Assessment of vulnerability of cattle farming to climate variability and change in South Africa

by

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PREFACE

The research contained in this dissertation was completed by the candidate while based in the Discipline of Agrometeorology, School of Agricultural, Earth and Environmental Sciences of the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg, South Africa. The research was financially supported by the Agricultural Research Council (ARC).

The contents of this work have not been submitted in any form to another university and, except where the work of others is acknowledged in the text, the results reported are due to investigations by the candidate.

[redacted]

Signed: Professor MJ Savage

Date: 25th January 2021

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Signed: Dr MI Tongwane

Date: 25th January 2021

DECLARATION 1: PLAGIARISM

I, Makgethwa Jillie Masemola, declare that:

(i) the research reported in this dissertation, except where otherwise indicated or acknowledged, is my original work;

(ii) this dissertation has not been submitted in full or in part for any degree or examination to any other university;

(iii) this dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;

(iv) this dissertation does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

a) their words have been re-written but the general information attributed to them has been referenced;

b) where their exact words have been used, their writing has been placed inside quotation marks, and referenced;

(v) where I have used material for which publications followed, I have indicated in detail my role in the work;

(vi) this dissertation is primarily a collection of material, prepared by myself, published as journal articles or presented as a poster and oral presentations at conferences. In some cases, additional material has been included;

(vii) this dissertation does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the dissertation and in the Reference sections.

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ABSTRACT

Livestock are dependent upon weather for their comfort and food supplies. Sometimes, adverse weather conditions can cause production losses, especially if experienced during critical stages of growth. Heat stress is a major cause of production losses in the dairy and beef industries. Heat stress occurs when the temperature of the environment increases above the comfort zone of cattle as a result of solar irradiance. Heat stress decreases grazing and feed intake in cattle, while drought can limit pasture availability for grazing cattle.

The temperature-humidity index (THI), a combination of air temperature and relative humidity, was used to determine the influence of heat stress on the productivity of cattle. The aim of the study was to investigate the air temperature and relative humidity conditions over South Africa accountable for high THI values for cattle farming for the period 1985 to 2015. The standard precipitation index (SPI) and normalised difference vegetation index (NDVI) at three months were computed to assess the soil moisture conditions and vegetation greenness for the season with high THI averages. The THI data analysis was performed seasonally, using a 15-year average and daily values from 75 weather stations in South Africa. Monthly rainfall data from 192 weather stations were used to compute SPI at three months. The NDVI used MODIS satellite information to create vegetation images for the three summer months.

Results indicated summer as a season when cattle are vulnerable to heat stress. The periods (2005/06, 2007/08, 2012/13, 2013/14) experienced high seasonal averages (THI > 80) compared to the remaining years. Daily THI extremes were prevalent in February in South Africa. The SPI results indicated that the North West, the western Free State and east of the Eastern Cape provinces were vulnerable to dry conditions for the four summer periods. The NDVI results indicated that the eastern and coastal parts of South Africa were areas of high vegetation activity and greenness for all the summers. The Northern Cape, Limpopo, North

West and Free State provinces had vegetation that was vulnerable to dry conditions. Heat stress and a healthy vegetation activity were a problem for the Northern Cape and Limpopo provinces, while KwaZulu-Natal and Mpumalanga had heat stress as their only challenge.

The northern and eastern parts of South Africa were heat stress areas with air temperature as the main driver in THI. New smaller areas were developing as heat stress zones, and areas that were identified as heat stress zones in the past were increasing in size for South Africa. Natural grazing areas indicated no significant relationship with THI but showed a relationship with SPI. Cattle farmers situated in the heat stressed regions of South Africa and new heat stress developing areas need to take the necessary precautions to make profitable decisions for their cattle production.

Keywords**:** dry conditions, heat stress, NDVI, SPI, THI**,** vulnerability, wet conditions

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CHAPTER 1: INTRODUCTION

1.1 Background

Agriculture remains a significant provider of employment, especially in the rural areas and it is also a major earner of foreign exchange (DAFF, 2018a). The value of agricultural production contribution to the gross domestic product (GDP) was estimated to be R90.458 billion at nominal prices in South Africa and in 2017 it increased by 4.7 %, and it was estimated at R281.37 billion (DAFF, 2018a). Despite its relatively small share of the total GDP (2.59 %), primary agriculture is an important sector in the South African economy (KPMG, 2012; South African Market Insights, 2020).

South Africa is mainly a pastoral country owing to the fact that 85 % of its total area can be used for grazing (Meissner et al., 2013). About 40 % of South Africa's disadvantaged population is located in rural areas and relies directly or indirectly on land as a source of livelihood (Turpie and Visser, 2013). Agricultural activities range from intensive crop cultivation, mixed livestock and crop farming in winter rainfall and high summer rainfall areas, to cattle ranching in the bushveld and sheep farming in the semi-arid regions (Turpie and Visser, 2013). Livestock is produced in the nine provinces of the country, with varied biomes extending from sub-tropical regions to more moderate regions, sub-tropical mediterranean and semi-desert regions (Mucina and Rutherford, 2006). Areas for grazing declined in the 1990s owing to expanding human settlements and other activities such as conservation, crop production, forestry and mining (DAFF, 2014).

The livestock sector is an integral component of South Africa's agricultural production system contributing positively towards the country's socio-economic development and food security (Swanepoel et al., 2010; Groenewald and Jooste, 2012; Meissner et al., 2013; DAFF, 2017a).

Cattle provide food in the form of meat and milk, and they are also used for income generation and cultural activities (Swanepoel et al., 2010). In 2016, South Africa produced approximately 20 % of the total meat produced in Africa, and accounted for 1 % of global meat production (AgriSETA, 2018). In addition, the livestock industry contributed 34 % of the total domestic agricultural production and provided 36 % of the national protein needs (AgriSETA, 2018).

1.2 Livestock characteristics in South Africa

The livestock industry in South Africa is characterized by a double system of highly developed commercial and undeveloped non-commercial (informal) sectors (DAFF, 2017a; AgriSETA, 2018). The non-commercial sector is further divided into two sub-sectors, which includes smallholder subsistence producers and emerging producers (Spies and Cloete, 2013). The total number of cattle in South Africa in 2018 was estimated at 12.83 million, comprising various purebred and cross-bred dairy and beef cattle breeds as well as indigenous breeds (DAFF, 2018b). The cattle industry is unevenly distributed in the country where 80 % is beef cattle and the remaining is dairy cattle (DAFF, 2017a).

The livestock industry in South Africa is built on a fixed dairy, beef and small stock industry where selection and breeding practices have been in operation for more than four decades (Mucina and Rutherford, 2006). The Eastern Cape Province has the highest concentration of cattle in the country, especially dairy while KwaZulu-Natal is second (Meissner et al., 2013; Milk South Africa, 2019). The Northern Cape and North West are other provinces with significant cattle populations (WWF SA, 2020).

There are four major dairy breeds in South Africa categorised according to heavy milk producing traits namely Holstein, Jersey, Ayrshire and Guernsey respectively (DAFF, 2017b). Dairy production is pasture-based in regions such as KwaZulu-Natal, the coastal regions of the

Eastern Cape and the Western Cape (Williams et al., 2016). The production of raw milk in South Africa is very seasonal and the highest production per day is more than 30 % higher than the lowest production (Milk South Africa, 2019). Most of South Africa's milk supply comes from the coastal provinces where a pasture-based feeding regime generally applies, as opposed to the generally drier inland provinces with mixed ration feeding regimes (Milk South Africa, 2019). The Western Cape contributed 31 % of the total milk produced in South Africa in 2016 followed by the Eastern Cape and KwaZulu-Natal with 28 % and 24 % respectively (DAFF, 2017b). The Free State contributed 7 %, North West 5 %, Mpumalanga 3 %, Gauteng 2 %, while the Northern Cape and Limpopo provinces shared less than 1 % (DAFF, 2017b).

Mpumalanga accounted for the greatest share of beef production in South Africa accounting for 21 % in 2016 followed by the Free State, Gauteng, KwaZulu-Natal and North West with 19 %, 14 %, 11 % and 9 % respectively (DAFF, 2017a). Beef cattle herds range from fairly small (less than 20 head of cattle) to large farms and feedlots (more than 4 000 head) (DAFF, 2018b). There has been a noticeable increase in the slaughtering of stock over the past ten years with the population of beef cattle decreasing (NDA, 2019). South Africa is a net importer of beef and feeder cattle (Mmbengwa et al., 2016). South Africa's beef and beef products imports are less compared to the world wide trade (Esterhuizen, 2015).

1.3 Management practises in cattle farming and the role of climate variability

Breeding season management is a very important means to optimise the reproductive performance of a breeding herd and the pre-wean growth rate of calves (Bergh, 2008). Cow and calf farmers normally choose to start breeding and calving at times of the year when weather is least stressful and there is adequate pasture (Sprott et al., 2001). Cows reach their best condition for breeding normally around three months after the month of the highest rainfall (Bergh, 2008). When breeding in the summer season, the best re-conception is reached if cows give birth about one month before, to about one month after the onset of the effective rainfall (Bergh, 2008).

Calving interval is defined as the time difference between two consecutive births in cows (Mostert et al., 2010). Calving rate is a good indicator of the breeding performance and the fertility of the herd (Mokantla et al., 2004). The calving interval is influenced by the first heat, number and length of services of the cow until pregnancy, and the length of gestation (Mostert et al., 2010). Calf production and associated costs are affected by calving season because environmental conditions, stage of production, and season of the year interact to affect nutritional status and reproductive performance (Sprott et al., 2001). The calving season is important and a universal calving date is not possible due to the differences within regions and production systems (Funston et al., 2016). Season of calving also affects milk production, both through the feeding regime and through the level of feeding, as well as by climatic factors (Baul et al., 2014).

South African dairy cows are calved throughout the year with slightly more calvings in the mid-winter season than in the mid-summer season, while beef cows calve about one month before to about one month after the first effective rainfall (Theron et al., 2002). Heat stress resulting from high air temperatures and humidity can reduce calf performance and negatively affect reproductive performance in both the male and female (Grobler et al., 2014; Funston et al., 2016). Rainfall and air temperature are the greatest influencers of traits on Bonsmara cows and overall grazing quality (Webb et al., 2017).

1.4 The role of seasonality on dairy and beef cattle

The danger of heat stress to animals in southern Africa increases from August to January and decreases from February to July (Du Preez et al., 1990). Dairy production in South Africa is affected by rainfall variability (Williams et al., 2016). Milk yield is the single most important determinant of profit for the dairy cow industry (M'hamdi et al., 2012). Even though autumn begins a decline in pasture conditions, cows that calve during this season and winter produce higher milk yield (Lynch, 1990; Olori and Galesloot, 1999; Theron et al., 2002; Torshizi, 2016). The highest daily milk yields in South Africa were obtained from cows calving in winter (Maltz et al., 2000; Theron et al., 2002; Strabel, 2004; Faqiri and Tanin, 2017).

The major priority of beef production is to produce many calves in the shortest possible time (DAFF, 2010). For beef cattle, weaning becomes important and it is accomplished by separating calves from their mothers, when they are 7 to 8 months old (Pirelli et al., 2018). In the eastern parts of South Africa, calves born during spring can be weaned early before winter while in the more western parts of the country calves can be weaned during winter as the breeding season tends to be later in these areas (NDA, 2000).

1.5 Indices used in the study

Temperature-humidity index (THI) computes the heat stress level in cattle (Brown-Brandl, 2018). The THI accounts for the combined effects of air temperature and relative humidity on cattle to evaluate the risk of heat stress and prevent major effects (Bouraoui et al., 2002). The Standard Precipitation Index (SPI) is the number of standard deviations that observed cumulative precipitation deviates from the climatological average (Guttman, 1999). The index is used to characterize drought on a range of timescales (Guttman, 1998). The Normalised Difference Vegetation Index (NDVI) defines values from -1.0 to 1.0 that characterizes vegetation greenness (Earth Observing System, 2020). The index measures the state of plant health based on how the plant reflects radiation at certain (short) wavelengths and is often used to monitor drought (Earth Observing System, 2020). The SPI in conjunction with the NDVI is used to assess if wet or dry conditions were experienced for South Africa. This will be done with reference to the vegetation greenness and activity, because vegetation growth fluctuates with the increase or decrease in rainfall (Spano et al., 1999).

1.6 Rationale for the research

Cattle are dependent upon weather and climatic variables for their comfort, productivity and food supplies. Adverse weather conditions regularly cause production losses (Vining, 2007). Heat stress in cattle has been identified as a major cause of production losses in the dairy and beef industries (Collier and Zimbelman, 2007; Upadhyay et al., 2008).

1.7 Aims and objectives

The aim of this study is to determine the air temperature and relative humidity conditions accountable for extreme high THI values from 1985 to 2015 and to assess the availability of natural rangeland for cattle through the monitoring of drought using NDVI in South Africa for cattle farming.

The objectives are:

1. to compute THI for dairy and beef cattle in different regions of South Africa and identify vulnerable regions;
2. to compute SPI for corresponding THI periods and relating the indices to vegetation greenness;
3. to map vegetation greenness using NDVI and associate it to potential grazing availability for the corresponding SPI periods of interest.

1.8 Structure of the dissertation

The dissertation contains six chapters:

Chapter 1 presents a background on the distribution of cattle and the cattle management practises for both beef and dairy cattle in South Africa;

Chapter 2 reviews the literature on the influences of climate variability on cattle and other livestock. It also investigates the effect of drought on animal feed, the natural grazing areas;

Chapter 3 analyses the trend, occurrence and severity of the THI in South Africa in all provinces. The findings in this chapter identify vulnerable areas for cattle production within provinces in the country;

Chapter 4 assesses if the THI extremes occurred during abnormal or normal wetness/dryness periods in South Africa using the SPI;

Chapter 5 uses the NDVI to assess vegetation activity and greenness as a result of the SPI to estimate feed availability for cattle in the natural grazing areas of the country;

Chapter 6 concludes with a review of the aims and objectives, presents findings and recommends further research.

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CHAPTER 2: LITERATURE REVIEW

2.1 Overview of climate variability in South Africa

Average annual air temperatures were observed to increase in South Africa in the past years (Kruger and Shongwe, 2004). The extreme rainfall events were also observed to have increased in frequency (Du Plessis and Burger, 2015). Extreme high air temperatures affect most of the important dynamics for cattle such as the production, reproduction performance and well-being. The feed quality and quantity are also affected by the decreases in rainfall and increase in air temperatures. Thus, decreases in rainfall coupled with increases in air temperatures reduces the carrying capacity of natural grazing lands for cattle production and other livestock especially for vulnerable communities.

2.1.1 Air temperature

Southern Africa has a warm climate, with the greater part of the region experiencing an average annual air temperature above 17 °C (Davis-Reddy and Vincent, 2017). In summer, air temperatures are highest over the desert areas in the west of the region (Adesina et al., 2015). In winter there is a latitudinal gradient, where air temperatures decrease southwards and are coldest in the high-altitude regions of South Africa (Davis-Reddy and Vincent, 2017).

Global air temperatures have been increasing since 1880 (IPCC, 2014). Trenberth et al. (2007) identified 1995-2006 to be the warmest period in global lower surface temperatures since 1850 and there have been increases ever since. Since then, the global surface temperatures have increased even further with 2018 as the hottest year on record (NASA, 2019). The ocean and land temperatures have an average warming of a linear trend by 0.85 ºC over the period 1880 to 2012 (IPCC, 2014). Weather extremes and climate events were observed from 1950 which includes a decline in cold temperature extremes, a rise in warm temperature extremes and an increase in the number of heavy precipitation events in a number of regions (IPCC, 2012).

A major increase in air temperature over Africa occurred in the years 1979 to 2010 with a value of 0.15 ºC per decade (Brown et al., 2008; Collins, 2011). South Africa experienced general warming over the past years (Kruger and Sekele, 2013). Temporal and spatial trends in air temperature in South Africa showed positive trends in annual mean maximum air temperatures (Kruger and Shongwe, 2004). An increase in maximum air temperatures between 0.014 to 0.039 °C/year, and minimum air temperatures between 0.011 to 0.21 °C/year for South Africa in all seasons was noticed by MacKeller et al. (2014). Yearly average maximum air temperatures have increased in South Africa between 1950 and 1993 (Easterling et al., 1997). Engelbrecht et al. (2015) observed and projected increases in air temperatures for southern Africa with a value of 3.2 °C per century.

2.1.2 Rainfall

South Africa receives an average annual rainfall of around 450 mm (Jury and Levey, 1993; Palmer and Ainslie, 2006). High seasonal rainfall is common with most rainfall occurring during summer while the south west of the country receives rainfall in winter (Tyson, 1986). More than 80 % of annual rainfall in southern Africa is received during the austral summer from October to March (Buckle, 1996). Rainfall variability is particularly pronounced over the dry western parts of the country where a dry year can have significant repercussions (Kruger and Nxumalo, 2017). Furthermore, extreme dry years tend to be more frequent in the driest regions of the country (Tyson, 1986). South Africa is classified as semi-arid with high inter-annual rainfall variability (Tyson, 1986; Schulze, 1997; Palmer and Ainslie, 2006). Some identifiable areas showed major changes in rainfall characteristics over South Africa between 1910 and 2004 (Kruger, 2006). Increases in the intensity of rainfall events between 1931 and 1990 were observed (Mason et al., 1999). A rainfall trend analysis for the years 1921 to 2015 indicated an increase over the west of South Africa, mostly in the interior towards the south and also decreases in some areas in the far north-east (Kruger and Nxumalo, 2017). A decreasing trend of rainfall and number of rain days was observed in South Africa with the exception of the southern Drakensberg during spring and summer (MacKellar et al., 2014).

2.2 Climate variability and its effects on cattle production and grasslands

2.2.1 Cattle production

In Africa, population of cattle is affected by climate variability where the populations increase and decrease during wet periods and droughts respectively (Kgosikoma, 2006; Ouma, 2015). In cold climates, cold winter air temperatures are the main cause of livestock mortality (Rao et al., 2015). An early summer drought and rainfall insufficiency were observed to be important drivers for cattle mortality, which worsen the impact of upcoming air temperatures in winter for livestock (Rao et al., 2015). Cooler air temperatures were found to be having an effect on dairy cattle mortality to a small extent in some regions (Nkondze, 2013; Morignat et al., 2017).

Low air temperatures accompanied by high humidity may be very unfavourable to cattle in that when the air temperature is low, cows emit more sensible heat into the environment (Herbut and Angrecka, 2012). They also increase heat production and eat more feed to compensate for body energy loss (Herbut and Angrecka, 2012). Hansen (2009) observed that breeds that evolved in hotter climates (such as Brahman) simply thermoregulate better than those that evolved in more temperate environments (such as Angus and Holstein breeds). A study by

Bishop-Williams et al. (2015) reported that an increased farm-mortality was because of heat waves, which indicated high levels of heat stress in dairy cattle.

Mortalities were ranked as the most common effect of drought in semi-arid environments whilst in sub-humid environments parasite incidence was ranked first (Dzavo et al., 2019). South Africa experienced the worst drought with the lowest rainfall since 1904 in 2015, and in many extensive production areas such as subsistence, small-scale and commercial, farmers were unable to provide feed for their animals, resulting in devastating results (Coetzee, 2016). The 2015/2016 summer season was the hottest and driest recorded in South Africa and the severe drought and extreme heat had a large effect on the pre-weaning performance of continental sired calves in the Northern Cape (Scholtz et al., 2018).

This 2015 drought forced livestock owners to slaughter or sell their cattle (Stoddard, 2016). Commercial livestock producers in all the provinces excluding Mpumalanga and Gauteng reported a significant impact on the average herd size and livestock feed (Mare et al., 2018). Commercial beef slaughters increased by 8 % in the year 2015 in South Africa (Bureau for Food and Agricultural Policy, 2016). The Red Meat Producers' Organisation estimated that over 40 000 cattle died because of extreme heat and drought by the end of 2015 in Kwa-Zulu Natal alone (Schreiner et al., 2018).

Motiang and Webb (2016) discovered that most cattle deaths for small-holder producers in the North West Province of South Africa were caused by diseases (50 %) and drought (34 %). The Northern Cape Province also witnessed a decline in the pre-weaning performance of beef calves in the 2015/16 summer due to extreme heat (Scholtz et al., 2018). Coleman (2018) reported cattle to be on the edge of death with large numbers of livestock already dead in the northern parts of the Limpopo Province due to the 2018 drought conditions, with the region's communal farming areas rendered nearly desert-like since the drought started.

2.2.2 Grasslands and other animal feed

Natural grazing areas in South Africa have become extremely depleted resulting in involuntary slaughtering of cattle and cattle deaths due to feed unavailability (Agri SA, 2016). The quality, distribution and amount of pasture is determined by the climate and soil of a location (Birch and Grahn, 2007). The higher altitudes on the eastern regions of South Africa are mostly occupied by grasslands from areas that are comparatively cool with reasonably good rainfall (Mucina and Rutherford, 2006). Grasslands are the most productive natural grazing lands but their carrying capacity is declining with the decrease in rainfall (Tainton, 1984). Over the years, the variability in climate, more especially the variability in rainfall, has had an undesirable influence on the local ecosystem's ability to accommodate the increases in demand for forage for livestock (Chibinga et al., 2012).

A failure in successive rainfall seasons can cause an inadequate restoration of grazing lands, while in some regions, diverse climate models project trends in wet and dry extremes that are dissimilar (Herrero et al., 2010). Grasslands are sensitive to both short-term climatic variability (e.g. variability in rainfall patterns within and between years) and longer-lasting changes in climate (e.g. multiyear droughts or directional changes in prevailing climate) (Blair et al., 2014).

Two different economic effects of drought on cattle farming were identified which are reliant on the scale of the drought (Schreiner et al., 2018). The scales includes a mild drought which results in cattle losing weight which affects revenue and household income, while the second is that harsh drought results in cattle dying from the lack of feed (Masike and Urich, 2008). Water shortage was ranked as the constituent of drought with the most severe impact on cattle production in semi-arid environments whilst in sub-humid environments, feed shortage was ranked first (Dzavo et al., 2019).

This chapter reviews the variability of the South African climate taking into account the air temperature and rainfall, this is done by discussing their spatial and temporal variability in the country. Literature on the effects of increasing air temperatures and decreased rainfall is reviewed looking at the effects it had on cattle production. Chapter 3 investigates the combined effects of air temperatures and relative humidity on cattle well-being through the use of THI. Chapter 3 will identify THI values above which heat stress begins for the different climatic regions of South Africa.

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CHAPTER 3: TEMPERATURE-HUMIDITY INDEX (THI) AS A MEASURE OF CATTLE STRESS IN SOUTH AFRICA

3.1 Abstract

Air temperature and relative humidity conditions over South Africa accountable for high THI values for cattle farming for 1985 to 2015 were investigated. The THI values were calculated from daily average air temperatures and relative humidity from 75 weather stations in the country. Data analysis was performed seasonally, using a 15-year average and daily values. Results indicated summer as a season when cattle are vulnerable to heat stress. The periods (2005/06, 2007/08, 2012/13, 2013/14) experienced high seasonal averages (THI > 80) in summer compared to the remaining years. The highest average was observed in the 2012/13 summer. The 15-year average indicated the Limpopo Province experiencing heat stress in a small part in the west.

Daily extremes (THI > 89) were prevalent in the February months with the values occurring in the Northern Cape and Eastern Cape provinces. Vulnerable areas of heat stress were the Northern Cape and Limpopo provinces with the KwaZulu-Natal and Mpumalanga provinces vulnerable on the eastern edges. Cattle producers situated in vulnerable areas will be impacted negatively and have to put strategies in place for the management of heat stress.

Keywords: extremes, heat stress, THI, vulnerable

3.2 Introduction

Heat stress is regarded as one of the major environmental factors that makes the production of livestock difficult in many locations of the world (Koubkova et al., 2002). Heat stress occurs when the air temperature (T_a) of the environment increases above the comfort zone of cattle (Muller, 2017). Cattle also have ranges of ambient environmental temperature referred to as the thermos neutral zone, where the ambient temperature above or below the thermos neutral zone creates stress conditions (Desalegn, 2016). Cattle can succumb to hyperthermia if they fail to maintain thermoneutrality (Kadzere et al., 2002).

Heat stress results from an imbalance in the homeostasis of the animal and has both physiological and thermodynamic components (Brown-Brandl, 2018). The type and magnitude of the physiological changes and adjustments to heat stress influences how well cattle are able to respond to hot conditions, with differences of species and breeds being factored (Barnes et al., 2004). The effects of heat stress are greater in cattle than in other ruminants because of their higher metabolic rate and poorly developed water retention in the kidney and gut (Bernabucci et al., 2010).

Heat stress is a major cause of production losses in the dairy and beef industries (Collier and Zimbelman, 2007). Heat stress is measured using the temperature-humidity index (THI) (Gantner et al., 2011; Habeeb et al., 2018). Breeds of dairy cattle in South Africa originated in western Europe and British Isles where the conditions in climate are very different from those in South Africa (Muller, 2017). Even though the dairy breeds have adapted to South African conditions to some extent over the years, they are still vulnerable to higher summer air temperatures (Muller, 2017).

Heat stress in beef cattle is usually considered less severe than in dairy cattle because beef cattle have a higher average THI threshold due to their lower metabolic rate and lower body heat production (Nardone et al., 2010). Heat stress in feedlot cattle is a common summertime occurrence in cattle-producing parts of the world (Brown-Brandl, 2018). Feedlot animals that are closest to the market endpoint are most at risk because they are physiologically overweight and have the least amount of lung capacity relative to body weight (Dahlen and Stoltenow, 2012). Animals that are very young and very old also are at increased risk as they do not have the physiologic reserves to withstand prolonged periods of heat (Dahlen and Stoltenow, 2012).

3.3 The THI as measure of heat stress in cattle

Air temperature alone is not an adequate measure of heat stress. Thus various indices have been developed which include other factors such as relative humidity (RH) and evaporation rate (RCI, 2019). One disadvantage of THI is that it may not predict the true impact of heat stress in extensive grazing systems because it does not account for accumulated heat load (RCI, 2019). Another weakness of THI is that it does not account for solar irradiance and wind speed which can affect heat load of cattle (RCI, 2019). The THI also does not account for metabolic and physiological influences in cattle (Hammami et al., 2013).

Nonetheless, the THI is still the simplest and most practical index used extensively in estimating heat stress in dairy and beef cattle in hot regions (Mader et al., 2006; Morton et al., 2007). Considering that the study is done for the entire South Africa and not at an experimental level at a farm, the index is very much useful. The THI are related to body temperatures of cattle exposed to heat stress (Dikmen and Hansen, 2009). Other methods exist that measure heat stress such as the Heat Load Index (HLI) and the Accumulated Heat Load Units (AHLU) (Kestrel Instruments, 2020). The HLI and AHLU require animal data (breed, colour, feed state, health and environmental conditions of housing) and advanced meteorological data that is not easily available such as the Globe Temperature which is not available on traditional weather stations (Kestrel Instruments, 2020).

Herbut and Angrecka (2012) emphasised that THI is a valuable tool for calculating animal thermal stress. The THI is broadly used in hot locations to evaluate the effect of heat stress on cattle (Bouraoui et al., 2002). Nesamvuni et al. (2012) investigated THI under projected climate conditions in South Africa and they found no stress in the present but mild stress in the intermediate to distant future climate along the northern border of the country.

The aim of this chapter is to determine THI for cattle in South Africa. The THI is calculated for different regions in the country and vulnerable regions identified. Seasonal and daily THI is calculated for both dairy and beef cattle for 1985 to 2015.

3.4 Methodology

3.4.1 Study area

According to the Koppen-Geiger classification, the climate of South Africa can be divided into three zones which includes arid, subtropical wet and subtropical dry (Kottek et al., 2006). The eastern parts of South Africa contain a subtropical wet climate with warm air temperatures, while the subtropical dry climate persisting with warm air temperatures during dry summers are situated over the northern part. The arid zones with desert climate regions experiencing high air temperatures are found in the western part of the country (Adesina et al., 2015). The highest concentration of dairy cattle is found in the Eastern Cape and KwaZulu-Natal provinces (Meissner et al., 2013; Milk South Africa, 2019). Beef cattle are produced throughout the country with Mpumalanga, Free State and Gauteng having the greatest share (Agribook Digital, 2020).

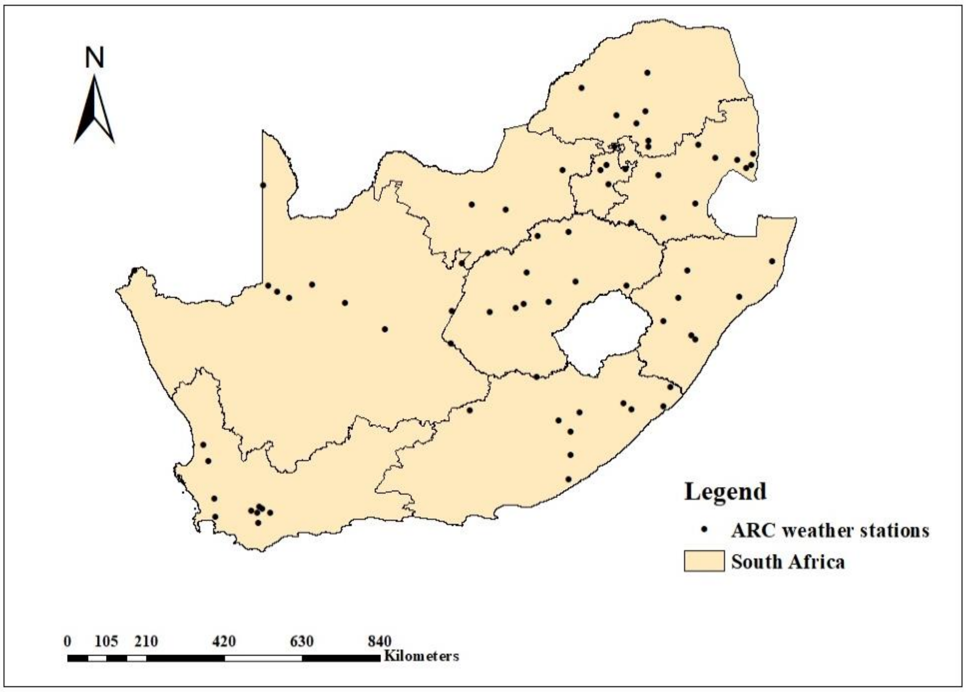

Figure 3.1: Location of stations used to calculate the THI.

3.4.2 Data

Daily data for maximum (T_{max}) and minimum (T_{min}) air temperature and maximum and minimum RH were obtained from the Agricultural Research Council (ARC) Agrometeorology database, Pretoria, South Africa. The data spanned 1985 to 2015 with a total of 75 representative weather stations (Figure 1). All the stations had 30 years of data and were spatially distributed in the different terrestrial biomes and climatic zones of South Africa. The choice of the stations was based on the data quality including stations with data required for the selected period. The database performs quality control on the data according to the set limits. The missing data were patched using the ARC standalone patching tool that utilises the Multiple Linear Regression (MLR) technique explained by Teegavarapu (2009) and Shabalala et al. (2019) where the missing data are estimated by calculating the regression coefficient between the target station and the best correlated neighbouring stations.

3.4.3 Method

The THI is a function of T_a and *RH* (Kibler, 1964). The Kibler (1964) equation calculates THI for both dairy and beef cattle. An early version of the temperature-humidity index (THI) was calculated, without explanation of its origin, by Kibler (1964) in his investigation of the thermal effects of temperature-humidity on eight physiological responses of Holstein cattle. In his equation, dry- and wet-bulb temperatures were used to calculate THI. Since then a modified version of the equation, invoking the psychrometric equation, has been used by many others (i.e Du Preez et al., 1990; Bouraoui et al., 2002; Gantner et al., 2011; Dimov et al., 2017; Hohnmann et al., 2021).

The study used the average daily air temperatures and average relative humidity data to compute daily THI values. Monthly and seasonal THI values were then computed from daily THI values using the equation:

$$THI = 1.8Ta - (1 - RH)(Ta - 14.3) + 32$$

where T_a is the measured air temperature (°C) and *RH* is the relative humidity (%).

The classification reported by St. Pierre et al., (2003) was adopted to compute the intensity of heat stress for dairy cattle and was used by several other studies together with the Kibler (1964) equation (Gaafar et al., 2011; Musari et al., 2014; Wangui et al., 2018). While that of beef cattle used the classification by Brown-Brandl (2018).

In the study, THI for both dairy and beef cattle were calculated because of their difference in stress levels (Hahn, 1999). Table 3.1 and Table 3.2 provide THI thresholds for dairy cattle and beef cattle respectively.

Table 3.1: Threshold THI values for heat stress in dairy cows (St. Pierre et al., 2003; Wangui et al., 2018).

THI	Effect
< 72	No stress
72 to 78	Mild stress
78 to 89	Severe stress
89 to 98	Very severe stress
> 98	Death

Table 3.2: Threshold THI values for heat stress in beef cattle (Brown-Brandl, 2018).

THI	Effect
< 74	Normal
74 to 79	Alert
79 to 84	Danger
> 84	Emergency

3.4.4 Data analysis

The first part of the analysis included the seasonal analysis of THI done by mapping a 30-year average (1985 to 2015) using ArcGIS for different seasons, summer (December-February), autumn (March-May), winter (June-August) and spring (September-November). The second part investigates use of a 15 year average in summer for 1985 to 1999 and 2000 to 2015. The third part identified years with the highest THI average (THI > 80) as they are a danger to both beef and dairy cattle (Tables 3.1 and 3.2) for the 30 years data and the results mapped.

The fourth part identified the extreme daily THI values (THI > 89) for stations and using descriptive statistics. Stations which had recordings corresponding to the highest stress level category were identified. The lower critical air temperature and *RH* at which heat stress began was identified for the stations that recorded the highest stress level category.

3.5 Results and discussion

3.5.1 Seasonal variation of average THI in South Africa

The THI varies according to seasons and location in South Africa. Figure 3.2 (a) represents a 30-year average of THI in summer with THI ranging from 62 to 79. Almost the entire Eastern Cape indicated no stress. The eastern Free State, Mpumalanga and KwaZulu-Natal (in the western part and a small tip on the north coast) had THI values ranging from 62 to 68. Large parts of the North West, Western Cape and a small part of the Free State had THI values below 70 which implied that there was no stress in the regions. Regions where THI ranged from 71 to 72 dominated the Northern Cape Province and small parts of the western Free State and North West provinces. The Limpopo Province also indicated a significant range of 71 to 72 values of THI in most parts of the Province. The most extreme THI values were visible in the Northern Cape Province in the Kalahari region towards the Namibian border with THI ranges of 73 to 75 and 76 to 79 (highest values) which are classified as severe stress. Extremes were also visible in small parts of eastern Kwazulu-Natal, the eastern parts of Mpumalanga and Limpopo in a small part towards the west.

A 30-year THI average in South Africa in autumn indicated no stress conditions (Figure 3.2 b). The lowest values ranged from 58 to 61 in the country’s interior mostly in the Free State

Province, and some small parts of the Eastern Cape and the western part of Mpumalanga. The highest values ranged from 68 to 71 in the central-north of the Northern Cape, a large part of the Limpopo, the eastern parts of Mpumalanga and KwaZulu-Natal provinces.

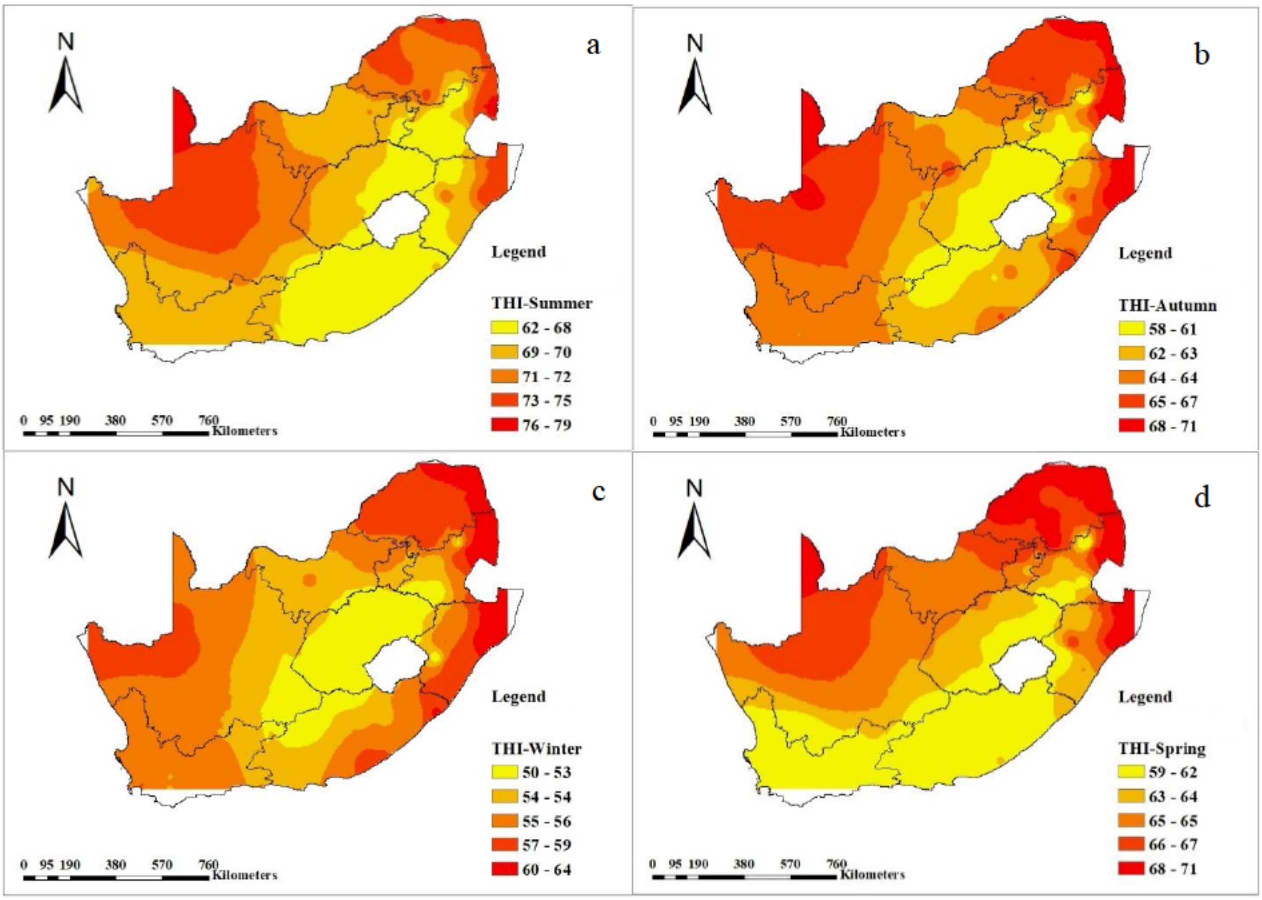

Figure 3.2: Seasonal variations of THI in South Africa from 1985 to 2015.

*Area in white inside South Africa is Lesotho

Figure 3.2 (c) shows the average THI in winter also with no stress in the country and showing a similar pattern observed in Figure 3.2 (b). Lowest values ranged from 50 to 53 in almost the entire Province of the Free State, a small region in the Eastern Cape extending into parts of the Northern Cape, Eastern Cape and Mpumalanga. Highest values ranged from 60 to 64 and were visible in the north-western Northern Cape, the eastern part of KwaZulu-Natal (coastal regions), Mpumalanga and a small region in the coastal Eastern Cape. A large part of the Limpopo Province showed a THI range of 57 to 59.

Figure 3.2 (d) also showed the average THI in spring for South Africa with no stress being evident. It followed the same pattern in Figure 3.2 (a), except for the lowest THI values extended into the whole of the Western Cape and Eastern Cape provinces with ranges of 59 to 62. The highest THI average value was 71 with an increasing risk of heat stress in the Northern Cape, Limpopo, eastern Mpumalanga and KwaZulu-Natal because summer was approaching. Du Preez et al. (1990) observed an increasing risk of heat stress for dairy cattle in large areas in spring in South Africa where conditions were above their normal limit with a THI value of 70.

3.5.2 A 15-year average of THI in summer

Figure 3.3 (a) shows a 15-year average THI from 1985 to 1999 with the highest THI value of 78, the Northern Cape was the most vulnerable to heat stress, followed by the eastern parts of the KwaZulu-Natal and Mpumalanga. The Limpopo Province showed a small part towards the west was prone to heat stress during the period. The eastern part of the North West indicated a potential for heat stress, because the central region of the Northern Cape which was heat stressed extended into the North West Province. Almost the entire Eastern Cape, western Mpumalanga, eastern Free State and western KwaZulu-Natal indicated cool conditions for cattle production for the 15-year average.

Figure 3.3 (b) shows the 15-year average from 2000 to 2015 with the highest THI value of 79. The pattern was very similar to the pattern in Figure 3.3 (a) except that the heat stress area in the west of the Limpopo Province had increased in size. Another noticeable change was in the North West Province with a decreased potential of heat stress in the west of the Province unlike in the previous period where it was larger. The Eastern Cape, eastern parts of Free State and the western parts of Mpumalanga and KwaZulu-Natal were comfortable regions for cattle farming (Figures 3.3 (a) and (b)).

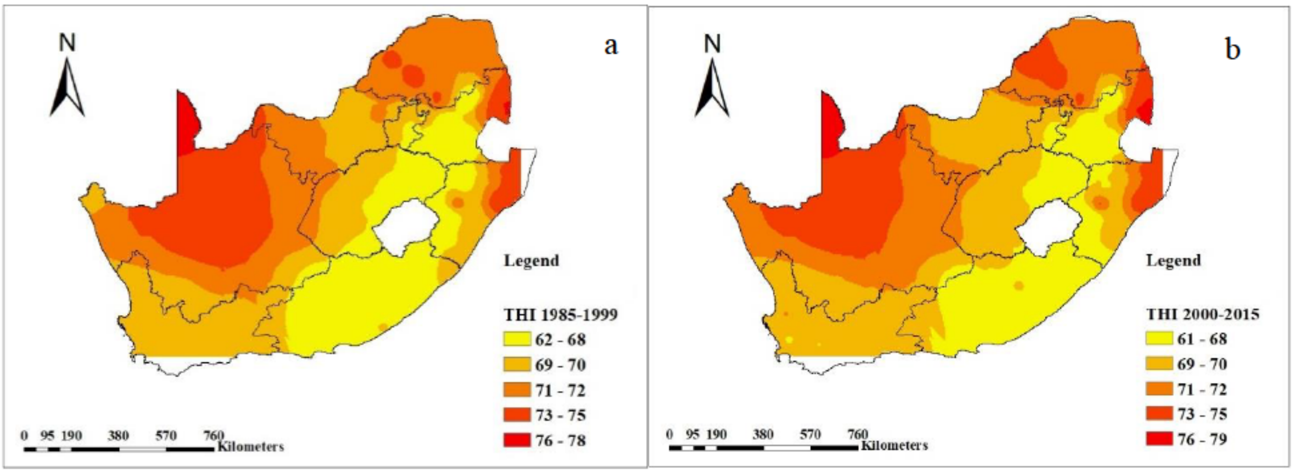

Figure 3.3: The 15-year average of THI in South Africa for (a) 1985 to 1999 and (b) 2000 to 2015.

*Area in white inside South Africa is Lesotho

3.5.3 Highest summer THI values by location and years in South Africa

The summer seasons 2005/06, 2007/08, 2012/13 and 2013/14 experienced average values of THI that were high (THI > 80) between 1985 and 2015 in South Africa. Although the average THI was greater than 80 during these seasons, there were locations in the country that experienced lower values. The summers of 2005/06, 2007/08, 2012/13 and 2013/14 had the highest average THI during the 30-year period. Figure 3.4 (a) shows the average THI for the 2005/06 summer in South Africa with the highest value of 81. The central-north of the Northern Cape, eastern parts of Mpumalanga and KwaZulu-Natal were vulnerable areas to heat stress. A small part in the west of Limpopo also showed stress with the rest of the provinces showing no stress. The Eastern Cape was the most comfortable with THI ranges between 60 and 68 prevalent in the entire Province.

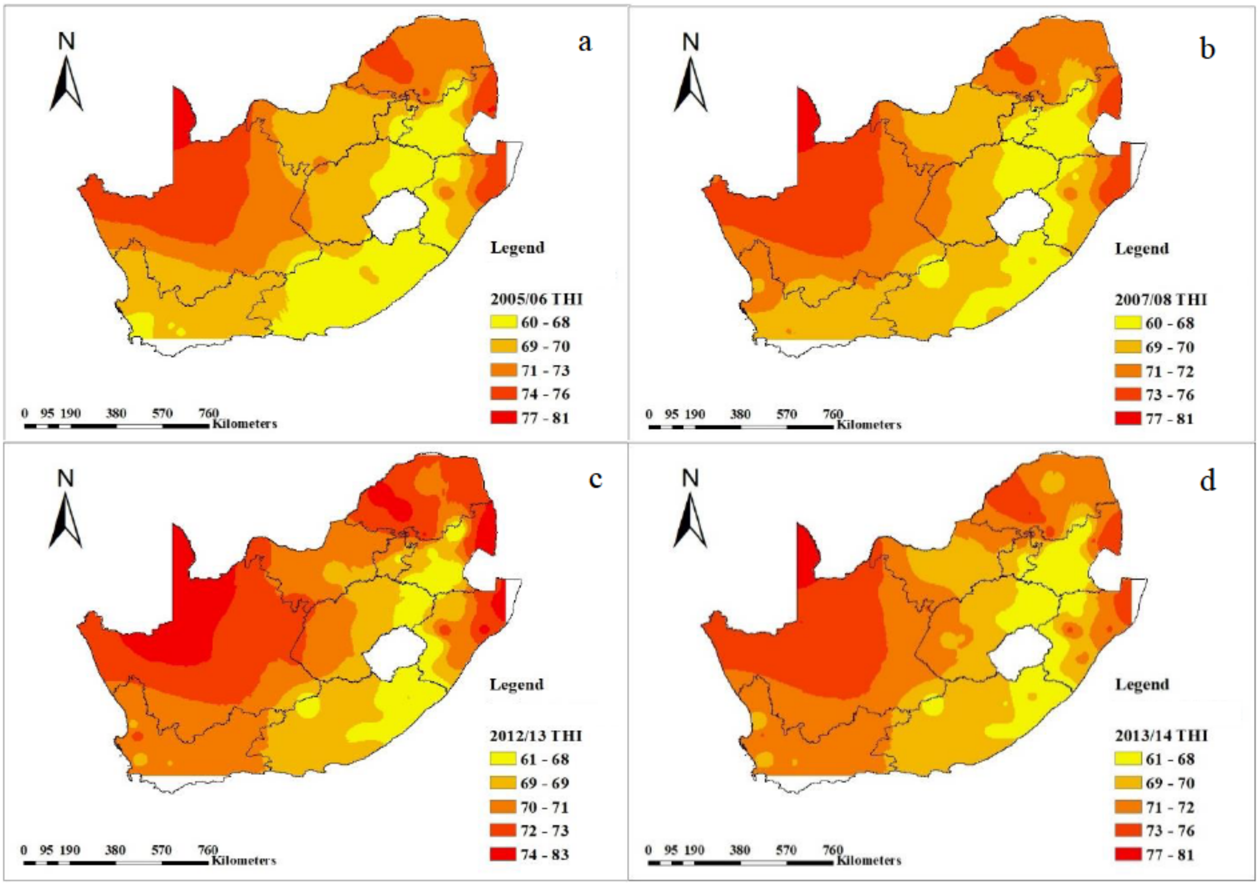

Figure 3.4: Summer seasons with highest THI averages in South Africa between 1985 and 2015.

*Area in white inside South Africa is Lesotho

Figure 3.4 (b) displays THI average for the summer of 2007/08. The highest average THI value was similar to that of the 2005/06 summer at 81. The Eastern Cape experienced low THI values between 60 and 68 in the west and mild increases between 69 and 70 in the east. The Free State Province indicated a similar pattern to that of the Eastern Cape Province. The small area in the west of the Limpopo indicated that it has decreased in size for this summer with the Northern Cape, Mpumalanga and KwaZulu-Natal showing the same pattern (Figure 3.4 (a)).

The 2012/13 summer shows the highest THI average compared to the rest of the years with a value of 83 (Figure 3.4 c). The greatest stress was visible in the central-north of the Northern Cape Province and the Limpopo Province in the west with THI values between 74 and 83, the provinces had large parts of their areas experiencing heat stress. The eastern parts of Mpumalanga and KwaZulu-Natal provinces also showed the greatest stress in the edges which extended further inland. Nearly the entire Western Cape, North West, Gauteng and the Free State in the west showed an increased risks of heat stress with THI values between 70 and 71 prevailing. The Free State Province showed an increased risk of heat stress in a large area towards the west that extended from the Northern Cape. This is in agreement with Mavis et al. (2018) where air temperature change between 1960 and 2013 was greater towards the north western regions of the Free State province, thus having an effect on THI.

Similar to the 2005/06 and 2007/08 summers, the average THI in the 2013/14 summer was 81 (Figure 3.4 d). Heat stress areas that increased in the 2012/13 summer had contracted in size because of the lower average of THI in 2013/14. An interesting feature were the areas in the west of the Limpopo Province which increased drastically in size compared to the rest of the three summers. The Western Cape Province showed an elevated risk of heat stress in the 2012/13 and 2013/14 summers. The Eastern Cape Province also showed an increased risk of heat stress in the west for the 2007/08, 2012/13 and 2013/14 summers.

The Northern Cape, Limpopo, Mpumalanga and KwaZulu-Natal in the eastern edges were the most vulnerable provinces to heat stress. A small area in the central KwaZulu-Natal indicated a very high potential for heat stress in cattle with the 2012/13 summer demonstrating this. This was also visible for North West, Gauteng, Free State and the Western Cape provinces where an increased risk of heat stress was evident. The North West Province introduced an adaptation plan because the majority of cattle are feedlot or graze in the open, making them vulnerable to high air temperatures and relative humidity (DREAD, 2015).

3.5.4 Daily extreme and high THI values

To understand the effects of climate variability on THI, three weather stations with the highest daily THI extremes of the stress category of very severe stress for South Africa were selected. Air temperature and relative humidity are the major climatic variables that are known to affect THI. Air temperatures above and below upper critical and lower critical respectively initiate bodily and behavioural reactions in cattle and in extreme cases can cause death through hyperthermia and hypothermia, knowledge of these comfort zones can be of crucial importance to farmers so that they take steps for optimum production (Scholtz et al., 2013). For dairy cattle, stress begins when T_a is above 25 °C and a high *RH*, while beef cattle are affected when T_a is at 30 °C with *RH* of below 80 % (Hahn, 1999). The 30-years summary statistics for the three weather stations is presented in Table 3.3 with the lower and upper critical values presented in Table 3.4.

Table 3.3: Summary of statistics for three stations that recorded extreme daily THI values over the 30-year period.

Site	Statistics	Average T_{air} (°C)	Average RH (%)	THI
Groblershoop	Minimum	3.25	10.85	41.72
	Maximum	35.30	100.00	*90.50
	Mean	19.89	49.94	64.70
	Std. dev	6.46	14.46	8.32
Lusikisiki	Minimum	5.15	18.60	43.04
	Maximum	34.10	100.00	*89.21
	Mean	18.55	70.08	64.11
	Std. dev	3.55	12.41	5.34
Prieska	Minimum	1.84	12.20	36.50

Maximum	37.50	100.00	*95.92
Mean	18.79	50.69	63.31
Std. dev	6.51	12.21	8.41

*T_{air} is air temperature. RH is relative humidity. THI is temperature humidity index and * represents the extreme daily THI*

Table 3.4: Climatic conditions of lower and upper critical values of THI for three different stations that recorded highest daily THI values.

Station	Climatic variable	Air temperature (˚C)	Relative humidity (%)	THI
Groblershoop	Lower critical	24.8	51	41.72
	Upper critical	34	88	90.50
Lusikisiki	Lower critical	24	67	43.04
	Upper critical	34	79	89.21
Prieska	Lower critical	25	46	36.50
	Upper critical	37	86	95.92

Groblershoop in the central Northern Cape showed a very severe stress. This was recorded on 7th February 1998 with a THI value of 90.50. The value was obtained for an average air temperature of 34 °C and an average *RH* of 88 % (also known as the upper critical value). The lower critical value for air temperature in this area was 24.8 °C and an *RH* of 51 % respectively with a THI value of 41.72, recorded on 26th May 1997. The regression graph (Figure 3.5) of T_a vs THI indicated that 96 % of the variation in THI can be explained by T_a, while that of *RH* vs THI indicated that 5 % of the variation in THI can be explained by *RH*.

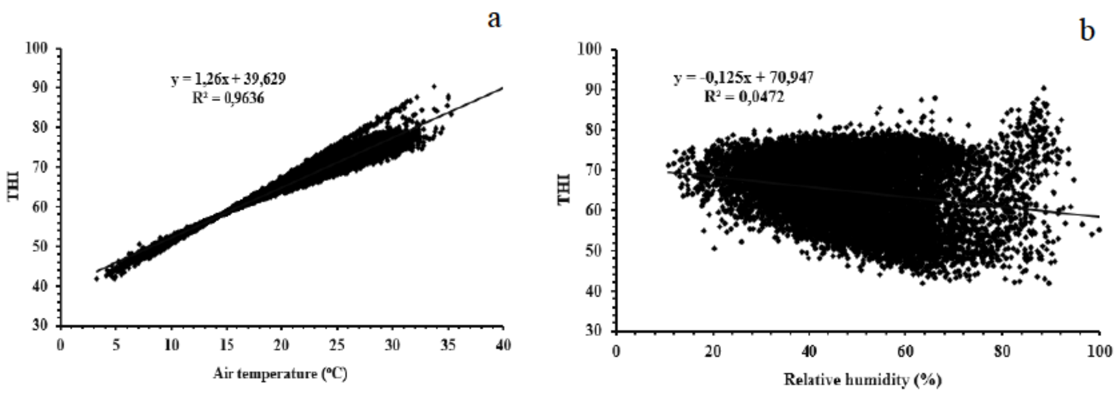

Figure 3.5: The daily (a) air temperature vs THI and (b) *RH* vs THI regression graphs for Groblershoop between 1985 and 2015.

Prieska in the central Northern Cape recorded a very severe stress for two consecutive days on the 20th February 1997 at an average air temperature of 37.8 °C and RH of 85 % with a THI value of 95.2, and on 21st February 1997 at an average air temperature of 37 °C and average RH of 86 % with a THI value of 95.9. The lower critical values of air temperature and RH were 25 °C and 46 % respectively with a THI value of 36.5, recorded on 14th August 1996. The regression graph (Figure 3.6) of T_a vs THI indicated that 99 % of the variation in THI can be explained by T_a, while that of *RH* vs THI indicated that 8 % of the variation in THI can be explained by *RH*. This means that air temperature had the greatest effect on the THI in Prieska.

EnviroTech Solutions (2019) mentioned that deaths rarely occur in the Northern Cape but milk yield and conception rates were observed to decrease when air temperatures were high showing the sensitivity of dairy cattle to THI. The Northern Cape was reported to experience extreme heat during summer in the regions bordering Namibia (Jordaan et al., 2013). This explains why cattle are not the primary livestock farming practice in the Northern Cape Province (Meissner et al., 2013).

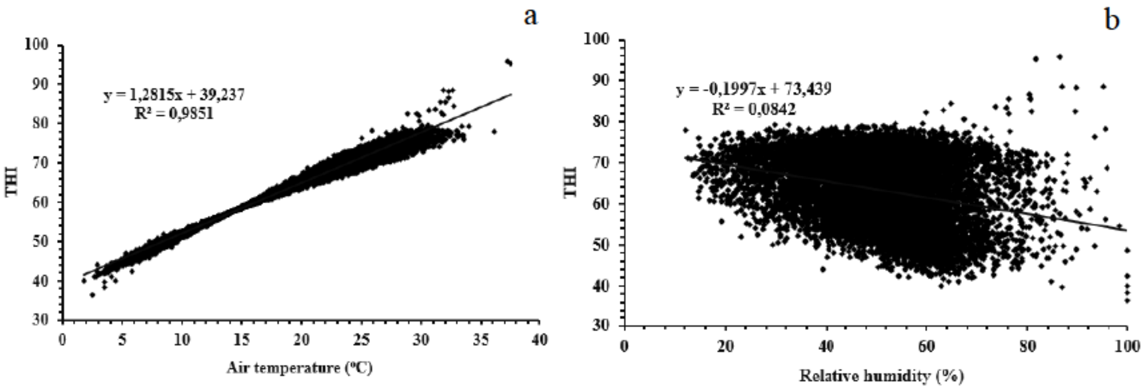

Figure 3.6: The daily (a) air temperature vs THI and (b) *RH* vs THI regression graphs for Prieska between 1985 and 2015.

Lusikisiki situated in the east of the Eastern Cape Province also reported very severe stress on the 25th February 2001 at an average air temperature of 34 °C and *RH* of 79 % with a THI value of 89.21. The lower critical values of air temperature and *RH* were 24 °C and 67 % respectively with a THI value of 43.04, recorded on 18th June 1997. The regression graph (Figure 3.7) of T_a vs THI indicated that 99 % of the variation in THI can be explained by T_a, while that of *RH* vs THI indicated that 0.45 % of the variation in THI can be explained by *RH*. Heat stress in these three areas has shown to occur when the air temperatures were above 24 °C with high *RH* (Table 3.4). The air temperatures had the greatest influence on THI and since the air temperature is expected to increase as result of the projected climate change, THI is likely to increase. An increase in THI will mean vulnerability to cattle farmers.

Daily THI extremes were prevalent in the February months in the study, which is in agreement with Du Preez et al. (1990), where an observed risk for moderate and advanced heat stress for cattle was from November to March in South Africa. The daily extremes occurred in the Northern Cape and Eastern Cape provinces. High average air temperatures and high average relative humidity accounted for the extreme high THI values in the two provinces. High average summer extremes were experienced in 2005/06, 2007/08, 2012/13 and 2013/14 for the period of study. The four highest seasonal averages identified for summer in the study failed to include the daily extreme indices identified, making the seasonal average unrelated to daily extremes.

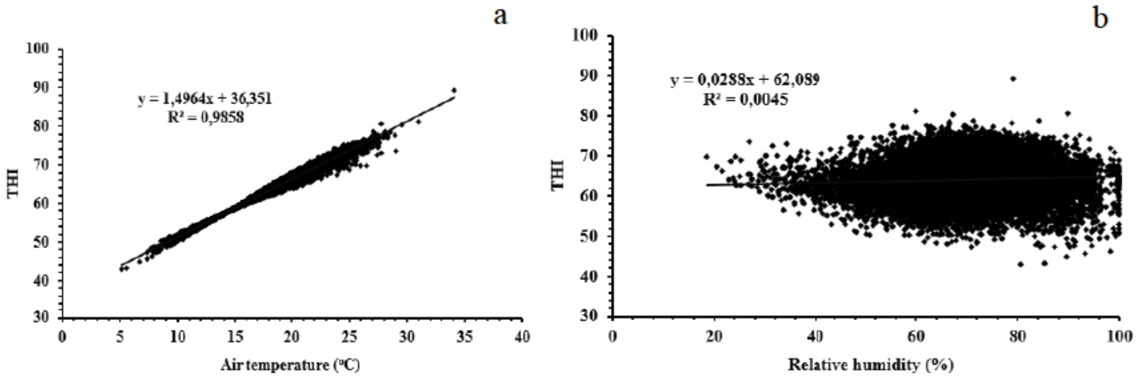

Figure 3.7: The daily (a) air temperature vs THI and (b) *RH* vs THI regression graphs for Lusikisiki between 1985 and 2015.

3.5.5 The THI values in relation to cattle

Seasons play a role in the management practices used in cattle farming. Rorie (2015) discussed that breeding of lactating dairy cows to maintain a reasonable calving interval can be challenging any time of year, but even more challenging during the hot summer months. A higher seasonal THI average meant more days experiencing heat stress in the season. Summer experienced a higher average compared to other seasons in the study.

Cows in South Africa are calved throughout the year with a slightly more calvings in the mid-winter than in mid-summer (Theron et al., 2002). Farmers calving their cows and heifers in autumn are likely to see them calve earlier than the calculated due date, when long periods of heat and drought are experienced through the third trimester (Rhinehart, 2017). It was found that breeding cows at relatively cool air temperatures with them later exposed to moderate and severely hot air temperatures decreases their pregnancy rates by 50 % and further makes the surviving foetuses smaller in heat stressed cows and made them more prone to loss later in pregnancy (Rhinehart, 2017).

The Free State province did not indicate stress conditions for the 2007/08 summer, yet Foster et al. (2009) found beef breeds to be sensitive to heat stress in the 2007 summer which resulted in elevated rectal temperatures in the south eastern Free State. This comes to show that even if a summer had low THI average, heat stress can still occur in some cattle breeds.

The THI ranges of (72 to 83) and (75 to 87) for summer in 2015 indicated a negative impact on the performance of dairy cattle resulting in low milk production and utilisation of nutrients in the Limpopo province, especially on smallholder farms (Kekana et al., 2018). Mugwabana et al. (2018) observed that cows in Mpumalanga had more chance to calve than those in Limpopo and KwaZulu-Natal from communal farmers and emerging farming systems. This was seen for the 2012/13 summer where a large part of the Limpopo and nearly half of KwaZulu-Natal provinces experienced heat stress compared to Mpumalanga.

Nesamvuni et al. (2012) projected a very severe heat stress for dairy cattle along the northern edges in South Africa which was evident from the 2012/13 summer that displayed the highest summer average of THI with the Northern Cape and Limpopo provinces as the most stressed.

Extreme daily THI indices with a category of very severe stress were observed mainly for two provinces, the Northern Cape and the Eastern Cape for both dairy and beef cattle. The daily THI extremes were a result of elevated air temperatures accompanied by high relative humidity in the study. When it is hot and very humid, the natural ability of cattle to dissipate heat through the skin and lungs is compromised because of the lowered ability to use evaporative cooling (Bilby, 2014). Cattle are able to tolerate considerably higher air temperatures when the relative humidity is lower because they are able to dissipate excessive heat more efficiently by sweating

(Bilby, 2014), this is why extremely hot days with low relative humidity in the study did to record the most extreme stress , unlike the selected four days in the study.

No deaths were reported as death in cattle occurred when THI becomes greater than 98 (St. Pierre et al., 2003). Summer et al. (2019) discussed that unlike dairy cattle, the impact of heat stress on the beef sector is not instantly measurable because it does not reflect on a daily production metric such as the litres of milk. Daily extreme THI indices become a threat in the beef industry because feedlot cattle are physiologically overweight and have the least amount of lung capacity relative to body weight (Dahlen and Stoltenow, 2012). The study indicated that high air temperatures had the most influence in THI. Hahn and Mader (1997) observed that extremely high air temperatures influenced THI which increased the likelihood of mortality of feedlot cattle. Lactating dairy cows exposed to high air temperatures influencing THI, often together with high *RH* usually respond with reduced milk yield (West et al., 2003).

Rural cattle production in South Africa comprises about 40 % of the national herd (Molefi et al., 2017) and their production efficiency is low as a result of low cow reproductive efficiency due to heat stress (Mapekula et al., 2009). The study revealed the Northern Cape, Limpopo, the eastern parts of Mpumalanga and KwaZulu-Natal to be vulnerable regions for cattle production in South Africa. The impact of heat stress on commercial farms situated in heat stressed regions will be very costly. For non-commercial farmers in rural areas, heat stress results in no produce due to the lack of adaptive capacity such as proper infrastructure and coping mechanisms (Kekana et al., 2018).

3.6 Conclusions

Seasonally, for South Africa, THI values were observed to be more extreme in summer than any other season. Winter was the season when THI was least likely to be a threat in most regions in the country. The vulnerable regions were the central-north parts of the Northern Cape and north western parts in Limpopo. The eastern edges of the Mpumalanga and KwaZulu-Natal provinces were also heat stress areas. The Eastern Cape, a large part in the west of Mpumalanga, a small part in the west of the KwaZulu-Natal and the eastern part of the Free State Provinces were areas of comfort for cattle in summer.

The areas of heat stress were increasing in the country, particularly in Limpopo because of the increase in air temperature. Some seasons had THI above 80, while the 2012/13 summer had the highest average THI of 83. On the other hand, daily THI values can exceed 90 in some areas, especially in the western and northern parts of the country. The Northern Cape experienced the highest seasonal and daily THI extremes, which makes cattle production in the province a risk. No relationship was observed between high seasonal averages and daily values of THI as both did not occur concurrently.

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CHAPTER 4: ESTIMATION OF WETNESS AND DRYNESS FOR SOUTH AFRICA USING THE STANDARD PRECIPITATION INDEX

4.1 Abstract

The standard precipitation index (SPI) is a useful technique in determining wet and dry periods at different time scales. Similarly, the temperature-humidity index (THI) is a useful tool for determining heat stress in cattle. The SPI allows for the assessment of wet and dry conditions at any area with a 30-year time series. The SPI is closely related to soil moisture conditions on short time scales. The SPI was used to investigate whether the 2005/06, 2007/08, 2012/13 and 2013/14 summers were wet or dry for South Africa because they had high THI averages. The SPI at 3 months' time scale (SPI-3) was computed. Monthly rainfall data from 192 weather stations were used to represent the country. Results indicated the North West, the western Free State and east of the Eastern Cape provinces were vulnerable to dry conditions. The SPI indicated that drought frequency and intensity was more evident in the east of the Eastern Cape Province. The western part of the country remained generally wet for three of the summers except for the 2013/14 summer.

Keywords: dry conditions, rainfall, SPI, time scale, vulnerability

4.2 Introduction

Heat stress decreases grazing and feed intake, while drought can limit pasture availability for grazing cattle (Rhinehart, 2017). The most obvious effect of drought on pasture is reduced growth because a deficiency in moisture suppresses plant growth and root development (The Beef Site, 2012). The cattle performance (milk production, fertility, maternal ability, growth rate and feed efficiency) is a function of nutrient requirement and intake (The Beef Site, 2012). Thus cattle performance will decline whenever pasture is insufficient (NDMC, 2020). Drought often reduces the number of days during which green forage is available to cattle (NDMC, 2020). The quantity and quality of available pasture are the main regulators of nutrient intake in grazing cattle (NDMC, 2020). Nutritional deficiencies also have an adverse effect on conception rates, especially if cows are thin at calving (Bindar et al., 2013). Conception rates will first decline in lactating first-calf heifers because they still need nutrients for growth compared to mature cows (Bindar et al., 2013). Lactation increases cow nutrient requirements significantly and continued nursing delays a cow's return to estrus when nutritional deficiencies occur (NDMC, 2020).

There is no single definition of drought (Wilhite and Glantz, 1985). Meteorological drought originates from a deficiency of precipitation over an extended period of time resulting in a water shortage for some activity, group, or environmental sector (AMS, 2013). Drought is not just a period of low rainfall but a prolonged, abnormally dry period where not enough rain falls for normal pasture growth (The Beef Site, 2012). Drought is often categorized as four general types: meteorological or climatological, agricultural, hydrological, and socioeconomic (Wang et al., 2016). Meteorological drought is mainly a prolonged lack of precipitation (Keyantash and Dracup, 2002). Agricultural drought results when the soil moisture availability to plants has decreased to such a level that it adversely affects the crop yield and hence agricultural profitability (Mannocchi et al., 2005). Hydrological drought is related to below-normal streamflow, lake and groundwater levels (Wang et al., 2016). Socioeconomic drought occurs when the demand for economic goods exceeds the supply as a result of a weather-related shortfall in water supply (Hisdal and Tallaksen, 2000).

Extremely wet conditions are a concern for cattle production as they can cause flooding. Flooding is defined as any high flow, overflow or accumulation of water which causes or threatens damage (Smith, 2020). The impacts of wet conditions are multifactorial and have features that can affect cattle (Lingnau, 2020). When heavy rains are experienced, feed that is not covered becomes saturated with water, making it difficult for cattle to consume (Lingnau, 2020). Cattle grazing during periods of extreme wet conditions can damage pasture stands and the structure of soil (Hartman, 2019).

The Standard Precipitation Index (SPI) is an index used to monitor the occurrence of abnormally wet or dry conditions (McKee et al., 1993; Masante et al., 2018). The SPI is multiscalar but only incorporates precipitation to calculate the drought index (Tirivarombo et al., 2018). Another drought index known as the standard precipitation evaporation index exist (SPEI) exists (Adisa et al., 2019). The SPEI is a multi-scalar drought index which takes into consideration precipitation and air temperature in addition to the ability to identify drought at different time scales (Vincente-Serrano et al., 2010; Gurrapu et al., 2014). The SPI was intended to measure the precipitation shortage for multiple timescales and can be calculated monthly up to 72 months (WMO, 2012). The SPI can also be useful for observing wetter than normal conditions (Guerreiro et al., 2008). The time scale over which precipitation deficits accumulate becomes extremely important and functionally separates different types of drought (McKee et al., 1993). Soil moisture conditions respond to precipitation anomalies on a relatively short time scale (McKee et al., 1993). Groundwater, streamflow and reservoir storage reflect the longer-term precipitation anomalies. For these reasons, McKee at al. (1993) originally calculated the SPI for 3-, 6-, 12-, 24- and 48-month timescales. One-month SPI can be used to monitor the start of an agricultural drought (WMO, 2012). A 6-month SPI and longer can be used to evaluate seasonal drought (WMO, 2012; Trambauer et al., 2014).

Advantages of the SPI includes the index requiring only monthly precipitation and being able to be compared across regions with markedly different climates (NCL, 2019). The standardization of the SPI allows the index to determine the rarity of a current drought and it can be created for differing periods (NCL, 2019). A regional 5-day precipitation revealed that SPI can also be used outside its normal analytical purpose by quantifying the probability that precipitation to come will end an ongoing drought (Anctil et al., 2002). The accuracy of SPI in detection of sub-monthly drought is limited (NCL, 2019). Aswathi et al. (2018) assessed the severity and persistency of meteorological drought using SPI. The accuracy of SPI in detection of sub-monthly drought was noted to be limited.

The SPI is very useful as a measure of precipitation deficits or meteorological drought but is limited since it does not deal with evapotranspiration (Trenbert et al., 2014). Regardless of the SPI being applied widely, its application for short time scales such as 1, 2 and 3 months in areas characterized by low seasonal precipitation may result in the underestimation or overestimation of the negative or positive SPI values (Lloyd-Hughes and Saunders, 2002).

The SPI was used to identify and simulate a hydrological drought in the Limpopo River and it proved to be a useful measure for identifying agricultural to long-term hydrological droughts (Trambauer et al., 2014). Analysis of drought frequencies and events revealed that there was an extended accumulation of a severe dry condition which lasted from 1991 to 1992 over the Limpopo river basin (Gebre and Getahun, 2016). At a 6-month timescale, the SPI displayed a severity in hydrological drought which reduced the streamflow to below mean annual flow (Fobo, 2009).

The SPI has been used to extensively study drought characteristics in various parts of the country (Rouault and Richard, 2003; Edossa et al., 2013; Botai et al., 2016; Phaduli, 2018; Swemmer et al., 2018). Similar studies have been conducted in other parts of the world (Seiler et al., 2002; Sabău et al., 2015; Nkiaka et al., 2017; Wang et al., 2016).

Heat stress and drought (dry conditions) are amongst the factors that affect cattle farming and pose the greatest risk for production losses as drought and rainfall deficits cause damage to pasture (Collier and Zimbelman, 2007; Kemper et al., 2013). The THI estimates the degree of thermal stress in cattle and uses the combined effects of air temperature and relative humidity and is an easy way to assess the risk of heat stress (Herbut and Angrecka, 2012).

The aim of this chapter is to compute SPI for South Africa for the corresponding extreme THI periods, identified in Chapter 3, investigate if they occur during dry or wet periods and relate them to the vegetation greenness in Chapter 5 for cattle feed.

4.3 Methodology

4.3.1 Study area

South Africa covers an area of approximately 1.21 million square kilometres (VACorps, 2020). The interior consists mostly of a flat plateau, and the areas adjacent the coast extend from 800 meters to sea level (VACorps, 2020). It is a dry country, classified as semi-arid with an average annual rainfall for the whole country at 464 mm (Alexander, 2018). The South African rainfall is characterized by high spatial and temporal variability occurring at several time scales (Chikoore and Jury, 2010). More than 80 % of the country's annual rainfall is received during

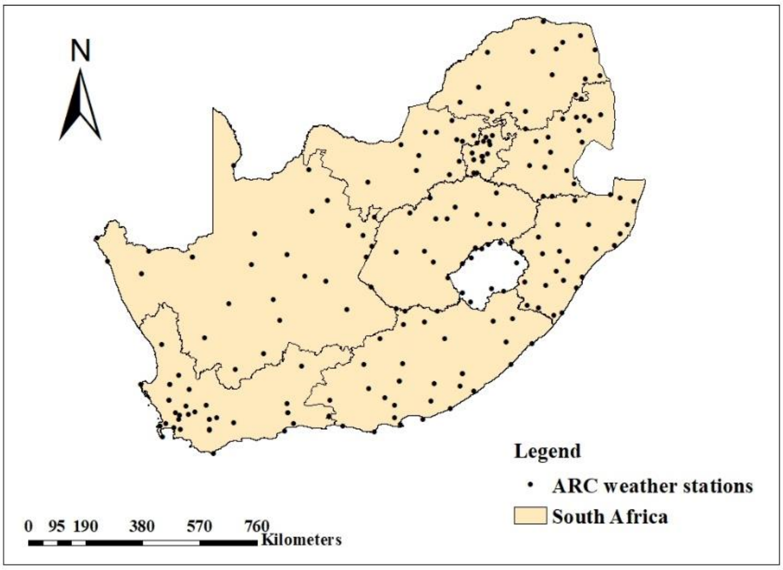

Figure 4.1: South African station network distribution for SPI.

the austral summer from December to February except in the southwest where rainfall occurs in winter (Buckle, 1996).

4.3.2 Data

Monthly rainfall data were obtained from the agricultural research council (ARC) Agrometeorology data base from 1985 to 2015. A total of 192 weather stations (Figure 4.1) with at least 30 years of data were selected to represent South Africa. The stations selected represented all the climate regions of the country. Missing rainfall values were calculated using the ARC standalone patching software. The software used the Inverse Distance Weighting (IDW) method defined by Shabalala et al. (2019) where the missing data are obtained by assuming that the target station data could be influenced mostly by the nearest station and less by further distance stations in accordance with Tobler's law (Sui, 2004).

4.3.3 Method

The SPI is normalised, and as a result wetter and drier climates can be represented in the same way (WMO, 2012). The SPI calculation for any location is based on the long-term precipitation record for a desired period (WMO, 2012). This long-term record is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero (Edwards and McKee, 1997). The weather data required for the drought index calculation is the monthly summarised rainfall values for each year. Calculation of SPI included fitting a gamma probability density function to a known frequency distribution of rainfall totals of a station (Edwards and McKee, 1997).

Positive SPI values indicate greater than median precipitation and negative values indicate less than median precipitation (Monacelli et al., 2005). Drought periods are represented by relatively high negative SPI values (Monacelli et al., 2005). A drought event starts when SPI value reaches -1.0 and ends when SPI becomes positive again (Table 4.1).

4.3.4 Data analysis

The RStudio software version 3.0.3 was used to compute SPI at 3-months' time scales which is associated with an agricultural drought. The software computes the SPI index from a predefined time scale (McKee et al., 1993). A 3-month SPI, included the summer months (December, January and February) computed seasonally with ArcGIS used in the computation of maps. The corresponding summer extreme THI periods (2005/06, 2007/08, 2012/13 and 2013/14) were used as indicators for the SPI periods to map and assess wetness or dryness. These seasons were selected based on the THI findings where highest THI averages were considered.

Table 4.1: The SPI values for various wetness and dryness ranges (McKee et al., 1993).

2.0+	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 and less	Extremely dry

4.4 Results and discussion

4.4.1 SPI at 3 months

Figure 4.2 displays the summer SPI at 3 months (SPI-3) in South Africa for the 2005/06 summer. The summer SPI-3 indicated a large part of the country being dry, especially in the country's interior. A large part of the Northern Cape Province experienced near-normal conditions to extremely dry conditions in the south-west. The Western Cape Province indicated a distribution of moderately dry to severely dry conditions throughout the province. The North West, Gauteng, Mpumalanga and Free State provinces were the most affected by dryness. The provinces experienced moderately dry conditions in small areas to extremely dry conditions in larger areas. The Limpopo Province showed a small area towards the east experiencing moderately wet to extremely wet conditions. The rest of the Province experienced moderately dry to extremely dry conditions. The KwaZulu-Natal Province indicated near-normal conditions for half of the region in the west to extremely wet conditions in a small region towards the south coastline and moderately dry to extremely dry in the south west. The Eastern Cape Province had a large part of its area experiencing moderately dry to extremely dry conditions and a small area towards the centre of the coast indicated moderately wet to extremely wet conditions. The highest SPI value for dryness was -8.94 and for wetness was 4.98.

Figure 4.3 displays the summer SPI-3 of 2007/08 with a much wetter season as compared to 2005/06 summer. Severely to extremely dry conditions were observed for much of the east in the Eastern Cape. Moderately dry conditions were visible for the eastern seaboard of Kwazulu-Natal and the Gauteng provinces extending into parts of the Free State, North West and Mpumalanga. A large area on the west of South Africa indicated extremely wet conditions including a large part of the Northern Cape Province.

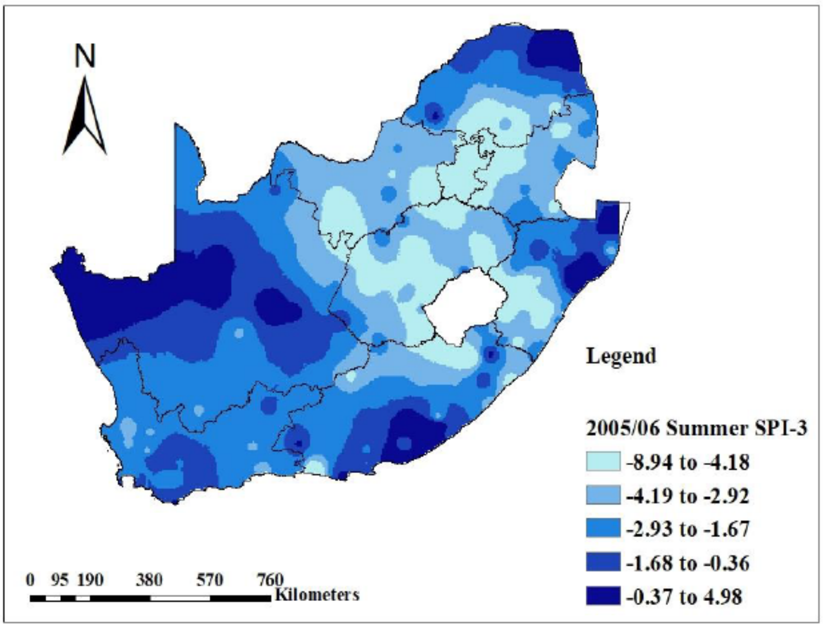

Figure 4.2: SPI-3 for the 2005/06 summer in South Africa.

*Area in white inside South Africa is Lesotho

The Western Cape Province showed extremely wet conditions in the east and a small part in the west indicated moderately to extremely dry conditions. Botai et al. (2016) indicated a mild drought event at 3 months' time scale in 2008 for the Western Cape Province and noted that drought conditions appeared to worsen towards the southern Cape regions. Limpopo Province showed moderately wet to extremely wet conditions for a large part of the Province. The Free State, Mpumalanga and the North West provinces had small regions indicating moderately dry conditions with the remaining provinces experiencing moderately to extreme wet conditions. The highest SPI value for dryness was at -3.14 and for wetness was at 8.64.

Figure 4.4 displays the 2012/13 SPI-3 in summer for the country with a large part of the west being wet and the east being very variable. Extremely wet conditions are observed for the Northern Cape and the Western Cape. A small area in the east of Northern Cape indicated severely to extremely dry conditions which extended into the Free State and the North West provinces.

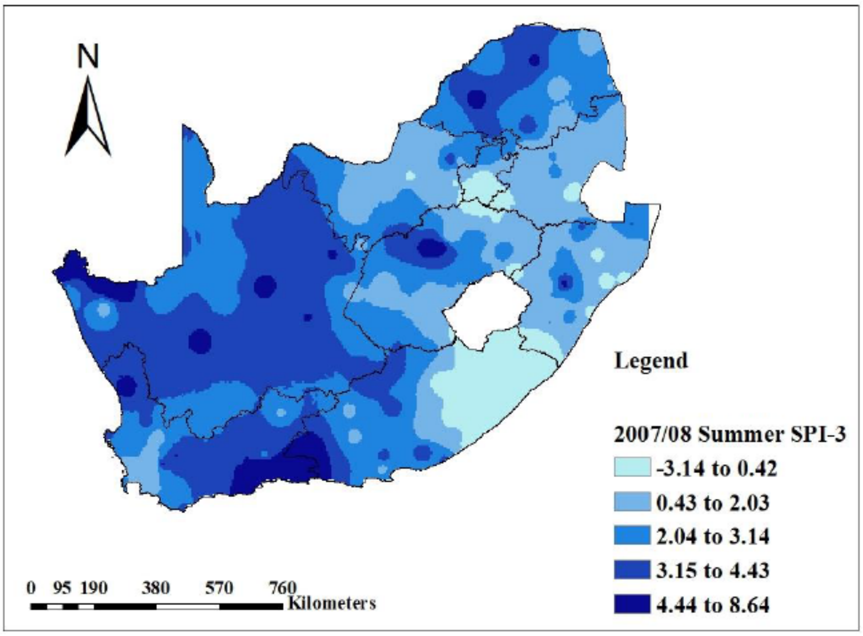

Figure 4.3: SPI-3 for the 2007/08 summer in South Africa.

*Area in white inside South Africa is Lesotho

The Eastern Cape showed a very variable SPI with the SPI increasing from the east to the west with a small region in the west depicting near-normal to extremely dry conditions and the west moderately wet to extremely wet conditions. The Free State indicated very to extremely wet conditions for a small part in the central-north, while the east and west parts of the Province showed moderately to extremely dry conditions. The North West Province also indicated very wet conditions in the central-south, which extended from the Free State. The west of the North West Province experienced moderately dry to near-normal conditions while the east indicated near-normal conditions.

The Limpopo Province indicated moderately to extremely wet conditions in small areas in the central-north and severely to extremely dry conditions in the south. The Gauteng Province also generally experienced near-normal to very wet conditions, a small area in the south of the Province showed moderately to extremely dry conditions. Mpumalanga indicated moderately dry conditions in the west and near-normal to extremely wet conditions in the west. A small area in the south of the Province showed extreme dry conditions. KwaZulu-Natal had a variable SPI where the north coast indicated near-normal to extreme wet conditions while the south coast of the Province showed near-normal conditions. A small area in the west of the Province showed extremely wet conditions. The highest SPI value for dryness was -6.82 and that of wetness was 5.14.

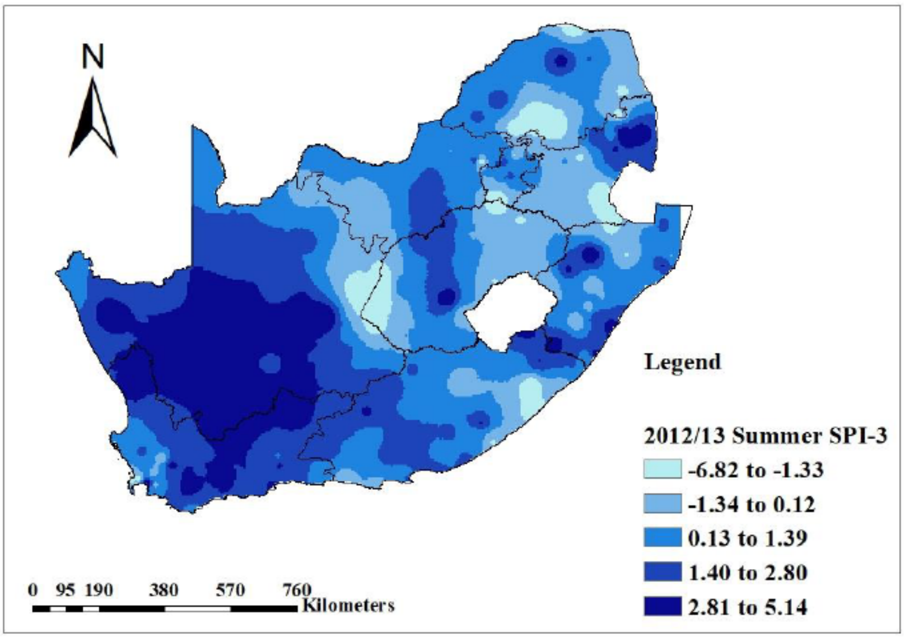

Figure 4.4: SPI-3 for the 2012/13 summer in South Africa.

*Area in white inside South Africa is Lesotho

Figure 4.5 shows the 2013/14 summer SPI-3 with a great variability over the country. A large area of the Northern Cape interior experienced near-normal to very wet conditions and near-normal to extreme wet conditions in the central-north (tip area). A small part in the east of the Province indicated moderately to extremely dry conditions that extended into the Free State and North West provinces. The Western Cape Province indicated very to extremely wet conditions for a large area, two small areas in the east and south-western of the Province indicated near-normal to severely dry conditions respectively. The Eastern Cape Province showed very to extremely wet conditions in the central-west, a small area in the east indicated moderately to extremely dry conditions. A large area of the North West Province indicated moderately to extremely dry conditions more prevalent in the west. Gauteng and Mpumalanga provinces had areas indicating extremely wet conditions.

The western and eastern areas of the Free State showed severely dry conditions while the central-south and northern parts experienced near-normal to extremely wet conditions. The Limpopo Province indicated near-normal conditions for a large area of the Province with the edges in the north-eastern experiencing extremely dry conditions. KwaZulu-Natal showed very wet to extremely wet conditions in the south-east. The central areas of the Province showed near-normal conditions with small areas in the east and west showing extremely wet conditions. Severely dry conditions were visible in a small area in the north and extended into Mpumalanga.

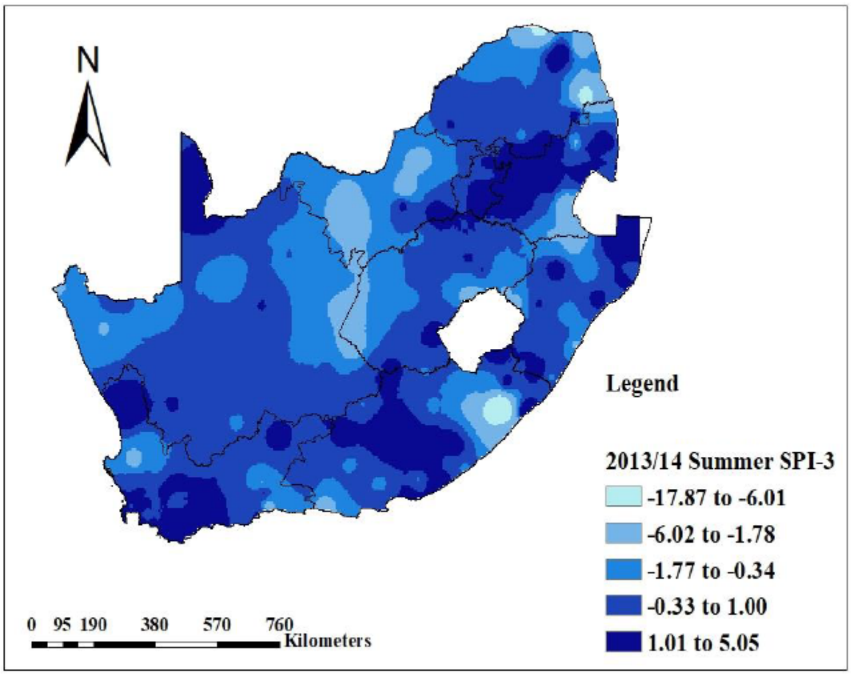

Figure 4.5: SPI-3 for the 2013/14 summer in South Africa.

* Area in white inside South Africa is Lesotho

4.4.2 SPI variability and intensity for the 2005/06, 2007/08, 2012/13 and 2013/14 summers

The Northern Cape Province was the most heat stressed in the summers of 2005/06, 2007/08 and 2012/13, while the SPI for the selected years indicated the western areas of the country being the most wet. This was in agreement with Kruger and Nxumalo (2017) where the western area of South Africa has observed an increase in rainfall. The 2005/06 summer indicated a large area of the east experienced dry conditions more especially in the interior which can be associated with weak El Niño's that occurred in 2004/05 and 2006/07 (NASA, 2010).

The summer of 2007/08 indicated the Eastern Cape Province as the most affected by dry conditions. The few areas that were wet in the Eastern Cape had the greatest intensity of wetness compared to the other 3 summers. Ngaka (2012) noted that the Eastern Cape Province experienced drought in 2007/08 which resulted in livestock losses for farmers. The standard precipitation evapotranspiration index at 3 months (SPEI-3) identified the 2005/06 and 2007/08 as major drought years in South Africa (Adisa et al., 2019).

The 2012/13 summer was dry in the east with a high variability of dryness. The USDA (2013) identified the North West and Free State provinces having experienced drought in the 2012/13 summer with the greatest severity experienced in the North West Province.

The 2013/14 summer was an exception with the eastern and western parts being wet, except for the North West Province. Botai et al. (2016) found that high intensity droughts occurred in the North West Province. The few areas that were dry for the 2013/14 summer are small regions in the Eastern Cape and Limpopo with a great intensity in dryness. Edossa et al. (2014) and Spinoni et al. (2019) identified major drought periods and none of the four summer periods are a part of the major drought years for South Africa.

Cattle that are heat stressed eat less frequently during cooler times of the day, but they eat more at each feeding (Shearer, 1999). An SPI value representing dry conditions in an area that is heat stressed provide a hostile combination for cattle production due to feed and water unavailability for when cattle eat more as mentioned by Shearer (1999). Small-scale farmers are extremely vulnerable to the impacts of climate variations/climate change as a result of poverty, marginalisation and reliance on natural resources (Frank and Buckley, 2012). Thus lack of adaptive capacity for heat stress for South African small-scale farmers will result in low produce or cattle mortality.

4.5 Conclusions

Dry conditions affect cattle production negatively through feed. Dry pastures lead to lower quality feed and decreases in feed availability which can lead to overgrazing. The SPI-3 was very variable for the corresponding THI years selected. Mainly, the country's interior and the eastern parts of the country experienced dry conditions for most of the summers. The Eastern Cape Province indicated vulnerability to dry conditions with the greatest frequency and intensity in the east for all the summers. The Limpopo Province experienced the most variable SPI-3 compared to the rest of the provinces.

Wet conditions were observed for the western areas of South Africa for most of the summers, especially in the Northern Cape Province. The 2013/14 summer indicated the greatest intensity in dryness compared to other summers. Generally, the selected years were not major drought years for South Africa.

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CHAPTER 5: ASSESSMENT OF VEGETATION GREENNESS AND ACTIVITY FOR SOUTH AFRICA USING THE NORMALISED DIFFERENCE VEGETATION INDEX

5.1 Abstract

Drought reduces forage growth in pastures and increases the chances of overgrazing in natural pastures. Allowing cattle unlimited access to pastures during drought can further weaken plants. The objective of this research was to produce normalised difference vegetation index (NDVI) images from the moderate-resolution imaging spectroradiometer (MODIS) satellite to assess the vegetation greenness during the 2005/06, 2007/08, 2012/13 and 2013/14 summers and estimate pasture availability for grazing cattle in South Africa. Results indicated that the eastern and coastal parts of South Africa were areas of high vegetation activity and greenness for the 2005/06, 2007/08, 2012/13 and 2013/14 summers investigated. Vegetation activities and greenness were minimal in the western of South Africa, while the interior was vulnerable to dry conditions. The interior contained areas with no vegetation activity when there was no rainfall which recovered when it rained. The Northern Cape, Limpopo, North West and Free State provinces had vegetation that was vulnerable to dry conditions.

Keywords: drought, MODIS satellite, NDVI, pasture, summer

5.2 Introduction

The vegetation of southern Africa is dominated by savanna grassland but forests and woodlands occur in the east with dry and thorny savannas in the central desert (Jury et al., 1997). The interior of South Africa where the bulk of grasslands are found is semi-arid to arid (Palmer and

Ainslie, 2019). Spatial gradients exist between the dense vegetation cover to the north-eastern and the arid south western desert (Jury et al., 1997). Natural pasture is the main feed source for grazing livestock in South Africa (Palmer and Ainslie, 2006). Grazing maintains the grass dominance and prevents the establishment of trees (Low and Rebelo, 1996). The productivity of these grasslands is affected by climate change (Soussana and Luescher, 2007).

Rangelands cover more than 80 % of the land surface of South Africa with livestock production depending largely on rangelands (Masigo and Matshego, 2002). Rangelands in the eastern parts of South Africa have a higher carrying capacity with cattle farming leading (Palmer and Ainslie, 2006). A dry season can be monitored using remote sensing where during the dry season, grazers are mainly limited by grass quantity rather than quality (Ramoelo and Cho, 2014). Dingaan and Tsubo (2019) found that during dry seasons in South Africa, non-green aboveground biomass maintained livestock grazing in the semi-arid grasslands.

Grasslands are a major component of the natural vegetation in South Africa with an area of 295. 233 km^2 of the central regions in the country and adjoining (Palmer and Ainslie, 2006). They extend into most of the major biomes (forest, savannah, thicket, Nama-Karoo) in the country (Palmer and Ainslie, 2006). Grasslands have the shortest response to drought, unlike other vegetation types (Hua et al., 2019).

Vegetation is positively correlated to rainfall in semi-arid areas due to high levels of evaporation (Davenport and Nicholson, 1993). Vegetation growth depends on rainfall and its growth pattern fluctuates with the increase or decrease in rainfall (Spano et al., 1999). Rainy seasons play important roles in regulating the growth pattern and the harvest time of vegetation (Omotosho, 1992).

Vegetation indices have been used in a variety of frameworks to assess green biomass and also as an alternative to overall environmental change, especially in the context of drought and rangeland management (Numata et al., 2007). Vegetation indices use radiance, surface reflectance or apparent reflectance values in the red (R) (635 to 700 nm) and near infrared (NIR) (700 to 1300 nm) spectral bands (Angerer, 2009).

The normalised difference vegetation index (NDVI) tool is accepted as an excellent indicator of global vegetation productivity and is also effective in monitoring climate variability, land use and vegetation type (Covele and Sannier, 2005). The most common instrument in relation to NDVI has been moderate-resolution imaging spectroradiometer (MODIS), which is on-board the Terra and Aqua satellites (Anon, 2012). The 36 spectral bands used, yield a wide range of data capture that covers visible and near-infra red parts of the electromagnetic spectrum (Anon, 2012). The value range of NDVI is -1 to 1 where healthy vegetation generally falls between values of 0.20 to 0.80 (NASA, 2000).

Studies have indicated that NDVI can be used effectively in monitoring the biomass of grasslands, forests and highlands (Tieszen et al., 1997; Wang et al., 2005; Gu et al., 2012; Wang et al., 2013; Chang et al., 2018). Several studies used the NDVI for the assessment of biomass for various rainfall zones in South Africa (Fox, 2003; Hoare and Frost, 2004; Wessels et al., 2005; Cramer and Hoffman, 2015; Fajji et al., 2017).

Long time series of approximately 20 years of NDVI observations allow utilisation of data sets for large-scale drought monitoring and exploring the relationship between vegetation and large-scale climate variability (Anyamba and Tucker, 2012). Negative NDVI anomalies could identify and map the spatial extent of drought response in vegetation (Anyamba and Tucker, 2005). There are strong relationships on an interannual time scale between NDVI anomalies and El Niño/La Niña - Southern Oscillation (ENSO) phenomena (Mennis, 2001; Martiny et al., 2006). The NDVI MODIS is a useful product for drought monitoring and vegetation assessment (Prasad et al., 2008: Meer and Ahmad, 2014; Sruthi and Aslam, 2015; Na-U-Dom et al., 2017; Qu et al., 2019).

The standard precipitation index (SPI) can also be used as a tool to assess vegetation cover, because precipitation is one of the important factors that influences vegetation growth and distribution (Yang et al., 2015). Comprehending the relationship between SPI and vegetation dynamics (NDVI) creates a potential for better management of natural resources such as natural grazing areas for cattle farming (Swinnen, 2008). Rokhmatullah et al. (2019) indicated that there was a close relation between a region with a high SPI value and the NDVI value, and a region having low NDVI value indicated several regions having high SPI values.

Mlenga et al. (2019) observed a positive relationship between SPI and the NDVI at a 3-month time scale. Yang et al. (2015) also established a good correlation between SPI and NDVI at a 6-month time scale. The correlation between the SPI average and the percentage of vegetation classes indicated that pastures were highly sensitive to SPI changes (Khosravi et al., 2017). The NDVI showed that pastures were highly sensitive to SPI changes (Sholihah et al., 2016; Khosravi et al., 2017; Yildirim and Asik, 2017). The succulent Karoo biome (winter-rainfall region) of South Africa showed no decrease in the mean annual rainfall or the occurrence of drought from using the SPI at 12-month time scale (Hoffman et al., 2009). Seasonality of precipitation, and more specifically, the proportion of total precipitation in summer, is related to the productivity of grasses (Winslow et al., 2003; Hamerlynck et al., 2013; Tong et al., 2017).

Heat stress decreases grazing and feed intake in cattle, while drought can limit feed availability from natural grazing areas (Rhinehart, 2017). Therefore, the aim of this research is to describe vegetation conditions using the NDVI during the seasons that were identified to have had heat stress in South Africa (2005/06, 2007/08, 2012/13 and 2013/14).

5.3 Methodology

5.3.1 Study area

South Africa is the southernmost country in Africa that extends from 22° to 34° south latitude (Climates to Travel, 2020). South Africa's climatic conditions generally range from Mediterranean in the south-western corner of South Africa to temperate in the interior plateau, and subtropical in the northeast. A small area in the northwest has a desert climate (SA-V, 2020). Most of the rainfall in the country occurs largely in summer, with the south-western part of the country receiving rainfall usually in winter (Botai et al., 2018). Natural vegetation in South Africa varies from savanna through grassland with fewer trees to scrub and scattered bush and drier western areas (Carbutt et al., 2011). The Grassland Biome is represented by four bioregions, namely, Drakensberg Grassland, Sub-escarpment Grassland, Dry Highveld Grassland, and Mesic Highveld Grassland (Mucina and Rutherford, 2006).

5.3.2 Data

Satellite NDVI Images were downloaded from the MODIS NDVI sensors. The MODIS vegetation indices are produced at 16-day intervals and at multiple spatial resolutions and provide consistent spatial and temporal comparisons of vegetation canopy greenness, a composite property of leaf area, chlorophyll and canopy structure (Chen et al., 2006).

The MODIS (MOD13Q1) data, with a resolution of 250 m, were used in the study from the National Aeronautical Space Agency (NASA) Earth Observing System (EOS) website. The MOD13Q1 data are provided every 16 days as a gridded level-3 product in the sinusoidal projection (Wardlow et al., 2007). Cloud-free global coverage is achieved by replacing clouds with the historical MODIS time series climatology record (Wardlow et al., 2007).

The images obtained were for four summer periods (2005/06, 2007/08, 2012/13 and 2013/14) based on the SPI summers selected. ArcGIS was used in the processing of the raster images and corrected so that NDVI values ranged from -1 to 1. The 2004 land cover map from the Department of Environmental Affairs, Forestry and Fisheries was used to extract grasslands and overlay them on the different NDVI maps.

5.3.3 Method

The NDVI includes low values of NDVI (0. 1 and less) which corresponds to barren areas of rock, sand, or snow, moderate values represent shrub and grassland (0. 2 to 0. 5), while high values indicate temperate and tropical rainforests (0. 6 to 0. 9) (Weier and Herring, 2000). An NDVI value of 0 means no vegetation and close to 1 (0.8 - 0.9) indicates the highest possible density of green leaves (maximum greenness) (NASA, 2000).

The NDVI is computed using the following:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

where NIR and RED are the spectral reflectance measurements in the NIR and RED regions of the electromagnetic spectrum, respectively (Anyamba and Tucker, 2012).

5.3.4 Data analysis

Normalised difference in vegetation index maps were created in the study with satellite images from MODIS because of its ability to represent vegetation studies at regional and global levels (Sruthi and Aslam, 2015). A grassland land cover shape file was overlaid on the NDVI maps produced in ArcGIS to assess the vegetation activity in South Africa.

Two images were created for each summer month which ended in a total of six images. The images represented the onset of rainfall (December), progression of rainfall in mid-season (January) and the peak of rainfall (February) towards the end of the summer season. This assisted in understanding the response of vegetation greenness to soil moisture in South Africa for the selected periods.

5.4 Results and discussion

5.4.1 Changes in the vegetation greenness for the 2005/06 summer

The Northern Cape experienced little vegetation greenness in the beginning of the season (Figure 5.1 (a) and (b)) in the 2005/06 summer with NDVI values between -0.04 and 0.24 dominant in the Province. As the season progressed, the east of the Province experienced a slight increase in vegetation greenness with NDVI values of 0.27 and 0.44 (in Figure 5.1 (c) and (d)). Towards the end of the season, almost half of the Province was green in vegetation. NDVI values between 0.47 and 0.65 were visible in the far east of the Province.

In the beginning of the 2005/06 summer season, vegetation greenness in the far west of the North West Province was almost not present with NDVI values between -0.04 and 0.24 (Figure 5.1 (a) and (b)). The central and western parts of the Province showed vegetation greenness with NDVI values between 0.25 and 0.41 being dominant. Vegetation greenness with NDVI values of 0.45 and 0.64 started to appear from the east of the Province in mid-season. Towards the end of the season, the entire Province experienced vegetation activity with maximum greenness in some parts in the east. The end of the season (Figure 5.1 (e) and (f)) showed the east experiencing an increase in the extent of vegetation greenness with NDVI values between 0.65 and 1.

Large variability in NDVI was noted for the Limpopo Province (Figure 5.1 (a) and (b)). The 2005/06 summer indicated vegetation greenness over the Province with NDVI values between 0.25 and 0.41 being dominant. As the season progressed, vegetation activity and greenness increased in the west and east of the Province with NDVI values reaching maximum greenness, excluding a small area in the central parts of the Province visible in Figure 5.1 (d). Figure 5.1 (e) showed a decreased vegetation greenness in the west of the Province. Towards the end of season in Figure 5.1 (f) vegetation greenness increased with maximum greenness experienced for a large part of the Province.

The grassland regions in the west of the Province experienced fluctuations in vegetation greenness while those in the east maintained greenness and higher NDVI values. For the 2005/06 summer, the Mpumalanga Province showed a healthy vegetation activity with the western part having NDVI values between 0.42 and 0.60 (Figures 5.1 (a) and (b)). Vegetation greenness was the highest in the east of the Province. During mid-season and end-of-the season, vegetation reached its maximum greenness for a large part of the Province (Figures 5.1 (c), (d), (e) and (f)).

The Gauteng Province showed NDVI values between 0.25 and 0.41 being dominant early in the season (Figures 5.1 (a) and (b)) for the 2005/06 summer. The progression and the end of the season showed an improved vegetation activity and greenness with maximum vegetation greenness visible in some parts of the Province. The vegetation for the KwaZulu-Natal Province was healthy for most of the summer in 2005/06. Vegetation greenness improved as the season progressed. A large part of the Province indicated maximum vegetation greenness except for a small area in the north-central parts with NDVI values between 0.42 and 0.65 (Figure 5.1).

The Free State Province indicated no vegetation greenness (Figures 5.1 (a) and (b)) in the south-west region for 2005/06 with NDVI values between -0.04 and 0.24 present at the onset of summer. Mid-season showed an increase in greenness in the west. At the end of the summer, the Province experienced maximum greenness in the eastern parts and an improved vegetation greenness in the west.

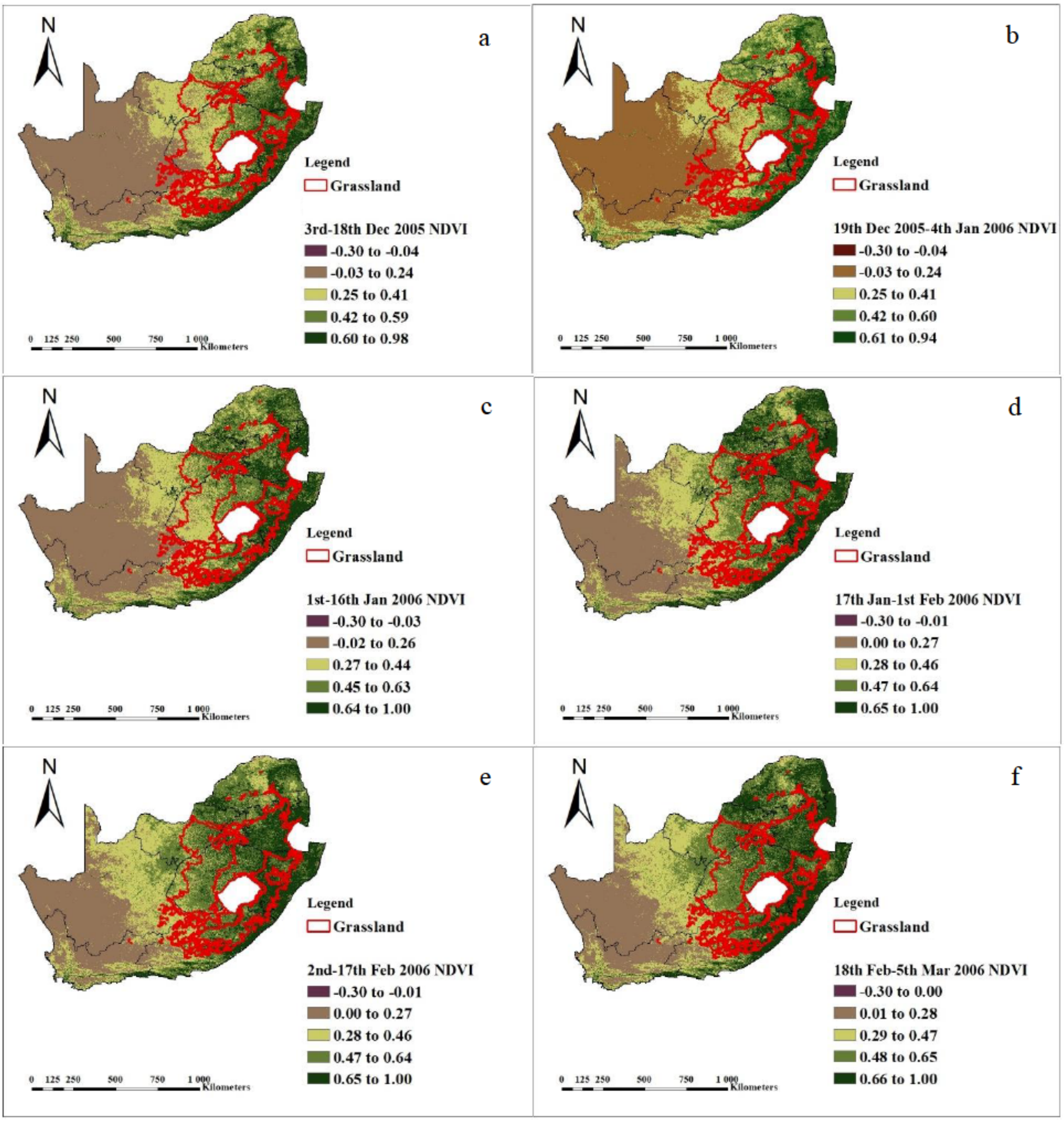

Figure 5.1: The 2005/06 summer 16 days Modis NDVI maps (a) 3rd - 19th Dec 2005, (b) 19th Dec 2005 - 4th Jan 2006, (c) 1st - 16th Jan 2006, (d) 17th Jan - 1st Feb 2006, (e) 2nd Feb - 17th Feb 2006 and (f) 18th Feb - 5th Mar 2006 for South Africa.

*Area in white inside South Africa is Lesotho

5.4.2 Changes in the vegetation greenness for the 2007/08 summer

The 2007/08 summer indicated a small portion of vegetation greenness in the far east of the Northern Cape Province (Figure 5.2 (a) and (b)) with NDVI values of 0.28 and 0.45 respectively. Mid-season NDVI values did not differ much from the beginning of the season, except for a slight increase in vegetation greenness (Figure 5.1 (c) and (d)). A decrease in vegetation was observed towards the end of the season.

The 2007/08 summer indicated an increased vegetation activity and greenness early in the season for the North West Province. The entire Province indicated vegetation greenness with NDVI values between 0.28 to 0.45 in the west and 0.46 to 0.63 in the centre-east. Mid-season showed maximum vegetation greenness being reached in the far north east of the province with NDVI values between 0.66 and 1 present. The end of the season showed a decline in vegetation greenness in the Province. The whole Province experienced vegetation activity and greenness for the 2007/08 summer. The North West, whose centre part is part of the major grassland biomes of South Africa, experienced variable vegetation greenness in the region for all years, and was mostly minimal at the beginning of the season.

For the Limpopo Province, the 2007/08 summer showed healthy vegetation early in the season as compared to the 2005/06 summer. Figure 5.2 (a) and (b) had NDVI values between 0.46 and 0.63 dominating the Province, and maximum vegetation greenness was visible in the eastern part of (Figure 5.2 (a)). Mid-season showed maximum vegetation greenness in the east of the Province in Figure 5.2 (c), while Figure 5.2 (d) showed maximum vegetation greenness in the west of the Province. Towards the end of the season, vegetation activity decreased, which was more visible in Figure 5.2 (e) and (f). The central parts of the Province indicated NDVI values between 0.02 and 0.29. This was not a normal occurrence as vegetation greenness increased towards the end of the season.

In the 2007/08 summer, Mpumalanga experienced maximum greenness for a large part of the Province with the vegetation greenness moderately decreasing (Figure 5.2 (c)), then recovering as the season progressed. Towards the end of the season, an increased vegetation greenness was observed (Figure 5.2 (e) and (f)).

The 2007/08 summer showed Gauteng with healthy vegetation early in the season (Figure 5.2 (a) and (b)) with maximum vegetation greenness reached in some parts of the Province. As the season progressed, NDVI fluctuated and vegetation greenness decreased (Figures 5.2 (c) and (f)), while it increased in Figures 5.2 (d) and (e). In KwaZulu-Natal, the 2007/08 summer showed a much healthier vegetation in the beginning of the season with maximum vegetation greenness reached (Figure 5.2 (a) and (b)). As the rest of the season progressed and ended, vegetation greenness decreased for the Province (Figures 5.2 (e) and (f)) with NDVI values between 0.29 and 0.47 emerging to a lesser extent in the north.

The Free State Province showed an improved vegetation greenness for the 2007/08 summer in the west compared to the 2005/06 summer earlier in the season. Maximum greenness was noted for the west part of the Province (Figure 5.2 (d)). Towards the end of the season, a decrease in vegetation greenness was visible in the east (Figure 5.2 (f)).

5.4.3 Changes in the vegetation greenness for the 2012/13 summer

For the Northern Cape Province, the 2012/13 summer showed a greater amount of vegetation greenness early in the season with NDVI values between 0.27 and 0.43 in the east compared to the 2005/06 summer in Figure 5.3 (a) and (b). Vegetation greenness decreased in the eastern Northern Cape during mid-season.

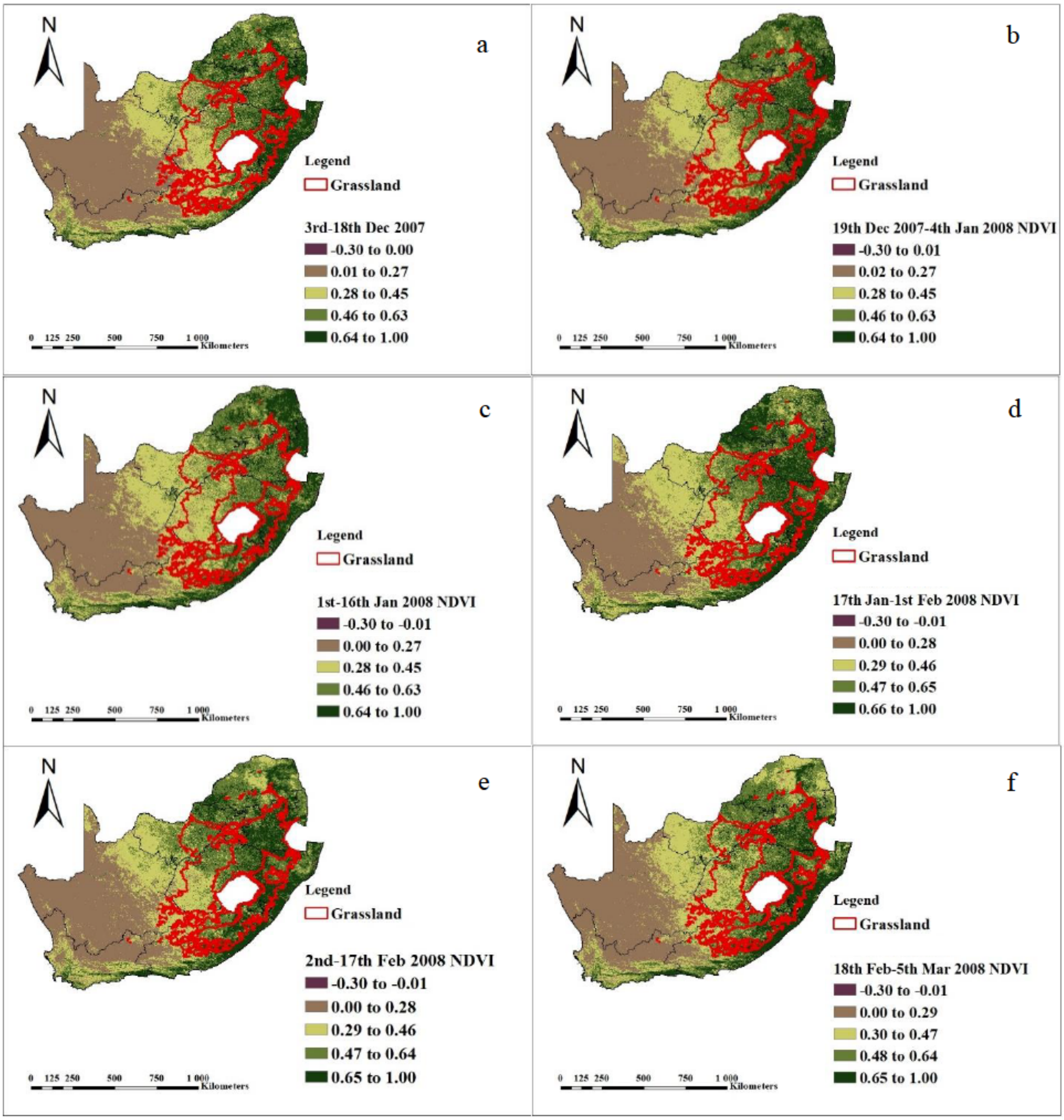

Figure 5.2: The 2007/08 summer 16 days Modis NDVI maps (a) 3rd - 19th Dec 2007, (b) 19th Dec 2008 - 4th Jan 2008, (c) 1st - 16th Jan 2008, (d) 17th Jan - 1st Feb 2008, (e) 2nd Feb - 17th Feb 2008 and (f) 18th Feb - 5th Mar 2008 for South Africa.

*Area in white inside South Africa is Lesotho

The end of the summer season experienced an even lower vegetation greenness (Figure 5.3 (e) and (f)) with NDVI values between 0.28 and 0.45 present in the area. The North West Province, for the 2012/13 summer, showed no vegetation greenness in the far west earlier in the season (Figure 5.3 (a) and (b)) with patches of NDVI values of 0.27 and 0.43 in the west, and 0.44 to 0.62 in the east. As the season progressed, the vegetation activity increased. Towards the end of the season, the extent of the greenness decreased for the Province. Maximum vegetation greenness was not reached in the Province in the 2012/13 summer.

The northern parts of the Limpopo Province showed poor vegetation activity and greenness for the 2012/13 summer with NDVI values between 0.001 and 0.26 present. The west of the Province showed improved vegetation conditions with NDVI values between 0.44 and 0.62, while the east indicated that NDVI values between 0.27 and 0.43 were dominant in the region (Figures 5.3 (a) and (b)). During mid-season, vegetation slightly recovered (Figure 5.3 (d)). At the end of the season, vegetation greenness recovered with maximum greenness reached and visible in the east of the Province (Figures 5.3 (e) and (f)). The Mpumalanga Province showed a healthy vegetation activity for the 2012/13 summer early in the season. Maximum vegetation greenness was visible during mid-season and towards the end of the season.

A large part of the Gauteng Province did not reach vegetation greenness for the 2012/13 summer. The NDVI values between 0.44 and 0.64 dominated the Province for this summer in the early, mid-and end -of -season. The KwaZulu-Natal Province showed a healthy vegetation greenness in the summer of 2012/13, as the season progressed and ended, the vegetation greenness increased mildly for a large part of the Province with maximum greenness being reached.

A large part of the Free State Province experienced vegetation greenness in the beginning of the 2012/13 summer. Vegetation greenness improved as the season progressed excluding towards the end of the season. Figure 5.3 (f) shows that the Free State experienced a decreased vegetation greenness in the central parts as result of NDVI values between 0.28 and 0.45 emerging and prevailing. Maximum vegetation greenness was visible in the far east of the Province.

5.4.4 Changes in the vegetation greenness for the 2013/14 summer

The Northern Cape showed small extents in vegetation activity in the onset of the 2013/14 summer with NDVI values between 0.26 and 0.45. Towards the end of the season, vegetation activity increased with NDVI values between 0.46 and 0.63 in the east. A small part of the Province that falls within the major grasslands of South Africa did not show much vegetation activity except towards the end of the season. Large areas of the province did not have vegetation greenness.

The North West Province experienced a great loss in vegetation greenness early in the 2013/14 summer. The NDVI values between 0.02 and 0.27 dominated the west of the Province, and the rest of the Province experienced patches of NDVI values between 0.26 and 0.45. During mid-season, vegetation activity recovered while at the end of the season greenness and activity in vegetation recovered significantly. This was notable especially in the grassland region, and in the east of the Province as maximum greenness was reached with NDVI values between 0.64 and 1.

The Limpopo Province indicated poor vegetation greenness on the edges, this was visible early in the summer of 2013/14, but with maximum vegetation greenness in the east-central parts of the Province. As the season progressed, in Figures 5.4 (c) and (d), vegetation greenness increased for the entire Province with the maximum vegetation greenness reached in the east, excluding a small part in the north.

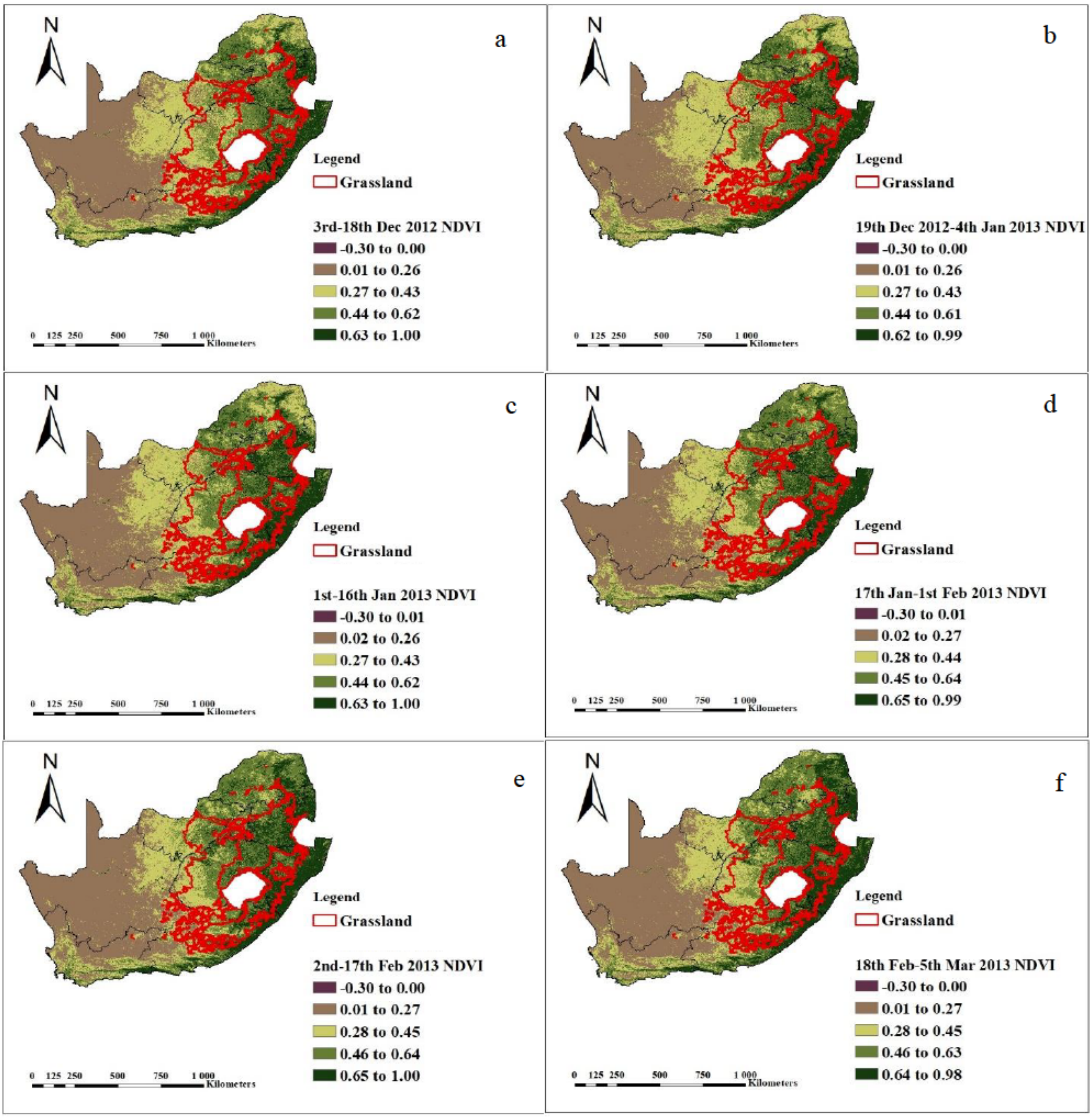

Figure 5.3: The 2012/13 summer 16 days Modis NDVI maps (a) 3rd - 19th Dec 2012, (b) 19th Dec 2012 - 4th Jan 2013, (c) 1st - 16th Jan 2013, (d) 17th Jan - 1st Feb 2013, (e) 2nd Feb - 17th Feb 2013 and (f) 18th Feb - 5th Mar 2013 for South Africa.

*Area in white inside South Africa is Lesotho

Towards the end of the season, vegetation greenness decreased moderately in the west of the Province with the east still maintaining its maximum greenness (Figures 5.4 (f) and (g)). Mpumalanga indicated a healthy vegetation activity and greenness for the 2013/14 summer, the rest of the season experienced an increase in vegetation greenness and maximum vegetation greenness which was visible in the east of the Province.

Gauteng showed a similar pattern as the 2012/13 summer for the 2013/14 summer. An exception was shown in Figure 5.4 (f) where vegetation greenness decreased with NDVI values between 0.29 and 0.45 being prevalent in the Province. KwaZulu-Natal showed decreased vegetation greenness early in the season (Figure 5.4 (a)) and as the season progressed, vegetation greenness increased until mid-early season. Towards the end of mid-season, Figure 5.4 (d), vegetation greenness decreased to a small extent within the grasslands in the west, and this continued until the end of summer.

The Free State Province showed a similar pattern to that in 2005/06 in the 2013/14 summer, where some parts in the south-west did not indicate any vegetation greenness. As the season progressed, vegetation activity and greenness increased significantly in the Province (Figure 5.4 (f)).

All the summers indicated the Eastern Cape Province experienced vegetation activity in the east and coastal areas, an exception was visible for a small area in the north-west, which experienced minimal to no vegetation greenness. The east of the Province indicated some greenness especially in the grassland regions. Vegetation greenness increased as the season progressed for all summers. The coastline showed maximum vegetation greenness for the entire summers. The Western Cape Province experienced minimal changes in terms of vegetation greenness and activity for the four summers 2005/06, 2007/08, 2012/13 and 2013/14. The general observation was the coastal part of the Province having minimal vegetation activity and greenness. A large part of the Province did not show vegetation greenness and activity. Maximum vegetation greenness was visible in the coastal regions.

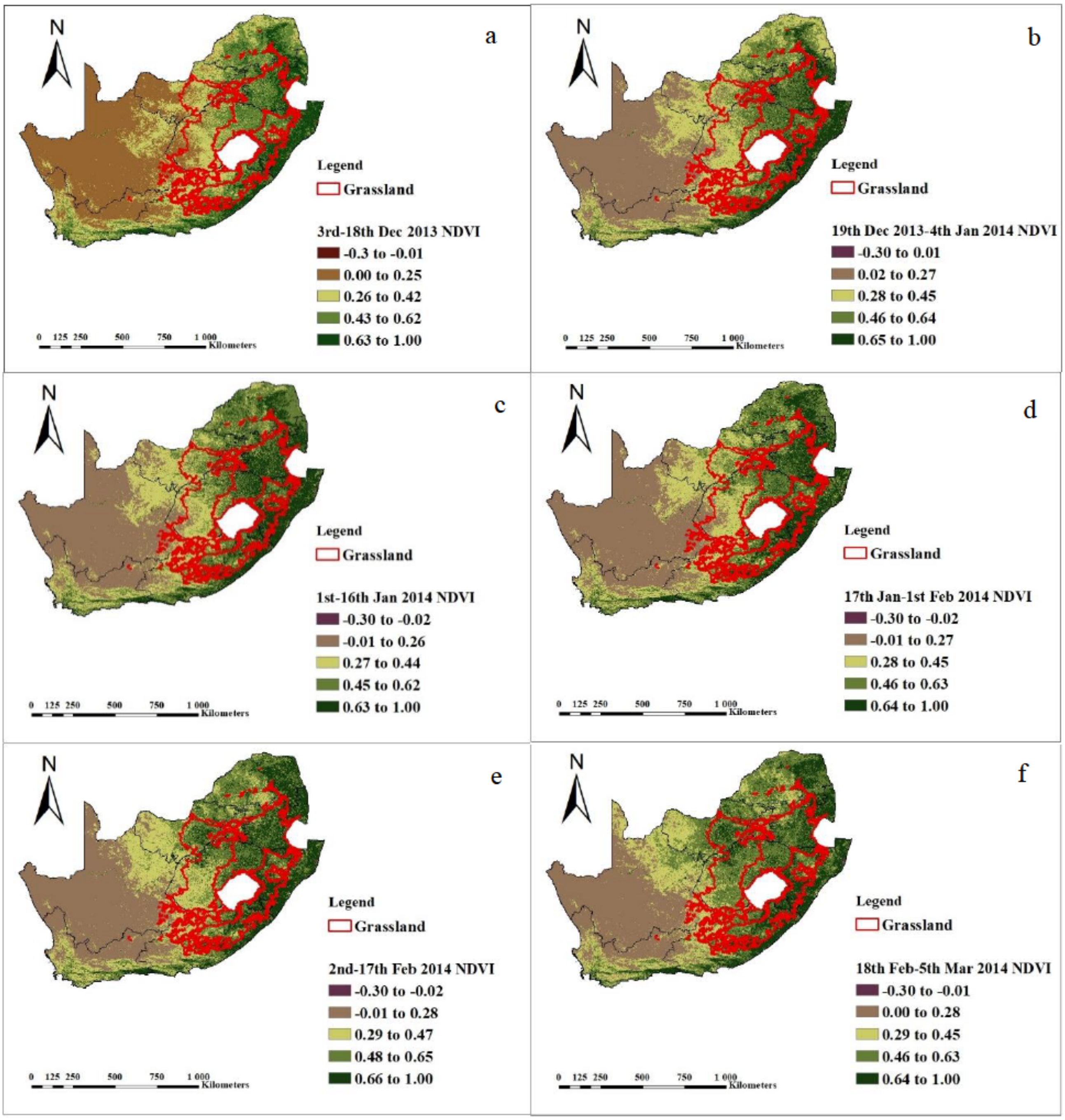

Figure 5.4: The 2013/14 summer 16 days Modis NDVI maps (a) 3rd - 19th Dec 2013, (b) 19th Dec 2014 - 4th Jan 2014, (c) 1st - 16th Jan 2014, (d) 17th Jan - 1st Feb 2014, (e) 2nd Feb - 17th Feb 2014 and (f) 18th Feb - 5th Mar 2014 for South Africa.

*Area in white inside South Africa is Lesotho

5.4.5 Vegetation greenness for the grassland regions in all summers

The grassland regions of the Northern Cape Province experienced minimal to no vegetation activity most of the summers and did not experience maximum vegetation greenness. The grassland regions located over the centre of the North West Province experienced variable vegetation greenness for the summers. In the beginning of the summers, vegetation greenness was minimal and increased towards the end of the seasons. The grassland regions of the Limpopo Province in the west experienced fluctuations in vegetation greenness while the east experienced maximum greenness most of the summers.

The grassland regions of Mpumalanga occupied a large part of the Province, and were the most productive as they maintained vegetation greenness for most of the summers. The Gauteng Province grassland regions were moderately changing in terms of greenness and always increased in vegetation greenness towards the end of the season, except for the 2007/08 summer where greenness decreased towards the end of the season. The grassland regions of the KwaZulu-Natal Province maintained a healthy NDVI for most of the summers with a small area in the north where vegetation greenness decreased when dry. The grassland region in KwaZulu-Natal was variable in terms of vegetation greenness and occupied a large part of the Province as is the case in Mpumalanga. The grassland regions in the Free State Province had a period when they did not show any vegetation greenness in the west, especially early in the season and recovered as the season progressed.

The grassland region of the Eastern Cape Province contained vegetation activity and greenness most of the time. Vegetation greenness advanced as the season progressed and maximum greenness in the grasslands occurred towards the end of the summers. The Western Cape Province had a small part of its area being a part of the major grasslands of South Africa with minimal vegetation activity occurring for most of the summers.

5.5 The NDVI results in relation to SPI

The NDVI is highly connected to SPI in semi-arid and transitional zones (Dutta et al., 2013). Cattle farmers and the many people living in communal areas are dependent on natural grazing areas with limited government intervention during droughts in South Africa. Limpopo Province experienced minimal vegetation activity and greenness early in the season of 2005/06, 2012/13 and 2013/14 especially in the northern parts. Recovery was observed as the summer progressed with maximum greenness reached in the east and some parts in the west. The SPI-3 indicated the Province experienced moderate to extreme wetness in the north which resulted in vegetation greenness recovery as the season progressed.

A different pattern was observed for Limpopo in the 2007/08 summer where vegetation activity was present and healthy early in the season and decreased towards the end. SPI-3 for Limpopo Province in the 2007/08 summer indicated that a large part of the Province experienced moderately wet to extremely wet conditions. The Gauteng Province contained vegetation greenness for most summers and indicated the same vegetation greenness pattern observed in Limpopo Province.

Bond et al. (2020) stated that from barren soils, grasses recovered biomass quickly when the rains returned. This was visible for the western parts of North West and Free State provinces in the 2005/06 and 2013/14 summers where for mid-season and the end of the season periods, vegetation greenness becomes prominent. Botai et al. (2016) also mentioned that the Free State and North West provinces are often hard hit by droughts which affects farm production and livestock holdings. The study also observed drought conditions for the Free Sate and the North West provinces especially in the 2005/06 and 2013/14 summers.

The Northern Cape Province experienced minimal vegetation activity and greenness in the east which was prominent towards the end of the 2005/06 and 2013/14 summers. SPI at 3 months indicated wet conditions for the west and extremely dry conditions for the east. The 2012/13 summer was different where more vegetation activity was seen early in the season which decreased as the season progressed. A small area in the east of the Northern Cape indicated moderately dry to extreme dry conditions for SPI-3 in the 2012/13 summer, this conditions extended into parts of the Free State and North West provinces.

KwaZulu-Natal, Mpumalanga and the eastern parts of the Eastern Cape provinces sustained a healthy NDVI for all of the four summers with slight changes in vegetation greenness in response to rainfall. The SPI-3 also indicated near-normal to wet conditions in the eastern parts of the country for the four summers. A small part in the west of the Eastern Cape Province did not show vegetation activity but as the season progressed small patches of greenness were visible, since rainfall in the Province is bimodal. Vegetation activity and greenness in the Western Cape Province was evident along the coast. The summer season did not contribute much to the changes in vegetation greenness because the Western Cape receives most of its rainfall in winter.

5.6 Estimation of cattle feed from vegetation greenness

Natural pasture is the main feed source for grazing cattle in South Africa (Palmer and Ainslie, 2006). The grassland biome and other economically essential biomes containing patches of grassland sustain the largest number of cattle grazing in South Africa (Avenant, 2019), especially in rural communities because they share grazing areas.

The eastern parts and coastal parts of South Africa are areas of intense vegetation activity and greenness for the 2005/06, 2007/08, 2012/13 and 2013/14 summers. Palmer and Ainslie (2006) noted that cattle predominate in the east, while sheep in the drier western and south-eastern parts of the country. KwaZulu-Natal maintained vegetation greenness in the study years for most of the summers which explains why it accounts for most of the dairy production in South Africa. The coastal Western Cape and Eastern Cape also contains dairy production because of the province's pasture based feeding regime (Williams et al., 2016) because of the existence of vegetation activity and greenness.

Mpumalanga maintained vegetation greenness after KwaZulu-Natal for most of the summers and accounts for the greatest beef production in South Africa (Williams et al., 2016). Beef production is also practised in the Free State and North West provinces which indicated vegetation activity and greenness in the east and parts of the grassland biome. Palmer and Ainslie (2006) indicated that commercial cattle ranching for the markets in the Free State placed stress on grasslands. The west of the provinces are extremely vulnerable to dry conditions and practise a mixed ration feeding regime. The Northern Cape contributes less than 1 % to milk production in the country as it has minimal vegetation activity and greenness. The Limpopo Province contains cattle as the main livestock owned by individual households feeding on natural grasslands (Whitbread et al., 2011), thus great variations in vegetation activity and greenness were observed in the north when dry conditions were experienced.

5.7 Conclusions

The SPI is useful in identifying wet and dry periods while the NDVI is effective in monitoring vegetation productivity, because vegetation changes with an increase or decrease in rainfall. Understanding the relationship of the two indices can help manage natural grazing areas for cattle farmers. The Limpopo, North West, Free State and Gauteng provinces showed vulnerability in vegetation activity and greenness. This means cattle production in these provinces that rely on natural pastures are vulnerable to feed unavailability. Mpumalanga, KwaZulu-Natal and the Eastern Cape provinces indicated vegetation activity and greenness for 2005/06, 2007/08, 2012/13 and 2012/14 summers.

The Eastern Cape Province indicated a healthy vegetation greenness even when SPI-3 indicated dryness in the east. The Northern Cape and Western Cape provinces had minimal vegetation activity. The general observation was that the eastern parts and coastal regions of South Africa had vegetation greenness, while the west contained reduced or no vegetation greenness in some instances. This explains why most of the cattle production in South Africa occurs in the east and in coastal areas.

5.8 References

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CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

6.1 Introduction

Heat stress causes production losses for both commercial and subsistence cattle farmers. Unlike commercial farmers, subsistence farmers do not have the adaptive capacity to manage cattle under heat stress conditions in South Africa. Drought conditions also play a role in the quality, distribution and amount of pasture available for cattle feed. A combination of heat stress and feed unavailability creates an adverse environment for cattle production.

The South African cattle industry is built on well-established dairy, beef and subsistence farming where selection and breeding practices have been functional for more than four decades. The highest number of cattle is found in the Eastern Cape Province with KwaZulu-Natal the second highest. Dairy production is mostly practised in the coastal provinces, while beef production is mostly in the Mpumalanga Province. The management of the breeding season is important for the optimisation of the reproductive performance of a breeding herd and pre-wean growth rate of calves.

The temperature-humidity index (THI) is a useful measure for cattle heat stress and uses air temperature and relative humidity (RH) as variables. Heat stress decreases milk production and quality in dairy cattle and compromises the quality of beef in beef cattle. Heats stress also affects the reproductive performance of cattle herds due to premature deaths.

Heat stress can also decrease grazing and feed intake, while drought can limit pasture availability for grazing cattle. Feed unavailability affects cattle production and is exacerbated by dry conditions. Natural pasture is the main feed source for grazing cattle in South Africa.

Dry pastures result in lower quality feed and overgrazing becomes an issue due to decreased feed availability. Grasslands are the most productive natural grazing areas in South Africa and are affected by decreased rainfall. The variability in rainfall has negative effects on local vegetation to accommodate the increases in demand for pasture.

The standard precipitation index (SPI) monitors the occurrence of abnormally wet or dry conditions. The SPI can also be used to assess vegetation cover as a result of precipitation being one of the important factors that influence vegetation growth. The normalised difference vegetation index (NDVI) is an excellent indicator of vegetation productivity and is also effective in monitoring climate variability effects on vegetation. Negative NDVI anomalies can identify and map the spatial impact of drought on vegetation. The SPI and NDVI can be used cooperatively for the assessment of vegetation cover for the improved management of natural grazing areas.

6.2 Aims and objectives

The aim of this study was to determine the air temperature and relative humidity conditions accountable for extreme high THI values from 1985 to 2015 and to assess the availability of natural rangeland for cattle through the monitoring of drought using NDVI in South Africa for cattle farming.

The objectives were:

1. to compute THI for dairy and beef cattle in different regions of South Africa and identify vulnerable regions;
2. to compute SPI for corresponding THI periods and relating the indices to vegetation greenness;

3. to map vegetation greenness using NDVI and associate it to potential grazing availability for the corresponding SPI periods of interest.

6.3 Contributions of the study

Areas in South Africa that reported a very severe stress indicated that air temperature is the biggest factor that affects THI. An area in the west of the Limpopo Province indicated to be developing as a hotspot in the country. A small area in the west of the KwaZulu-Natal Province was also indicated to have a potential to be a heat stress zone. Areas that were already identified as heat stress areas for South Africa increased in size when the seasonal THI average was extremely high. The high summer THI averages failed to include daily extremes that occurred in February.

The THI did not affect vegetation greenness directly but the high air temperatures did. Extremely high air temperatures coupled with dry soil moisture conditions can be harmful to plants. This accounted for the slight relationship observed between high summer THI averages and decreased or vegetation greenness (activity) for some areas.

6.4 Research findings

The THI is valuable for the calculation of cattle heat stress. The SPI and NDVI are also useful tools for the assessment of drought and vegetation greenness (activity). Understanding the relationship between the SPI and vegetation dynamics forms a possibility for the better management of natural grazing areas.

The THI indicated summer as the season when heat stress was experienced in South Africa. The summer periods 2005/06, 2007/08, 2012/13 and 2013/14 were identified as having high THI averages for the 30-year period investigated. The Northern Cape, Limpopo, Mpumalanga and KwaZulu-Natal provinces on the eastern edges were areas that commonly experienced heat stress. Daily extreme indices were observed for the Northern Cape (Groblershoop and Prieska) and Eastern Cape (Lusikisiki) provinces of South Africa.

The daily extremes were predominant in February, but did not occur in the years identified as having the highest summer THI averages. Daily extremes also indicated the air temperature as the most significant factor that affects THI as compared to the relative humidity.

The SPI at 3 months indicated wet conditions for the western parts of South Africa for the 2005/06, 2007/08 and 2012/13 summers, while the central-east of the country indicated dry conditions. Large parts of the country experienced wet conditions during the 2013/14 summer. The Eastern Cape Province had a small area in the east which was prone to dry conditions. In the Eastern Cape Province, the greatest intensity of dryness was experienced in the 2012/14 summer.

The NDVI indicated a healthy vegetation greenness for the eastern parts of the country with variability observed for the interior for the 2005/06, 2007/08, 2012/13 and 2013/14 summers. Vegetation greenness was variable for the North West, Limpopo, Free State and Gauteng provinces. A general trend with vegetation greenness was that it was minimal in the beginning of summer and increased towards the end of the season. An exception was observed for the 2007/08 summer for which vegetation greenness was abundant in the beginning of the season and decreased towards the end of the season.

Heat stressed regions such as the Northern Cape and Limpopo provinces had vegetation greenness that was vulnerable for the four summers. A combination of an increased heat stress potential for cattle in a particular area and a decrease in feed availability from natural grazing areas contributes to a decline in cattle performance. Heat stress and a healthy vegetation activity was a problem for the two provinces.

KwaZulu-Natal and Mpumalanga also indicated heat stress potential in the eastern edges of the provinces. Heat stress was a challenge for cattle but vegetation activity was healthy. Thus farmers will need to have adaptive capacities in place for cattle production in areas of heat stress, and those that experience feed insufficiency.

6.5 Challenges

The greatest challenge was that many weather stations did not have data for RH and those that did, had large amounts of data missing which consumed time during data patching and also reduced station density. This also resulted in some provinces not having enough weather stations recording data for RH, while some had but with insufficient and poor data quality.

Working with large datasets was another challenge, with daily data for long periods requiring a lot of time for preparation and analysis.

6.6 Future possibilities

There are many future research areas involving the use of THI as a tool to measure heat stress that need attention, namely:

1. the THI equation focuses on the main environmental stressors in cattle (air temperature and relative humidity). The relationship can be improved by incorporating wind speed as a variable because slow air movement contributes to heat stress risk;

2. the THI equation uses meteorological data to relate the body temperatures of cattle exposed to heat stress, thus an improvement can be made to the equation by including animal data;

3. the THI is useful for the prediction of heat stress but does not measure the accumulation of heat load over time. Cattle gain heat during the day and dissipate this accumulated heat to the

environment at night. If this accumulated heat overnight is not dissipated, the animal carries a heat load into the following day. Thus the equation will need to account for the accumulated heat load so that THI is not underestimated.

6.7 Final comments and summary conclusions

Summer-averaged THI indicated the Northern Cape, Limpopo and the eastern edges of the KwaZulu-Natal and Mpumalanga provinces as areas of heat stress, making them risky areas for cattle farming. The SPI at 3 months indicated the central-eastern parts of South Africa to be vulnerable to dry conditions, while NDVI indicated vegetation greenness as vulnerable for the central-western parts of South Africa. Hence the east of South Africa is the most favourable for cattle production.