
52. Nkomboni, D., Sisito, G., van Rooyen, A., Homann-Kee Tui, S, Sikosana, J. L.N. and Ndlovu, L. R., 2014. *The potential for increasing cattle productivity in mixed farming systems of Zimbabwe.* Matopos Research Institute, Bulawayo, Zimbabwe. Livestock Research for Rural Development 26 (6) 2014.
53. Nkomboni, P. and Beekman, S., 2015. *Beef value chains in A2 resettled farms in Zimbabwe: A review*. Livestock Research for Rural Development 27(7).
54. Norval, R.A.T., Perry, B.D. and Young, A.S., 1992. *The Epidemiology of theileriosis in Africa.* ILRI (aka ILCA and ILRAD). Available on line < https://all-med.net/pdf/the-epidemiology-of-theileriosis-in-africa/ >.[Accessed on 31/05/2020].
55. Nyahangare, E.T., Mvumi, B.M. and Mutibvu, T., 2015. *Ethnoveterinary plants and practices used for ecto-parasite control in semi-arid smallholder farming areas of Zimbabwe.* J.Ethnobiol Ethnomeed. v. 11; 2015. Available online < https://dx.doi.org/10.1186%2Fs13002-015-0006-6>. [Accessed on 04/10/2020].
56. Olwoch, J. M., Reyers, B., Engelbrecht, F.A. and Erasmus,B.F.N., *Climate change and the tick-borne disease, Theileriosis (East Coast fever) in sub-Saharan Africa.* Department of Zoology, University of Pretoria, Pretoria, South Africa. Journal of Arid Environments

72 (2008) 108–120. Available online < http://www.ehrn.co.za/publications/download/33.pdf>. [Accessed on 10/08/2020].

57. OIE, 2018. *Terrestrial Manual. Chapter 3.4.14. Theileriosis*. World organisation for Animal Health. Available on line < https://www.oie.int/fileadmin/Home/eng/Animal_Health_in_the_World/docs/pdf/Disease_cards/THEILERIOSIS.pdf>. [Accessed on 05/10/2020].
58. Perry, B.D., Norval, R.A.I., Kruska', R.L., Ushewokunze-Obatolu, U. And Booth, T.H., 1991. *Predicting the Epidemiology of Tick-Borne Diseases of Cattle in Zimbabwe Using Geographic Information Systems*. Proceedings of the 6th International Symposium on Veterinary Epidemiology and Economics, 1991.
59. Stoltsz, H. 2005. *Theileria parva infections*. Available on line < http://www.afrivip.org/sites/default/files/theileria_1_introduction.pdf> [Accessed on [9/04/2019].
60. Sungirai, M.,Moyo, D.Z., De Clercq, P. and Madder, M., 2016[a]. *Communal Farmers' Perceptions of tick-borne Diseases Affecting Cattle and Investigation of Tick Control Methods Practiced in Zimbabwe.* Ticks and Tick-borne diseases vol 7, pp 1-9. Available online < https://www-sciencedirect-com.uplib.idm.oclc.org/science/article/pii/S1877959X15001454>. [Accessed on 09/06/2019].
61. Sungirai, M., Madder, M., Moyo, D.Z., De Clercq, P. and Abath, N., 2015. *An update on the ecological distribution of the Ixodidae ticks in Zimbabwe*. Available from: https://www.researchgate.net/publication/272797897> [Accessed on 14/09/14 2019].
62. Sungirai, M., Abath, E.N., Moyo, D.Z., DE Clercq, P. and Madder, M., 2016[b]. *Shifts in the distribution of ixodid ticks parasitizing cattle in Zimbabwe*. Medical and Veterinary Entomology (2017) 31, 78–87.
63. Sonenshine, D.E., Lane, R.S. and Nicholson, W. L., 2002. *Ticks (Ixodida)*. Medical and Veterinary Entomology, 517–558. doi:10.1016/b978-012510451-7/50026-8).
64. Svinurai, W., Mapanda, F., Sithole,. D., Moyo, E., N., Ndidzano, K., Tsiga, A. and Zhakata, W., 2017. *Enteric methane emissions and their response to agro-ecological and livestock production systems dynamics in Zimbabwe.* Animal Nutrition and Production, University of Zimbabwe Marondera College of Agricultural Sciences and Technology. Science of the Total Environment 616–617 (2018) 710–719. Available online < https://doi.org/10.1016/j.scitotenv.2017.10.257>. [Accessed on 08/06/2020].

65. Tavirimirwa, B., Mwembe, R., Ngulube, B., Banana, N.Y.D., Nyamushamba, G.B., Ncube, S. and Nkomboni, D., 2013. *Communal Cattle Production in Zimbabwe: A Review*. Livestock for Research for Rural Development 25 (12) 2013. Available on line at < http://www.lrrd.cipav.org.co/lrrd25/12/tavi25217.htm >. [Accessed on 09/12/2019].
66. Thomson, G.R., Penrith, M.L., Atkinson, M.W.,Atkinson, S.J., Cassidy, D. and Osofsky, S.A., 2012. *Balancing livestock production and wildlife conservation in and around southern Africa's transfrontier conservation areas*. Transboundary and Emerging Diseases 60 (6), 492-506. Available online <http://hdl.handle.net/2263/32640>. [Accessed on 06/08/2020].
67. Thompson, B. E., 2007. *Occurrence of Theileria parva infection in cattle on a farm in KwaZulu-Natal, South Africa.* Faculty of Veterinary Science, University of Pretoria, South Africa.
68. Thrusfield, M., 2007. *Veterinary Epidemiology, 3rd Edition.* Blackwell publishing company. UK. Available online < https://b-ok.africa/book/865172/11ed91?dsource=recommend&regionChanged> . [Accessed on 18/12/2019].
69. Uilenberg, G., Dobbelaere, D.A.E., de Gee, A.L.W. and Koch, H.T., 1993. *Progress in research on tick-borne diseases: Theileriosis and heart water.* Veterinary Quarterly, Vol 15:2, pages 48-54. Available online at < https://doi.org/10.1080/01652176.1993.9694371>. [Accessed on 23/05/2020].
70. Verhoef, J.M. and P.L. Boveng., 2007. *Quasi-Poisson vs. negative binomial regression: How should we model overdispersed count data?* Ecology 88(11) 2766–2772. Available on line http://fisher.utstat.toronto.edu/ . [Accessed on 05/10/2020].
71. Worthington, R. W. and Bigalke, R.D., 2001. *A review of the infectious diseases of African wild Ruminants*. Onderstepoort Journal of Veterinary Research, 68:291-323 (2001). Pretoria, South Africa. Available online < https://repository.up.ac.za/bitstream/handle/2263/19023/44worthington2001.pdf?sequence=3 > [Accessed on 20/08/19].
72. ZIMSTAT, 2015. Compendium of Statistics 2014. Zimbabwe National Statistics Agency (ZIMSTAT), Harare.

# APPENDIXES

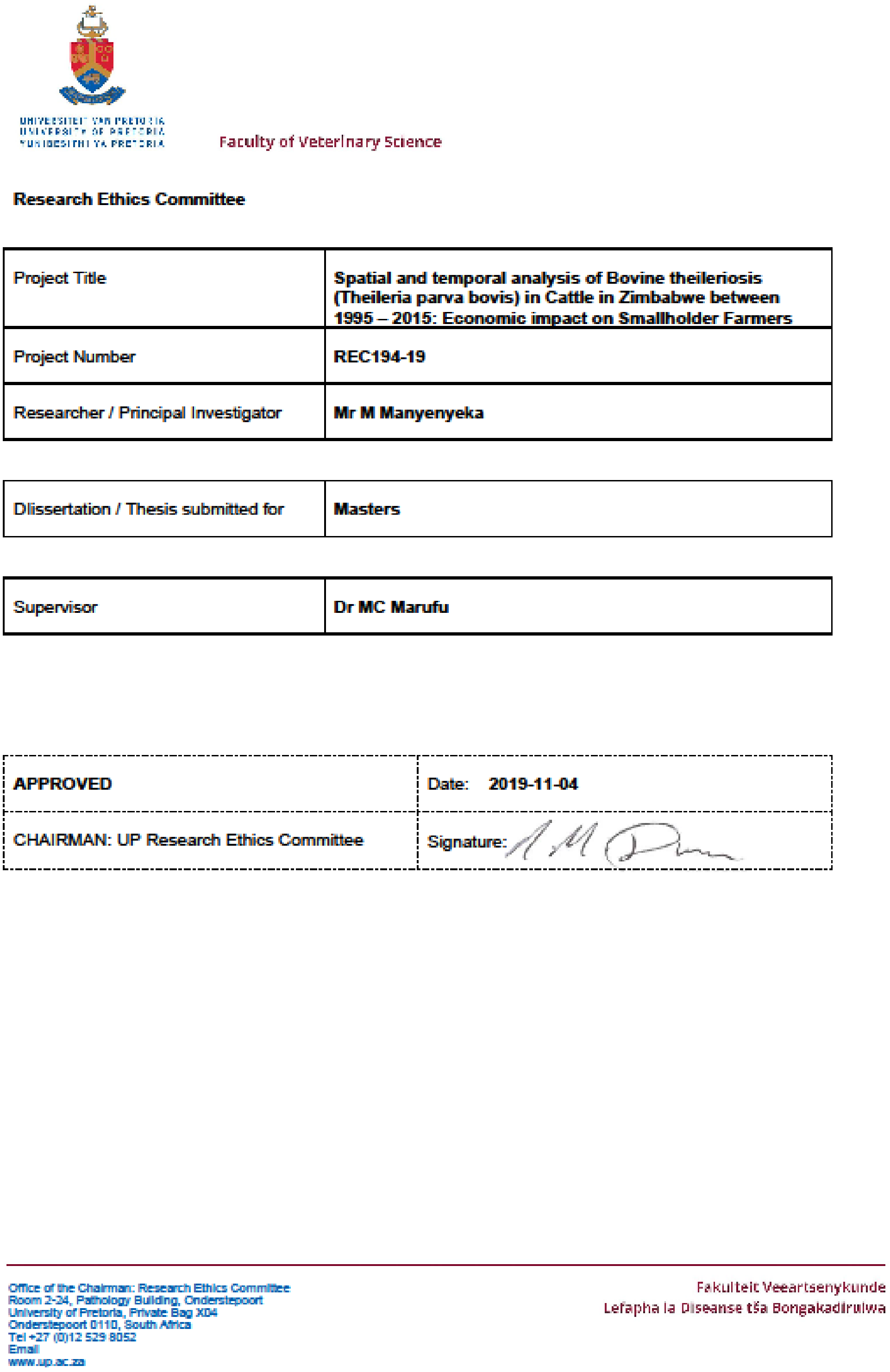
## Appendix 1: Cattle age groups

Four different age groups for cattle were used for the purposes of this study. This format of cattle age classification was obtained from the DLVSZ. The age groups were defined as shown in the table below.

**Table 6: Cattle age groups defined**

| Cattle Age category | Cattle Age in months |
|---|---|
| Neonate | 0 - 12months |
| Juvenile | 13 – 24 months |
| Sub adult | 25 – 36 months |
| Adult | Over 36 months |

## Appendix 2: Research Ethics Committee approval



UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Veterinary Science

**Research Ethics Committee**

| | |
|---|---|
| Project Title | **Spatial and temporal analysis of Bovine theileriosis (Theileria parva bovis) in Cattle in Zimbabwe between 1995 – 2015: Economic impact on Smallholder Farmers** |
| Project Number | **REC194-19** |
| Researcher / Principal Investigator | **Mr M Manyenyeka** |

| | |
|---|---|
| Dlissertation / Thesis submitted for | **Masters** |

| | |
|---|---|
| Supervisor | **Dr MC Marufu** |

| | |
|---|---|
| **APPROVED** | Date: **2019-11-04** |
| CHAIRMAN: UP Research Ethics Committee | Signature: |

Office of the Chairman: Research Ethics Committee
Room 2-24, Pathology Building, Onderstepoort
University of Pretoria, Private Bag X04
Onderstepoort 0110, South Africa
Tel +27 (0)12 529 8052
Email
www.up.ac.za

Fakulteit Veeartsenykunde
Lefapha la Diseanse tša Bongakadiruiwa

## Appendix 3: DLVSZ bovine theileriosis data use approval

*"All communications should be addressed to*
*Director Division of Veterinary Services"*

Telephone: 263-4-705503
Fax: +263-4-792516
Email: dvfs@vetservices.co.zw

ZIMBABWE

Reference: 2019/021

DIVISION OF VETERINARY SERVICES
**DEPARTMENT OF LIVESTOCK AND VETERINARY SERVICES**
Ministry of Lands, Agriculture and Rural Resettlement
P.O. Box CY 56
Causeway
Harare

25 October 2019

To: Whom it may concern

Dear Sir/Madam

**Subject: Notification and certification of intended research by Dr. Chris Marufu and his team**

This serves to confirm that the above mentioned researcher and his research team have notified me of their intention to utilise secondary data and conduct research on bovine theileriosis in the area under my jurisdiction (Goromonzi and Seke Districts, Zimbabwe). The research will involve the analysis of secondary data obtained from the Epidemiology Unit of Department of Veterinary Services and the administration of questionnaires to farmers. I consent for the research group to utilise secondary data and to conduct the questionnaire study in the above-mentioned areas.

Should you have questions regarding the contents of this letter, please contact me on the details provided below.

Yours sincerely

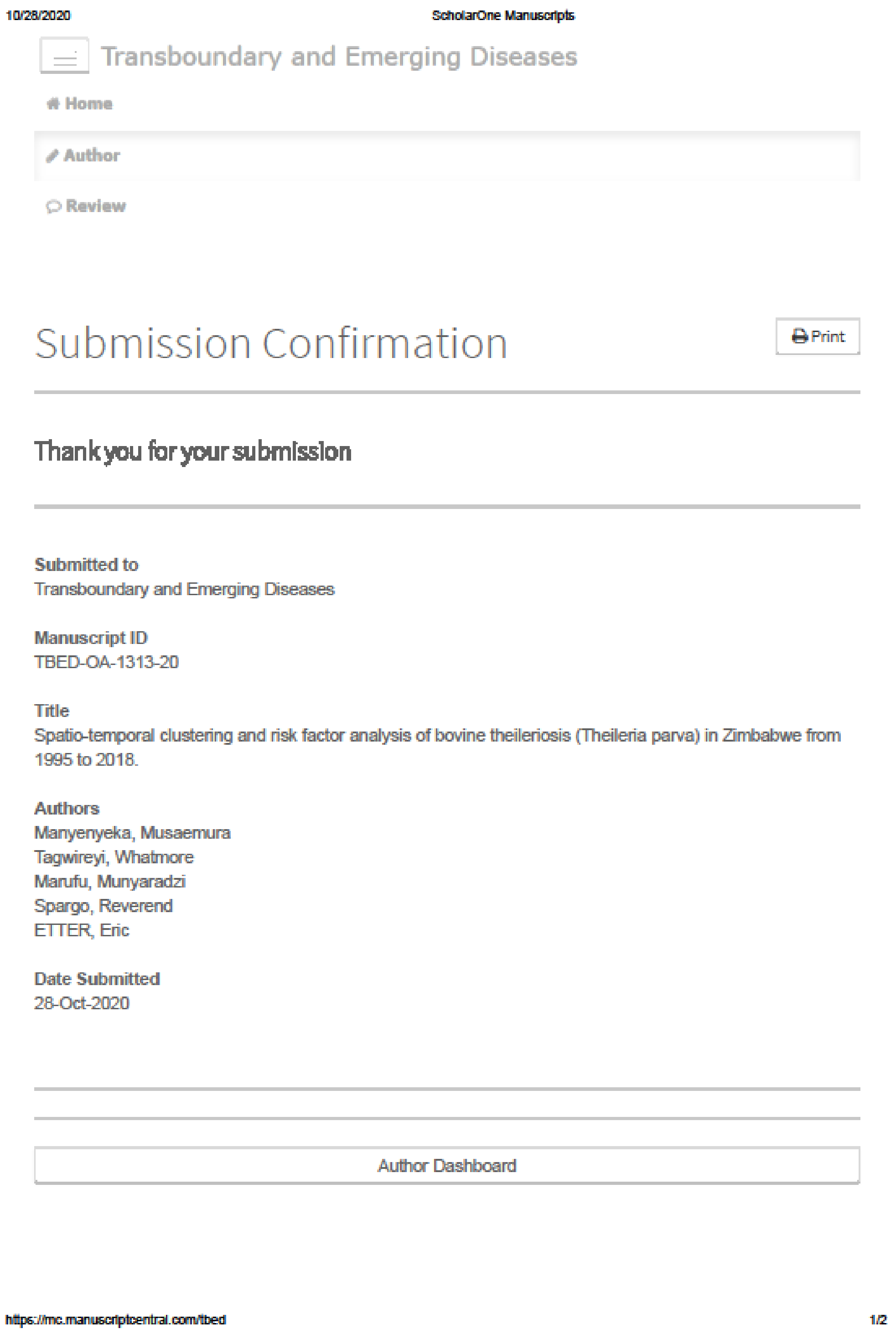
**Dr R.M. Spargo**
**Chief Veterinary Epidemiologist**
**Cell: +263 777876589**
**Email: more.spargo@gmail.com**

DIVISION OF VETERINARY SERVICES
EPIDEMIOLOGY AND DISEASE
CONTROL

25 OCT 2019

P.O. BOX CY 52, CAUSEWAY
ZIM. TEL: 04-708503/706603

## Appendix 4: Proof of publication submission



10/28/2020 ScholarOne Manuscripts

Transboundary and Emerging Diseases

Submission Confirmation

Thank you for your submission

**Submitted to**
Transboundary and Emerging Diseases

**Manuscript ID**
TBED-OA-1313-20

**Title**
Spatio-temporal clustering and risk factor analysis of bovine theileriosis (Theileria parva) in Zimbabwe from 1995 to 2018.

**Authors**
Manyenyeka, Musaemura
Tagwireyi, Whatmore
Marufu, Munyaradzi
Spargo, Reverend
ETTER, Eric

**Date Submitted**
28-Oct-2020

https://mc.manuscriptcentral.com/tbed 1/2