An analysis of Extreme Temperature Events (ETEs) of Namibia

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Declaration

I declare that this thesis is my own, unaided work, except where otherwise acknowledged. It is being submitted for the Degree of Master's in Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for examination for any degree at this or any other university.

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21 day of August 2021 at Bloemfontein

Abstract

Heatwaves, warm spells, cold waves, and cold spells are examples of extreme temperature events (ETEs) that have catastrophic consequences for human health and ecosystems. Climate change is expected to increase the frequency, intensity, and length of ETEs. Effective adaptation to ETEs necessitates an appreciation of their current frequency and likelihood of occurrence in the face of climate change. Extreme events have received very little attention, especially in developing countries, including Namibia. Due to Namibia's low adaptive ability, urgent development needs, and relatively poor infrastructure, these events pose a significant danger. This research examines extreme weather events over time, both annually and seasonally, as well as spatially over the period 2008-2018. The World Meteorological Organisation Expert Team on Climate Change Detection (ETCCDI) and the World Meteorological Organisation Commission for Climatology and Indices Expert Team on Sector-Specific Climate Indices (ET-SCI) were used to determine ETEs, using ClimPACT and RClimDex. The non-parametric Mann-Kendall, Spearman Rank Correlation Coefficient, and Sen's slope estimates were used to quantify trends. Annual and seasonal cold spell duration were identified as 4.86 days. An average of 1.99 cold waves was identified with an average duration of 4.59 days. The results identified an average number of heatwaves of 1.6 lasting 3.2 days. The majority of ETEs occur in the central, northeast and southeast of the country. The west coast has experienced ETEs, but with less intensity. Since studies indicate that unusually temperature events may persist in a warming world, these findings help raise awareness and recognise the frequency and length of extreme events in Namibia.

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List of Acronyms

AO: Arctic Oscillation

CCI: Commission for Climatology and Indices

EM-DAT: Emergency Events Database

ENSO: El Niño-Southern Oscillation

ET: Extreme temperature

ETCCDI: Expert Team on Climate Change Detection

ETE: Extreme Temperature Event

ET-SCI: Expert Team on Sector-Specific Climate Indices

IOD: Indian Ocean Dipole

IPCC AR5: Fifth Assessment Report of the Intergovernmental Panel on Climate Change

IPCC: Intergovernmental Panel on Climate Change

ITCZ: Intertropical Convergence Zone

JCOMM: Joint Commission for Oceanography and Marine Meteorology

La Niña: La Niña Southern Oscillation

LTAS: Long-Term Adaption Scenarios Flagship Research Programme

MJO: Madden-Julian Oscillation

NOA: North Atlantic Oscillation

PDO: Pacific Decadal Oscillation

RCM: Regional Climate Model

SAA: South Atlantic Anticyclone

SAM: Southern Annular Mode

SAWS: South African Weather Service

SIOD: Subtropical Indian Ocean Dipole

SST: Sea Surface Temperatures

WMO: World Meteorological Organisation

WRCP: World Climate Research Programme

List of Statistical Terms

$.y^{-1}$: Per year

CDSI: Cold spell duration indicator

CHF: Excess Cold Factor

Cool nights: Days when TN<10th percentile

Cool days: Days when TX<10th percentile

CSDId: User-defined Cold Spell Duration Indicator

CWD: Duration of cold wave days

CWN: Number of cold waves

ECI: Extreme climate index

EHF: Excess Heat Factor

FD: Frost days

HWD: Heatwave duration days

HWN: Number of heatwaves

IDW: Inverse Distance Weighted

MK: Mann-Kendall trend test

SR/ρ: Spearman’s Rank correlation coefficient

SS: Theil-Sen’s slope estimator

SU: Summer days

SU35: Very hot days were TX>35°C

T_{max}: Daily maximum temperatures

T_{min}: Daily minimum temperatures

TN: Daily minimum temperatures

TN10p: Cool nights (days when TN<10th percentile)

TN90p: Warm nights (days when TN>90th percentile)

TNMean: Mean minimum temperatures

TNn: Minimum TN

TNx: Maximum TN

TX: Daily maximum temperatures

TX10p: Cool days (days when TX<10th percentile)

TX90p: Warm days (days when TX>90th percentile)

TXMean: Mean maximum temperatures

TXn: Minimum TN

TXx: Maximum TX

Warm days: Days when TX>90th percentile

Warm nights: Days when TN>90th percentile

WSDI: Warm spell duration indicator

WSDId: User-defined Warm Spell Duration Indicator

Chapter 1: Introduction

1.1. Background

Extreme climatic events are rare, infrequent, and unpredictable climate phenomena described by their meteorological characteristics or their consequences (Stott *et al.*, 2016; Vogel *et al.*, 2019). The most common extreme climate events relate to temperature, i.e. maximum (TX), minimum (TN) and mean (Tmean) temperature (Kousari *et al.*, 2013). Over the last 100 years, there has been a significant increase in interest regarding the changing climate and the occurrence of extreme temperatures and extreme temperature events (ETEs; Alexander *et al.*, 2006; IPCC, 2018). However, there is little agreement in the literature about how to classify ETEs, and there is no standard description for ETEs (Allen & Scott, 2015; Perkins-Kirkpatrick & Gibson 2017; Sheridan & Lee, 2018; Radovic & Ilglesias, 2019). Warm/cold occurrences, heatwaves/cold waves, and warm/cold spells are the most widely used terminology in the literature to describe ETEs (Van der Walt & Fitchett, 2021). Each of these has its own definition and thresholds. The more simple definitions of ETEs use the magnitude of the deviation from the statistical mean of daily, weekly, or annual temperatures for a given place or area (Easterling *et al.*, 2000; Lewis & King, 2017). However, the point at which a deviation qualifies as an extreme event is widely debated (Lewis & King, 2017).

The National Climate Change Strategy and Action plan for 2013-2020 summarises the environmental impacts of ETEs (GRN, 2013). A reduction in groundwater and quality, reduction of fish stock, damage to infrastructure, reduction in plant growth and associated reduction in grazing capabilities, increases in invasive species, an increase in pests and further aridification is all linked to more intense and more frequent ETEs (GRN, 2002; Reid *et al.*, 2007; Dirkx *et al.*, 2008; MET, 2011, 2012). These impacts place extreme pressure on water resources, infrastructure and energy, agriculture, food security, ecotourism, biodiversity and human health (GNR, 2011). ETEs can also cause heat stress which can be dangerous to human (and animal) health (Pappenberger *et al.,* 2014). Heat stress is a condition where the human body is at risk of overheating (Havenith, 2001). It includes a range of symptoms, from headaches to loss of life (Ikäheimo, 2014). Young children, the elderly and people with existing medical problems are at higher risk compared to the middle aged and people without existing medical conditions (Harvard Medical School, 2019). The IPCC (2018) highlights that there will be an amplification of existing risks to natural and human systems. An increase in frequency and severity of extreme weather events, such as flooding and heatwaves, can be observed in Europe, Asia, Australia and Africa (Kreft *et al.*, 2015).

The IPCC (2018) project that extreme weather events will increase, in frequency and severity, with a global mean annual temperature increase. There has been a decrease in the mean annual frequency of cold nights (nights where minimum temperature falls below the 10th percentile) with an increase in warm nights (nights where minimum temperature exceeds the 90th percentile), globally. Additionally, is has been estimated that the land and ocean surface temperatures increased with 1.09°C from 1850-2020 globally (IPCC, 2021). Over 70% of the world experienced a significant increase in TX and TN temperatures during 1951-2003 (Fyfe *et al.*, 2013). There has been an average increase in the warming rate for the daily average ambient surface air temperature of 0.06°C per decade for the period 1880-2012, compared to the increase rate of 0.14°C per decade between 1991-2012 (Jones *et al.*, 2012; Fyfe *et al.*, 2013; IPCC, 2018).

The African continent is unique because it covers four hemispheres and spans over 8,000km, creating different climate regions classified by the Köppen-Geiger climate classification system (Peel *et al.,* 2007; Collins, 2011). Compared to the literature for the global North, there have been very few studies exploring Africa's climate, mainly due to the lack of reliable temperature data across Africa and southern Africa (Frich *et al.*, 2002; Caesar & Alexander, 2006). The studies which have been conducted found an increase of 0.5°C over the last 50-100 years for the majority of Africa (Niang *et al.*, 2014), with increasing TX, TN and Tmean temperature trends identified in southern Africa over the last two decades (New *et al.*, 2006). In addition, TN temperatures are increasing at a faster rate than TX temperatures (Hulme *et al.*, 2001; Kruger & Shongwe, 2004; New *et al.*, 2006; Nicholson *et al.*, 2013; Niang *et al.*, 2014), together with an increase in the number of extreme warm events since 1961 for countries bordering the western Indian Ocean (Vincent *et al.*, 2011).

Temperatures across the African continent are expected to increase quicker than the global average during the 21st century and reaching the 20th-century simulations between 2047-2069 (Zhou *et al.*, 2010; Kruger & Seleke, 2012; Niang *et al.*, 2014). Temperatures in southern African are expected to increase across all seasons with temperatures above 3.4°C-4.2°C the 1981-2000 average (Collins, 2011; Kruger & Seleke, 2012). The arid areas, specifically northwestern parts of southern Africa: South Africa, Namibia and Botswana, are expected to experience very large warming rates within the 21st century (New *et al.*, 2006; Zhou *et al.*, 2010; Collins, 2011; Niang *et al.*, 2014).

Namibia's climate can be characterized as arid, semi-arid and hyper-arid, primarily due to its location regarding the air movement driven by the Intertropical Convergence Zone (ITCZ), the

Subtropical High-Pressure Zone and the Temperate zone (Midgley *et al.,* 2004). The influence of the Benguela current in the Atlantic Ocean creates a persistent high-pressure system that allows most of the country to be dry throughout most of the year (Dirkx *et al.*, 2008; Turpie *et al.*, 2010). Namibia has a complex earth-atmospheric interaction with high temperatures, low-humidity, evaporation, evapotranspiration, precipitation and temperatures in the interior with high humidity and moisture along the coastal areas (Shui *et al.*, 2012; Kgabi *et al.*, 2016). The northeastern parts of Namibia experience frequent floods while the whole of Namibia experiences persistent and recurring droughts, ETEs (i.e. heat waves and cold waves), and unpredictable rainfall (GNR, 2011; Grab & Zumthurm, 2018).

An increase of 4°C in Namibia's annual average Tmean temperature is anticipated by 2040 (Crawford & Terton, 2016). The temperature increase is expected to have a range of impacts on human health (thermal stress) and food security, especially for the rural population (GNR, 2013). The Global Facility for Disaster Reduction and Recovery (GFDRR) estimated an increase of 25% prolonged exposure to heat in the next five years due to increased greenhouse emissions (IPCC, 2018). The increase in greenhouse emissions will cause more extreme weather events such as ETs in Namibia (IPCC, 2018; Angula and Kaundjua, 2016). Namibia has a large population (52%) living in rural areas dependent on crops and livestock for their livelihoods (RVAA, 2019). Furthermore, 24% of the population experiences food insecurity, and this percentage is expected to rise in the coming years (MET 2011; RVAA, 2019). Another concern is the dryland areas in Namibia, increasing the degradation of rangelands and natural resources (Kuvare *et al.*, 2008; Angula and Menjono, 2014).

Namibia's limited amount of arable land is under threat and is expected to decline with an increase in temperature, droughts and floods (Klintenberg *et al.*, 2007; Gremlowski, 2010). Another threat is the rising population and resources mismanagement (Klintenberg *et al.*, 2007; MET, 2011). Furthermore, a lack of diversification in and alternatives to agriculture makes the rural population vulnerable to climate changes (Newsham and Thomas, 2009; Turpie *et al.*, 2010; Zeidler *et al.*, 2010). With the current climatic and socio-economic conditions, these factors contribute to making an already vulnerable region even more insecure in the presence of extreme events, in particular ETEs (Spear *et al.*, 2018).

1.2. Rationale and Contribution to Existing Knowledge

Extreme events, especially ETEs, are understudied in Africa (Otto *et al.*, 2012; Van der Walt & Fitchett, 2021). Although most models suggest that Africa and sub-Sahara Africa (SSA) are hotspots for ETEs, only two extreme heat events were recorded by the Emergency Event Database (EM-DAT) for SSA since 1900-2019 (Harrington & Otto, 2020). By contrast, the same database has recorded 83 extreme heat events for Europe from 1980-2019 (Adrijevic *et al.*, 2020; Harrington & Otto, 2020).

Less economically developed countries in Africa have weaker governance frameworks, sparse observational networks and climate data, a lack of experience to develop local metrics, and a lack of integration with epidemiological information (Donat *et al.*, 2013; Andrijevic *et al.*, 2020; Harrington & Otto, 2020). This creates a gap in the research and limited knowledge of the frequency, intensity and incidence of ETEs, especially in southern Africa and Namibia. The trend analysis of extreme warm and cold events will be the first known studies in Namibia. The World Meteorological Organisation (WMO) Commission for Climatology and Indices (CCI)

Expert Team on Sector-Specific Climate Indices (ET-SCI; Alexander & Herold, 2016; Yosef *et al.* 2019) is used for the first time in a Namibian context for both warm and cold extremes. The ET-SCI considers sector-specific indices derived from the Expert Team on Climate Change Detection (ETCCDI; Alexander & Herold, 2016; Yosef *et al.*, 2019); the indices consider health, water and agriculture and can identify short ETEs (i.e. three-day events) and are thus more relevant in a Namibian context.

Examining areas with a similar climate and environment to Namibia, including Arizona, Nevada, Iran, and Egypt that are classified as deserts to subtropical deserts with similar climate drivers (Hylke *et al.,* 2018), it becomes apparent why it is essential to identify and explore ETE trends, which could lead to heat-related stress. Between 2001-2011, there have been 1096 heat-related deaths in Iran, with a total increase in the number of deaths in the most recent heatwaves (Ahmadnezhad *et al.*, 2013). Iran also had record-breaking temperatures between 2017-2019 (Saeid *et al.*, 2019). In the United States of America (USA), Arizona and Nevada have also experienced increased heat-related deaths. Heat-related deaths increased from 105 in 2014 to 374 in 2017 (Flavelle & Popovich, 2019). Over the past three years, a record number of heat-related deaths was recorded in Arizona alone (Hondula *et al.,* 2015; Vanos *et al.,* 2015; Hondula & Georgescu, 2018). Heat-related deaths reached a new record in 2020, leading to a total of 494 deaths. This is the highest number in the last 13 years (Totiyapungprasert, 2019; ADHS, 2021). Egypt has also experienced ETEs in the last two decades, causing an increase in the number of heat-related deaths, like with the heatwave in 2015 that attributed to 61 deaths with 581 hospitalizations (Kenawy *et al.,* 2019). There has also been an increase in the number of warm days with a decrease in the number of cold nights (Kenawy *et al.*, 2019; Saeid *et al.*, 2019).

These ETEs threaten human life and the immediate environment, plant and animal development (Hatfield & Prueger, 2015). Namibia will be affected more in the coming years, making assessments in these areas extremely important. The third hottest year in Namibian history was in 2017, against a pre-industrial mean (New & Bosworth, 2018). Although a range of climate modelling derived projections have been published for southern Africa (New *et al.,* 2006; Niange *et al.,* 2014; Harington & Otto, 2020), very few studies focus on ETEs, which could lead to heat or cold stress and result in loss of life. This study will contribute to a better understanding of the effects of extreme temperature on humans and allow for management systems to be implemented to reduce these impacts.

1.3. Study Aim and Objectives

The primary aim of this research is to investigate the incidence of extreme temperature events over Namibia over the period 2008-2019. To address the primary aim of this research, the specific objectives of this research are:

1. Determine the frequency of occurrence of monthly, annual and seasonal warm temperature events over the period 2008-2019.
2. Determine the frequency of occurrence of monthly, annual and seasonal cold temperature events over the period 2008-2019.

1.4. Dissertation Structure

This dissertation is divided into seven chapters. They are constructed as follows:

An extensive literature review that focuses on climate trends Globally and in Namibia, including Namibia’s main climate drivers and explaining the different climatic indices, is provided in Chapter 2. Background to the study area and the climatic characteristics of Namibia is provided in Chapter 3. Chapter 4 provides the method for collecting the data and outline the statistical approaches, selection of temperature indices, spatial interpolation and data presentation and thought process throughout. The results obtained are presented in Chapter 5, followed by a discussion in Chapter 6. Finally, Chapter 7 will provide a conclusion to the research that has been conducted.

Chapter 2: Literature Review

2.1. Introduction

Namibia is classified as semi-arid, characterized by highly variable climatic conditions and is the driest country in sub-Saharan Africa (Andreas, 2015; Angula & Kaundjua, 2016). Over the past 30-40 years, Namibia experienced recurring droughts, periods of high temperatures, unpredictable and variable rainfall events (Newsham & Thomas, 2011; Kaunjua, Angula & Angombe, 2012; Angula & Kaundjua, 2016). These extreme weather events, in particular ETEs, may be further exacerbated with an increase in global temperatures as projected by the Intergovernmental Panel on Climate Change (IPCC) fifth assessment report and the United Nations Framework Convention on Climate Change's (UNFCCC) report (Angula & Kaundjua, 2016). Projections indicate an increase in temperature between 1-3.5°C (Engelbrecht *et al.,* 2015). This would have dire effects on key sectors that support Namibia's economy, including tourism, agriculture, health and food security which are most vulnerable (Crawford & Terton, 2016). These changes could furthermore increase the existing vulnerability of rural livelihoods and reduce adaptive capacity to extreme events in Namibia (Tervo-Kankare *et al.,* 2016).

Research on extreme weather events, especially ETEs, are limited in the African continent (Niange *et al.,* 2014) and in a Namibian context. Reasons for the lack of research on the African continent can be attributed to the large spatial extent and natural variability within the African continent and countries, making it difficult to draw a general conclusion (Peterson *et al.,* 2013; Otto *et al.,* 2015). To this end, this literature review chapter is divided into four sections. The first section explores the different definitions used in the existing literature to define ETEs. The second and third section looks at the existing literature on ETEs on a global level, and, African and southern African level, respectively. The last section focuses on existing research that has been done on ETEs in Namibia.

2.2. Global Research on ETEs

There is a need for a standardised approach in exploring temperature metrics, through indices that are universally applied, to allow for comparability (Jendritzky *et al.*, 2007). There is clear evidence high impact ETE's are occurring more frequent (Vogel *et al.,* 2019). The increase in heat-related deaths in Arizona, Nevada, Iran and Egypt, serves as evidence for more high impact ETEs. Heat-related deaths in the USA, in 2018, was the highest number in the last 13 years (Totiyapungprasert, 2019). The USA is not the only country where there has been an increase in deaths due to extreme temperatures. In June 2010, 55 000 people were killed in a heatwave in Russia, causing a 25% decrease in crop yields, 1 million ha of land to burn and cost the economy US$15 billion (Otto *et al.,* 2011; Hoag, 2014; Ragone *et al.,* 2018). During the summer in Europe, 2003, 2010, 2015,2017, 2018, and 2019 saw pronounced warming with an increase in frequency of extreme heatwaves (Few *et al.,* 2019; WMO *et al.,* 2019). The heatwave in 2003 attributed to 70,000 heat-related deaths, disrupting ecosystems, agriculture, the economy and infrastructure (Pappenberger *et al.*, 2015; Yu & Li, 2015).

Recent studies have found an increase in warm index values and decrease in cold index values over over most land surfaces since 1900 (Alexander *et al.,* 2006; Irannezhad *et al.,* 2019). A significant increase in the number of warm nights covering 70% of the land surface, specifically North America, southern Greenland, the southern parts of South America, is recorded from 1950-2003 (Alexander *et al.,* 2006). However, studies exist that explore changes over large spatial areas and found between 1950-2004 a more rapid increase in the minimum temperatures than with maximum temperatures. The large scale studies exclude the following regions: southern Argentina, eastern Africa, and southeastern Australia (Vose *et al.,* 2015). Additionally, global studies that explore extreme and regional temperatures revealed a decrease in the number of cold days and nights with an increase in warm days and nights for North America, South America, Europe, the Mediterranean, and Australia (Alexander *et al.,* 2006; Brown *et al.,* 2008; Peterson *et al.,* 2008; IPCC 2018). Several studies that used different methodologies confirm an increase in warm extremes while decreasing cold extremes over the Global North (Van der Walt & Fitchett, 2021).

Various studies (Peterson *et al.*, 2008; Kunkel *et al.*, 2013; Schoof and Robeson, 2016) indicate that the United States is experiencing an increase in intensity, duration and frequency of warm extremes, with a decrease in the intensity, duration and frequency of cold extremes, since the 1960s. These trends have also been observed in other countries over the Northern Hemisphere, including Finland, Austria, Portugal, Romania, Spain, Canada, and New Zealand (Steffen *et al.,* 2014; Mallet *et al.,* 2018; Irannezhad *et al.,* 2019). Statistical evidence suggests that observed changes in the climate caused an increase in the severity of heat waves in the past 50 years (Luterbacher *et al.*, 2007; Coumou & Robinson, 2013). Coumou and Robinson (2013) suggest that 10% of the Earth’s surface are now affected when extreme temperature events occur, whereas, in the 1960s, only 1% were affected by extreme events. Additionally, the number of record-breaking daily-, monthly-, and yearly temperatures have primarily occurred in the last two decades (Coumou & Robinson, 2013; Mallet *et al.*, 2018). Since 2003, United States, Europe, Russia, Australia, and Japan have recorded a combined death toll of over 122,500 people, linked to heat-related deaths (Coumou *et al.*, 2013; Perkins-Kirkpatrick *et al.*, 2016; Johnson *et al.*, 2018; Flavelle & Popovich, 2019; Kew *et al.*, 2019). Furthermore, Canada and New Zealand recorded warmer temperatures for autumn and winter, while countries like Argentina and Chile recorded colder winter temperatures up to -25°C in 2007 and 2010 (Khandekar, 2013; Caloierio, 2017; Mallet *et al.,* 2018).

Although a large number of countries experienced warm extremes throughout the last two decades, several countries in the Northern Hemisphere experienced extreme cold conditions in the winters of 2002/2003, 2005/2006, 2009/2010, 2011/2012, 2013/2014 and 2018/2019 (Khandekar, 2013; Messori *et al.,* 2016; De Prerez *et al.,* 2018; Johnson *et al.,* 2018; Van Oldenborgh *et al.,* 2019). South Asia, including Vietnam, Bangladesh, and northern India, experienced severe cold temperatures in 2002/2003, which led to the death of over 900 people in India (De Prerez *et al.,* 2018). North America and Eurasia experienced significantly colder than average conditions and higher snowfall in 2002/2003, 2007/2008, 2009/2010 and 2018/2019 (Johnson *et al.,* 2018). In 2008, China experienced an extreme cold spell that caused significant damage to the economy and the social and natural environment. Subsequently, 140,000 people lost their lives, 75 million animals died, 0.45 million ton of aquaculture fish and 30% of bee colonies died, 40% of winter crops were lost, and an estimate of US $22.3 billion was lost (Zhou *et al.,* 2014; Ponjoan *et al.,* 2017). During the winter of 2012 in Central Europe, temperatures plummeted to below -40°C causing adverse damage to infrastructure and the loss of hundreds of lives (Khandekar, 2013). The cold wave of 2019 in North America reported over 20 cold-related deaths (Van Oldenbergh *et al.,* 2019). The biggest threat from cold extremes are towards populations that are not acclimated and unprepared for extremely cold temperatures and can lead to a loss of life (Kandekar, 2013; Zhou *et al.,* 2014; De Prerez *et al.,* 2018; Van Oldenborgh *et al.,* 2019). The cold events described above can be caused by natural variability, including ENSO, Arctic Oscillation (AO), North Atlantic Oscillation (NAO), and the Pacific Decadal Oscillation (PDO).

The apparent increase in the frequency and duration of extreme high-temperature events is attributed to anthropogenic causes (Jones *et al.,* 2008; Christopher, 2014; Fahey *et al.,* 2017). Different studies that focused on individual extreme events found a strong correlation between human activities and increased probability of extreme events (Christidis & Stott, 2016; Yin & Sun, 2018). These attribution studies use different methods such as intensity-based, frequency-based or the fingerprint method (Kim *et al.,* 2016; Yin & Sun, 2018). These studies focus on determining whether the changes are caused by natural variability or by external forces such as anthropogenic activities and the extent to which it influences the change (Morak *et al.,* 2013; Bellprat *et al.,* 2019). The increase in the concentration of greenhouse gasses has been linked to the increase in maximum temperatures and decreased minimum temperatures across the globe (Stott *et al.,* 2010). The extreme heatwaves in Russia, Europe, India and Australia can all be linked to anthropogenic factors (Stott *et al.,* 2010; Vogel *et al.,* 2019). Although the research on the Southern Hemisphere's climatic conditions has increased in the last decade, a gap is still present, specifically in Africa, compared to those of the Northern Hemisphere (Arendse & Crane, 2010; Niang *et al.,* 2014). This gap can primarily be linked to a lack of reliable data across rural areas, lack of historical data, and the large area covered (Madzwamuse, 2010; Denton *et al.,* 2011; Niang *et al.*, 2014).

2.3. Research on ETEs in Africa and southern Africa

The African continent is considered the most vulnerable to climate change changes (Otto *et al.,* 2015). Therefore, the need exists to better understand the changes in climate and their impact on weather events (Harington & Otto, 2020). Unfortunately, the African climate situation and extreme events receives a lack of research focus in general.(Otto *et al.,* 2012; Van der Walt & Fitchett, 2021). The United States National Oceanic and Atmospheric Administration (NOAA, 2020) suggest that Africa has a much higher average increase in temperature per decade than the global average, at 0.31°C/decade. Observational temperature data suggest that between 1950 -2017, Africa had an increase in cumulative heat of 50% per decade (Perkinds-Kirkpatrick & Lewis, 2020; Miller *et al.,* 2020). Cumulative heat is a relatively new conceptual metric that asses the heatwave duration and intensity during a season (Perkinds-Kirkpatrick & Lewis, 2020). East Africa, West African, and Southern Africa experienced temperature anomalies in 2019, with a temperature increase between 1°C and 2°C compared to 1981-2010 (Blunden & Arndt, 2020). The latest data suggest that temperatures above 2°C above the average for 1981-2010 were recorded in South Africa, Namibia and Angola (WMO, 2020). For the period 1989-2009, the northern parts of Africa experienced, on average, 40- 50 heatwave days per anum (Vizy & Cook, 2012). East Africa has experienced more frequent droughts over the past 60 years during spring and summer due to an increase in the temperature of the Indian-Pacific warm pool and is projected to increase in the future (Funk *et al.,* 2008; Shongwe *et al.,* 2011; Niange *et al.,* 2014). Southern and West Africa has and is expected to continue to experience a significant increase in hot days, hot nights and a decrease in cold nights and cold days, using ETCCDI (New *et al.,* 2006; Miller *et al.,* 2020; Van der Walt & Fitchett, 2021). These increases are in line with global warming trends (Niange *et al.,* 2014). Furthermore, South Africa has experienced an increase in austral summer heatwaves in the last two decades compared to 1961-1980 (Miller *et al.,* 2020).

Studies using a high-resolution global atmosphere model under a 1.5°C and 2.0°C scenario, for a base period of 1971-2006 and a projected period from 2007-2100, found an insignificant increase in precipitation but forecast an increase in extreme warm events and heatwave magnitudes over Africa (Dosio *et al.,* 2018). The number of heatwaves in Africa are expected to increase in the 21st century (Vizy & Cook, 2012; Niang *et al.,* 2014). The southwestern regions of Africa are projected to experience further increases in heatwaves and droughts, mainly due to ENSO and changes in the sea surface temperatures (Niang *et al.,* 2014; Miller *et al.,* 2020). Models also project that with this increase in heat events, the duration and intensity of droughts will increase over most Southern Africa (Perkinds-Kirkpatrick & Lewis, 2020; Miller *et al.,* 2020). Perkinds-Kirkpatrick & Lewis (2020) estimate that the cumulative heat will increase at 10°C/decade. A median increase of 2.5 heatwave events per season is projected for Central and Southern Africa (Miller *et al.,* 2020). An estimated increase in the average temperature for 1900-2000 in Africa was 0.5°C (Hulme *et al.,* 2001) but, more recent studies suggest that the actual increase was 0.89°C for the same period (Perkins *et al.,* 2015; Miller *et al.,* 2020). It is expected that some regions in Africa will become uninhabitable by 2070 because of the increase in heat and its effects on human health and a decrease in usable land, which will have significant implications (Xu *et al.,* 2020).

It is relevant to note that most of the studies related to the ETEs are conducted in the Northern Hemisphere with very few projections and modelling in sub-Saharan Africa. This creates a gap in the research and knowledge of the effects and extent of extreme temperatures in the Southern Hemisphere, primarily Africa and southern Africa (Alexander *et al.,* 2006). As explained by Harrington and Otto (2020), similar models that are used worldwide are influenced by challenges faced in less developed countries, for example, the availability of data and infrastructure Less developed countries in Africa have poorer governance frameworks, sparse observational networks and climate data, as well as a lack of expertise to develop local metrics and a lack of integration with epidemiological information (Donat *et al.,* 2013; Andrijevic *et al.,* 2020; Harrington & Otto, 2020). Unlike in more developed countries, the data reported to databases are from non-governmental agencies that seek areas in need of humanitarian aid, thus only covering specific location (Niange *et al.,* 2014). Probabilistic event attribution studies that have been undertaken have concentrated more on high profile events in midlatitude climates with minimal attempts to conduct attribution studies on Africa (Stott *et al.,* 2004; Peterson *et al.,* 2013; Otto *et al.,* 2015). Furthermore, studies that focus on an average 1.5-2°C temperature increase have been far more extensive in the global North than in Africa (Lott *et al.,* 2013; Nangombe *et al.,* 2019). Studies that focus on different models and means of methodology have received more attention in countries like North America, Europe, Asia and Australia (Li *et al.,* 2018). This leaves a significant gap in understanding climate change, frequency, duration, and effects on the African continent (Nangombe *et al.,* 2019).

Extreme weather events will impact the daily lives of people all around the world, but more so in developing countries due to a lack of resources and infrastructure to deal with ETEs (Angula & Kaundjua, 2016). Prolonged exposure to extreme temperatures will affect human health because this exacerbates any underlying health conditions (Miller *et al.,* 2020). Exposure to abnormally low or high temperatures over a prolonged time will have adverse effects on the human body (Ikäheimo's, 2014). These adverse effects are well documented and researched (Barnett *et al.*, 2005, 2007; Alpérovitch *et al.*, 2009; Näyhä *et al.*, 2011; Baccini *et al.*, 2013; Hyrkäs *et al.*, 2014; Jaakkola *et al.*, 2014; Näyhäet *et al.*, 2014). It is proven that when the ambient temperature exceeds a person's average skin temperature, between 32-35°C, it can cause physical exhaustion and mental fatigue (Luber and McGeehin, 2009). Symptoms of heat stress span in intensity from headaches to loss of life (Ikäheimo, 2014). The body typically manages the core body temperature by sweating, and this is very effective, but in areas of high humidity, sweating is not an effective way of managing core temperature (Miller *et al.,* 2020). During heat extremes in Pakistan and India in 2015, it was found that the high mortality rate can be attributed to the addition of high humidity (Mazdiyasni *et al.,* 2017). This is important for Africa since it consists of several regions with high humidity (Mora *et al.,* 2017). Consequently, extreme temperatures will dramatically affect the body's ability to function at peak performance (Ikäheimo, 2014). The importance of studying the effects of extreme temperature on the human body is outlined by Ikäheimo's (2014) as an increased need to identify groups in the population that are most vulnerable due to an increase in extreme weather events, an increased risk in morbidity because of illness and lastly to identify the importance of establishing a management plan to reduce health care costs and the prevention of mortality (Miller *et al.,* 2020).

Africa comprises of developing countries that rely mainly on agriculture for economic growth and holds 60% employment over Africa (Collier *et al.,* 2008). ETEs are likely to have a vast impact on the sector due to the critical role temperature plays in agriculture (Miller *et al.,* 2020). Crops grown in Africa are already pushed to their limits in terms of their thermal tolerance and resistance to droughts, and the most crop is produced in semi-arid regions which are already challenged by ETEs (Miller *et al.,* 2020; WMO, 2020). Heat stress, droughts, increased pest, and flood damage will affect food security and impact all livelihoods in the region (WMO, 2020). It is also projected that seasonal weather patterns will be affected and negatively impact the agricultural sector (Miller *et al.,* 2020). The price of food may continue to increase, without adaption measures, as food productivity decreases, and the agricultural sector continues to struggle, making food affordability even lower in an already economically struggling continent (Orimoloye *et al.,* 2019; WMO, 2020). Water shortages are already a problem in much of Africa and are expected to become an even more significant problem (Garland *et al.,* 2015). It will disrupt food production and the daily lives of people (Niange *et al.,* 2014). ETEs effect on the economy and social structures of a region also adds to the conflict in many African regions (WMO, 2020). Although there is debate among scientists regarding the role of changing climate in driving conflict, there is a consensus that these climate changes can exacerbate existing conflict (ICRC, 2020). Studies (O'Loughlin *et al.,* 2012, 2014; Scheffran *et al.,* 2012, 2014, von Uexkull *et al.,* 2016) have shown a link between high-temperature anomalies and increases in violence within the specific region. Between 1991-2009 in East Africa and 1980-2012 in sub-Saharan Africa, higher than average temperatures or extreme warm events have increased violence up to 26.6% (O'Loughlin *et al.,* 2012, 2014). The leading causes of the increase in conflict are attributed to overexploitation of scarce resources during these temperature anomalies, mass migration due to shortages of food and water, and the increased need for more extensive agricultural land (ICRC; 2020; Miller *et al.,* 2020; WMO, 2020).

A change in the mean climate of Africa and regions thereof will have adverse effects on biodiversity, with multiple fauna and flora species going extinct (Niang *et al.,* 2014). Crop harvesting time, phenological cues for plant and animal species, and melting periods for glaciers are dependent on the length of time in which threshold temperatures are exceeded

(Niang *et al.,* 2014). Seasonal perspective on warm and cold extremes are critical and can have adverse effects on the natural, social and economic environment (Harrington *et al.,* 2017).

A lot of African biodiversity has adapted to the scarcity or abundance of resources, it is challenging to determine the exact impact the climate changes will have on the different species (Miller *et al.,* 2020). Models project that at least 100 South African Cape Floral region species will go extinct, with some models projecting a loss of 2000 species under the current climate change conditions (Kidane *et al.,* 2019). It is difficult to make projections about the impact on biodiversity due to the lack of observational data within Africa and the extent of the impact on freshwater supplies, which is a crucial driver in African biodiversity (Kidane *et al.,* 2019). Although projections are difficult to make, it is clear that a large scale change in habitat will lead to sensitive species going extinct (Niange *et al.,* 2014; Miller *et al.,* 2020). One reason why literature is uncertain about the impact on biodiversity is that there is a lack of observational data within Africa and the extent of the impact on freshwater supplies, which is a crucial driver in African biodiversity (Kidane *et al.,* 2019). Unfortunately, climate change is not a problem created by Africa (Niange *et al.,* 2014). However, large areas of Africa will be more affected than others due to the dependence on agriculture, not just for subsistence farmers but also for entire countries that rely on agriculture for economic sustainability (Niange *et al.,* 2014; Kidane *et al.,* 2019; Miller *et al.,* 2020). Even though African households have shown resistance to short term shortages, it is usually not sustainable, and with changes becoming more permanent, it is unclear how the households and economy will be able to adapt (Miller *et al.,* 2020). Since the 2000s, there has been an increase in the use of indices to identify ETEs over Africa (Table 1). In the last decade, the use of ETCCDI and ET-SCI has increased significantly, although ETCCDI has been used more often (Table 1)

Table 1: Studies conducted since 2000 assessing ETEs in Africa.

Author	Research Topic	Indices used	Location
Frich *et al.*, 2002	Observed coherent changes in climatic extremes during the second half of the twentieth century	ETCCDI	International, Africa
New *et al.*, 2006	Evidence of trends in daily climate extremes over southern and west Africa	ETCCDI	West and Southern Africa
Aguilar *et al.*, 2009	Changes in temperature and precipitation extremes in western central Africa, Guinea Conakry, and Zimbabwe, 1995-2006	ETCCDI	Western Central Africa, Guinea Conakry and Zimbabwe
Orlowsky & Seneviratne, 2012	Global changes in extreme events: regional and seasonal dimension	ET-SCI	International, Africa
Kruger & Seleke, 2012	Trends in extreme temperature indices in South Africa: 1962-2009	ETCCDI	South Africa
Ly *et al.*, 2013	Evolution of some observed climate extremes in West African Sahel	ETCCDI	West Africa
Donat *et al.*, 2013	Updated analyses of temperature and precipitation extreme indices since the beginning of the twentieth century: HadEX2 dataset	ETCCDI	International, Africa
Omondi *et al.*, 2014	Changes in temperature and precipitation extremes over the Greater Horn of Africa region from 1961 to 2010	ETCCDI	East Africa
Chaney *et al.*, 2014	Development of a High-Resolution Gridded Daily Meteorological Dataset over Sub-Sahara Africa: Spatial Analyses of Trends in Climate Extremes	ETCCDI	Sub -Sahara Africa
Diallo *et al.*, 2014	Evaluation of RegCM4 driven by CAM4 over Southern Africa: mean climatology, interannual variability and daily extremes of wet season temperature and precipitation	ETCCDI	Southern Africa
Mekasha *et al.*, 2014	Trends in daily observed temperature and precipitation extremes over three Ethiopian eco-environments	ETCCDI	Ethiopia
Moron *et al.*, 2015	Trends of mean temperatures and warm extremes in northern tropical Africa (1961-2014) from observed and PPCA-reconstructed time series	ETCCDI	Northern Tropical Africa
Abatan *et al.* 2016	Trends in extreme temperature over Nigeria from percentile-based threshold indices	ETCCDI	Nigeria
Filahi *et al.*, 2016	Trends in indices of daily temperature and precipitations extremes in Morocco	ETCCDI	Morocco

Marigi *et al.,* 2016	Trends of Extreme Temperature and Rainfall Indices for Arid and Semi-Arid Lands of South Eastern Kenya	ETCCDI	South Eastern Kenya
Mequanunta *et al.,* 2016	Observed and Future Climate Variability and Extremes Over East Shoa Zone, Ethiopia	ETCCDI	Ethiopia
Russo *et al.,* 2016	When will unusual heat waves become normal in a warming Africa?	ET-SCI	Africa
Ceccherini *et al.,* 2017	Heatwaves in Africa 1981-2015, observations, and reanalysis	ET-SCI	Africa
Kruger & Nxumalo, 2017	Surface Temperature Trends from Homogenised Time Series in South Africa: 1931-2015	ETCCDI	South Africa
Dosio, 2017	Projection of temperature and heat waves for Africa with an ensemble of CORDEX Region Climate Models	ETCCDI	Africa
Abatan *et al.* 2018	Trends in mean extreme temperatures over Ibadan, Southwest Nigeria	ETCCDI	Southwest Nigeria
Gebrechorkos *et al.,* 2018	Changes in temperature and precipitation extremes in Ethiopia, Kenya, and Tanzania	ETCCDI	Ethiopia, Kenia and Tanzania
Nkemelang *et al.,* 2018	Temperature and precipitation extremes undercurrent, 1.5°C and 2.0°C global warming above pre-industrial levels over Botswana, and implications of climate change vulnerability	ETCCDI	Botswana
Diebhiou *et al.,* 2018	Changes in climate extremes over West and Central Africa at 1.5°C and 2.0°C global warming	ETCCDI	Central and West Africa
Kruger *et al.* 2019	Historical and projected trends in near surface temperature indices for 22 locations in South Africa	ETCCDI	South Africa
Nangombe *et al.,* 2019	High-Temperature Extreme Events Over Africa Under 1.5 and 2 °C of Global Warming	ETCCDI	Africa
Amou *et al.* 2021	Heatwaves in Kenya 1987–2016: Facts from CHIRTS High Resolution Satellite Remotely Sensed and Station Blended Temperature Dataset	ETCCDI	Kenya
Van der Walt & Fitchett, 2021a	Exploring extreme warm temperature trends in South Africa: 1960–2016	ETCCDI, ET-SCI	South Africa
Van der Walt & Fitchett, 2021b	Exploring extreme cold temperature trends in South Africa: 1960–2016	ETCCDI, ET-SCI	South Africa

2.3.1. ETEs in Namibia

Namibia is considered the most arid country in sub-Shahara Africa (MET, 2002; Zeidler and Chunga, 2007). The frequency of droughts, floods, and extreme temperatures are on the rise in southern Africa, including Namibia (Niange *et al.,* 2014). In the past 50 years, Namibia has experienced an increase in the average temperature of 1°C and 1.2°C, with a more significant increase in Namibia's Northern parts (MET, 2011). New *et al.* (2006) conducted a study over southern Africa exploring temperature trends. The research display evidence that Namibia has seen an increase in the frequency of warm extremes for 1961-2000 (New *et al.,* 2006). Additionally, the research indicates a decrease in the frequency colder extremes (New *et al.,* 2006). The majority of research is over a broader region and uses point data, causing the results to have a low resolution for Namibia (New *et al.,* 2006). In the Fifth Assessment Report of the IPCC (2018), it is noted that Namibia has also seen a decrease in cool nights and days with an increase of warm nights and days.

Evidence indicates that the 1980s and 1990s were the two hottest decades, globally, of the 20th century (Christensen *et al.,* 2013). Since then, record-breaking high temperatures were recorded from 2003 and onwards (Dieckmann *et al.,* 2013). These temperature increases in Namibia are three times higher than the global average (Reid *et al.,* 2008). Namibia experienced above-average temperatures for summer and winter periods in 2018 (WMO, 2018). The WMO (2020) noted that 2019 was a significant year for ETEs, with heatwaves in the early summer exceeding 45°C, in Spitzkoppe Mountains. There was also an abnormal increase for winter temperatures, with some sites recording 40°C in coastal areas (WMO, 2019). Namibia, with its neighbouring countries, experienced temperatures 2°C above the global average (WMO, 2019). There has also been an increase in the number of warm spells and heatwaves across Namibia for the last two decades (New *et al.,* 2006; WMO, 2018, 2019). Although there is not the same amount of research on southern Africa as in the Global North, it is, nevertheless clear that the observed temperature changes over the last 60 years indicate a rise in temperatures (Niange *et al.,* 2014; WMO, 2019). Pinto (2020) used gridded data to illustrate the temperature anomalies for 2019 with a base period of 1981-2010 (Figure 1). The temperatures for 2019 for all of the SADC countries were above normal. Namibia recorded above normal temperatures in all four seasons with some areas exceeding a 2°C above normal. Only the west coast of Namibia experienced below average temperatures in Autumn (Figure 1; Pinto 2020). Rural and developing areas such as sub-Saharan Africa will bear the effects of climate change more so than developed countries, and since southern Africa is more prone to extreme temperatures, droughts and floods, the effects will be even more significant (Otto *et al.,* 2015; Miller *et al.,* 2020). Therefore, the effects of climate change are no longer just a concern for the natural environment but also the survival of the people in Namibia and the country’s economy (Niange *et al.,* 2014; Otto *et al.,* 2015).

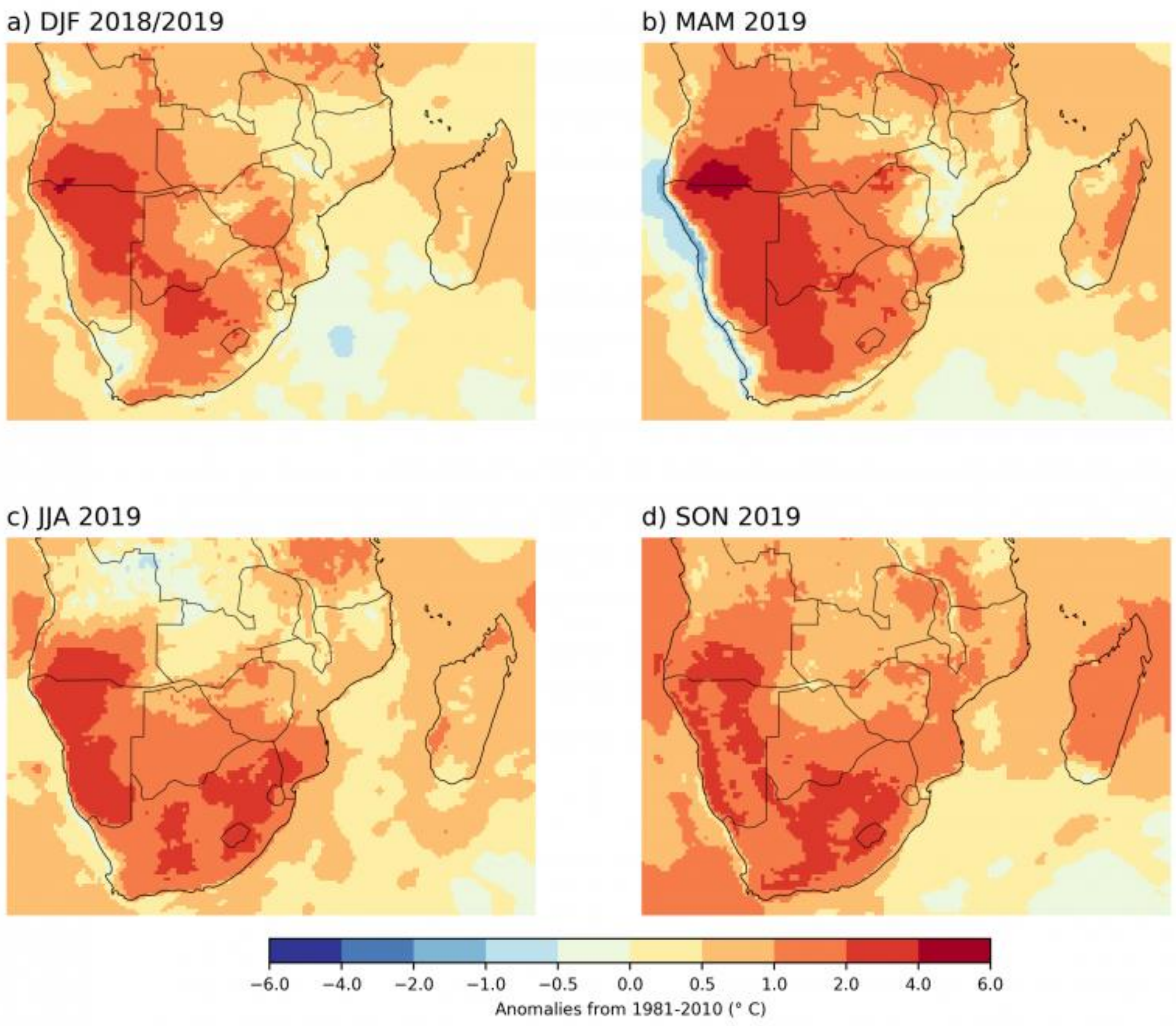


Figure 1: Seasonal monthly averages in mean temperature anomalies for southern Africa with a baseline of 1981-2010 (Pinto, 2020).

The impacts of the temperature changes can already be seen in the agricultural, economic and socio-economic sectors in countries across Africa, including Namibia (Niange et al., 2014; WMO 2019). Over the last two decades, the frequency and intensity of ETEs pose further vulnerability to the economy, agricultural sector, water demands, habitat loss, tourism, and the health sector in Namibia (MET, 2011; WMO, 2019). Water scarcity has been a problem in Namibia before the first industrial revolution, but the changing climate has only exacerbated the problem (Reid *et al.,* 2007). A decrease in the rainfall, as expected with a further temperature change and an increase in evaporation, have reduced runoff and infiltration (Reid *et al.,* 2007; MET, 2011). This already caused a decrease of 30-70% in groundwater recharge as well as a decrease in river discharge over the past three decades (Kandjinga *et al.,* 2010; MET, 2011). These reductions have created a problem for farmers since a large percentage of available water is used in crop farming for irrigation and livestock farming (MET, 2011; Schneider *et al.,* 2015). Due to increased heat stress on the agricultural sector, more people are moving to urban areas from rural areas, thus putting even more strain on the water resources (Barnes *et al.,* 2012). Reduction of river discharge also affects hydroelectricity supply, as in Ruacana Hydropower station (MET, 2011; Barnes *et al.,* 2012). Two-thirds of agricultural land in Namibia is used for subsistence farming, with pastoralism already decreasing (Spear *et al.,* 2018). Changes in temperatures, seasonal lengths, humidity and rainfall led to crop failure and reduced food production throughout Namibia (Spear *et al.,* 2018). Other factors influenced by climate change are the reduction of soil fertility, soil erosion, pesticides, and crop pathogen dynamics (Reid *et al.,* 2007; Barnes *et al.,* 2012; Spear *et al.,* 2018). The spread of diseases, such as malaria, dengue fever and schistosomiasis (GRN, 2015), is also changing due to the changes in temperatures, and there is little understanding of how these diseases react to warming temperatures (Kandjinga *et al.,* 2010). Moreover, the reduction in vegetation cover reduced grazing land; thus, changing grazing patterns (Reid *et al.,* 2007).

Namibia is made up of extremely sensitive biodiversity, and even with a large number of protected areas, there is already signs of biodiversity loss (GRN, 2015). A loss of vegetation cover and a decrease in the number of deciduous broad-leaved trees are concerning and is linked to an increase in CO_2 emissions (Thuiller *et al.,* 2006; Spear *et al.,* 2018). Expanding arid areas and reducing savanna biomes are threatening people's livelihoods in the area, and with an increase of veld fires worsening the situation (GRN, 2015; Spear *et al.,* 2018). The loss of biodiversity directly impacts other processes, such as water purification and the availability of medicinal plants (David *et al.,* 2013). The loss in biodiversity also has a significant effect on tourism in the country since it relies heavily on natural attractions for tourism (Reid *et al.,* 2007; Spear *et al.,* 2018). The rise in the average temperature and ETEs also influence the ease at which tourist activities are conducted (GRN, 2015). This is a drawback for the country's economy as the government relies heavily on tourism to add to the GDP (Thuiller *et al.,* 2006; GRN, 2015). ETEs affects the comfortability of the industry's activities and increases the running cost of tourist sites, for example, the increased use of cooling systems (Spear *et al.,* 2018; Keja-Kaereho & Tjizu, 2019). The tourism of a country relies on the region's political stability, but with a changing climate, the area's stability can very quickly change (GRN, 2015; Spear *et al.,* 2018). The impacts mentioned above also directly impact the country's healthcare system (GRN, 2015). Namibia has a high percentage of people living with HIV/Aids and tuberculosis, which puts a strain on the healthcare system (Thuiller *et al.,* 2006; GNR, 2015). A large proportion of people in Namibia are malnourished (GNR, 2015). The already strained healthcare system is put under more pressure due to increased poverty, malnutrition, increased diseases, heat stress and dehydration (Thuiller *et al.,* 2006; GRN, 2015; Spear *et al.,* 2018). The previous ETEs in Namibia has also affected infrastructure, such as the Ruacana hydroelectricity plant (GNR, 2015; Spear *et al.,* 2018). The reduction in water availability and the increased temperatures workers have to endure in the agriculture and mining sector reduces their productivity and, in turn, the economy (Spear *et al.,* 2018). The effects already endured by the country due to climate change and the history of Namibia negatively impact their vulnerability and adaptive capacity for future changes (MET, 2011;

GRN, 2015). Unfortunately, developing countries are less capable of adapting and surviving significant climate changes, mainly due to a lack of financial resources, technology and large percentages of poverty (Reid *et al.,* 2008). Over 30% of the gross domestic product (GDP) in Namibia depends on the natural environment, and further changes can be catastrophic for the economy, further reducing the country’s financial capability to adapt to the changes (Keja-Kaereho & Tjizu, 2019). An estimated loss of 6% of the GDP is projected to damage natural resources in the next ten year. Furthermore, the most vulnerable portion of Namibia's population (elderly and children) live in rural areas where most adaption is needed (GRN, 2015; Spear *et al.,* 2018; Keja-Kaereho & Tjizu, 2019).

Climate change projections for Namibia are discussed in the National Climate Change Strategy and Action Plan for 2013-2020 (MET, 2011). Even though climatic variability is a normal phenomenon, with erratic temperatures, rainfall, and persistent droughts, the country will be affected by even more unpredictable weather (Mfune & Ndombo, 2005; Dirkx *et al.*, 2008). From global climate models, rainfall projections for Namibia indicate an increase in late summer rainfall in most parts of the country and a decrease in the winter rainfall, especially in the western and southern parts of the country (Kgabi *et al.,* 2021). It is projected that by 2050, temperatures be 2-4°C higher when compared to the baselines of 1961-1990 (IPCC, 2018). Furthermore, it has been projected that with the increase in temperature, Namibia will be struck with more severe floods, droughts, rising sea levels, loss of biodiversity, weakening of water supplies, and food insecurity (Hulm *et al.*, 2001). A 50% reduction in food production is projected by 2050, and with the current increase in population, this can lead to malnutrition in 50% of the population (Kotir, 2011; Keja-Kaereho & Tjizu, 2019). Due to the country’s aridity, climate patterns, socio-economic factors, and its natural resource-based economy, it is classified as highly vulnerable to climate change (MET, 2011). With a high degree of certainty, it is predicted that by 2046-2065, summer temperatures will increase between 1-3.5°C and winter temperatures will increase between 1-4°C (Dirkx *et al.,* 2008). The frequency of days above 35°C is increasing, and days below 5°C is decreasing, which suggests overall warming in Namibia's climate (MET, 2011). Namibia already faces the threat of water scarcity, and the impacts of climate change only worsening the situation.

2.4. Conclusion

ETEs have a significant impact on the livelihoods of people and the environment in Namibia (Spear *et al.,* 2018). There is evidence that the night and day temperatures are warming and increase in the frequency and intensity of ETEs (Niange *et al.,* 2014; Miller *et al.,* 2020). Countries with a similar climate to Namibia, is clear evidence of the consequences of the changes in temperature on a country and its environment (Stott *et al.,* 2004; Peterson *et al.,* 2013; Otto *et al.,* 2015). Developing countries do not have the number of resources and technology at their disposal as developed countries making them more susceptible to changes in climatic conditions (New *et al.,* 2006). The African continent has already experienced some significant changes in rainfall patterns, temperature increases and ETEs (Niange *et al.,* 2014; Spear *et al.,* 2018; Miller *et al.,* 2020). There is a large gap within the literature that explains these effects (Miller *et al.,* 2020). There are different reasons for the lack of research, such as lack of funding, extensive spatial coverage and sparse reliable data (Niange *et al.,* 2014; Harrington & Otto, 2020). ETEs in Namibia are increasing and negatively impact the economic, environmental, and socioeconomic sectors (MET, 2011; GNR, 2015; Pinto, 2020). The majority of the population live in rural areas and live on the surrounding resources (GNR, 2015). A number of limited resources in Namibia (i.e., water availability) will become scarcer with the current projections and further pressure rural communities (Harrington *et al.,* 2017). There should be a focus on the environmental impact or socio-economic impacts, but instead, they should be seen in tandem to understand the changes thoroughly and adapt accordingly and sustainably (Niange *et al.,* Muller *et al.,* 2020; Kgabi *et al.,* 2021).

Chapter 3: Study Region

3.1. Introduction

Namibia is on the southwestern coast of Africa, situated south of the equator, with the Tropic of Capricorn running through the country (Dirkx *et al.,* 2008). Namibia covers an area of 825,615km^2, spanning 17-29°S and 12-25°E (Figure 1; Klaus, 2005). Countries that border on Namibia are South Africa on the south-east and south, Botswana in the east, Zambia in the northeast, Angola in the north, and the Atlantic Ocean in the west. A coastline of about 1572km and the perennial Kunene, Kavango, Zambezi, Kwando, Linyanti, Chobe and the Orange Rivers form the borders throughout Namibia Klaus, 2005; Jänis, 2011).

The topography of Namibia can be classified into five main areas: the Namib Desert Lodge, the Great Escarpment, the Central Plateau, the Kalahari Desert and the Bushveld (Klaus, 2005; Jänis, 2011). The areas are separated with characteristic vegetation and abiotic conditions, with some overlap between each border (Logan, 2009). The Namib Desert Lodge consists of hyper-arid gravel and sand that make up the world's highest dunes (Spriggs, 2001). It stretches over the entire coastline of Namibia from South Africa to Angola (2000km) and spreads inland to the Great Escarpment (130-160km; Logan, 2009). The Great Escarpment spreads from the north to the south of Namibia that separates the coastal areas and the plateau (Spriggs, 2001). It is made up of different mountain ranges that reach up to 2500m.asl, with large valleys throughout the Escarpment that have been eroded over millions of years (Jänis, 2011).

The Central Plateau is the most extensive landscape in Namibia and borders the Great Escarpment and the Kalahari Desert. Windhoek, the capital city of Namibia, is situated in the

Escarpment. Additionally, the Escarpment reaches heights of between 1000-2000m.asl (Logan, 2009). The Kalahari Desert spans several countries - South Africa, Botswana, Zimbabwe, Zambia, Angola and the Democratic Republic of Congo (Logan & Silberbauer, 2019) and comprises three main characteristics: sand sheets, longitudinal dunes and pans (also called vleis; Spriggs, 2001). Lastly, the Bushveld is dominated by flat plains and borders Botswana, Zimbabwe, Zambia and Angola (Rutherford *et al.,* 2006; Jänis, 2011).

3.2. Weather Station Locations

The weathers stations selected were Klein Aus Vista, Etosha Safari, Hochfeld, Windhoek, Swakopmund, Namib Desert Lodge Lodge, and Stampriet (Kalahari Farmhouse). These sites were selected due to their spatial variability and data availability for a ten year period. Unfortunately, two of the stations did not have sufficient data to calculate the necessary indices for the study. Thus, only five stations were used for the study (Table 2, Figure 3).

Table 2: Selected weather stations

Study Area	**Latitude**	**Longitude**	**Elevation (m.asl)**	**Rainfall (mm)**	**Max Temp (C°)**	**Min Temp (C°)**
Hochfeld	21°25'47'’S	17°51’17’’E	1,576	52.74	31.43	6.19
Kalahari Farmhouse	24°20’14’’S	18°24’03’’E	1,211	20.16	36.72	4.53
Namib Desert Lodge	24°06'00' ’S	15°54'00''E	664	10.25	35.77	6.67
Swakopmund	22°40’44’’S	14°31’52’’E	90	2.32	27.87	10.29
Windhoek	22°34'36'’S	17°04’32’’E	1,673	40.63	31.29	8.89

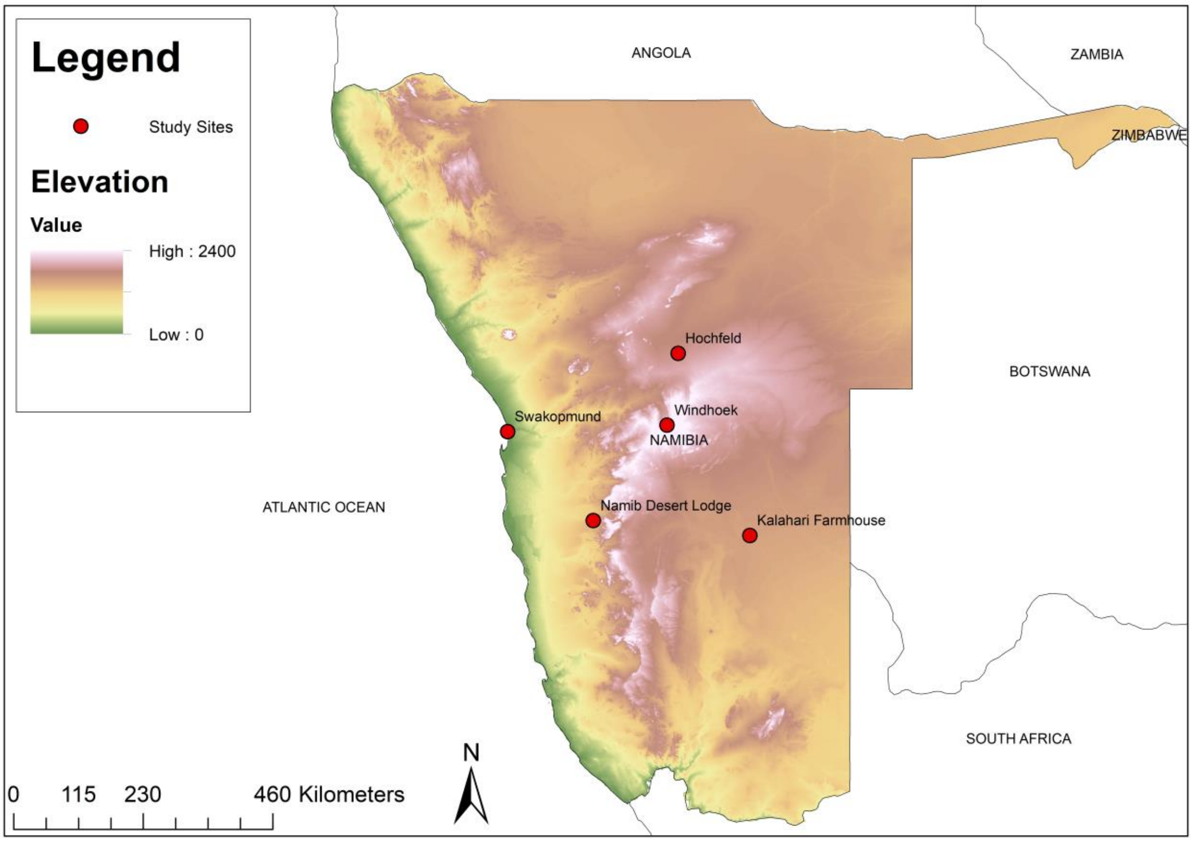


Figure 2: Map of study region of Namibia, topography and the study area.

3.3. Climate and Weather

The mean annual temperature of Namibia is 20.2°C for the period of 1901-2016 (Pinto, 2020). Temperatures are highest in the north and south of the country, with the average maximum for the hottest month exceeding 34°C (Turpie et al., 2010). The Southern Kalahari has the coldest temperatures, with an average minimum temperature of <2°C in the coldest month (Turpie et al., 2010). The dry season months of June, July and August have the lowest temperatures. The country's high evaporation rates range from 3800mm/yr in the south to 2600mm/yr in the north and are expected to be five times more than the annual rainfall (MET, 2011).

The amount of rain that falls in Namibia varies greatly depending on the region (Spear et al., 2018). Namibia has only one rainy season, which runs from November to April and coincides with the southward migration of the ITCZ (Spear et al., 2018). The ITCZ has a significant influence on the ENSO (Spear *et al.,* 2018). The northeast of Namibia receives about 600mm of annual rainfall on average, while the south and coastal regions receive less than 50mm (GRN, 2015). As a result, other types of precipitation, such as fog, have become essential water sources for desert fauna and flora (GRN, 2015). In some coastal regions, coastal fog can provide up to five times the amount of moisture and water as rainfall (Kaseke et al., 2018). The Namibian climate is projected to become more sensitive to ENSO, with above-average temperatures and below-average rainfall (GRN, 2002; Lakhraj-Govender & Grab, 2018).

3.4. Population structure and Socio-economic landscape

In 2020 Namibia's census data revealed that the country has 2.6 million people, with 35.68% of the population younger than 15 years and 3.9% older than 65 (World Bank, 2020). Namibia's largest town is Windhoek, with a population of 260,000 and with the rest of the urban population spread out through smaller towns. Urban areas and informal settlements make up 55% of the total population, while 45% occupy rural areas (Karuaihe, 2019; World Bank, 2020). A large proportion of the population that reside in rural areas rely on subsistence farming for survival. The dependency on subsistence farming has decreased in Namibia due to climate change, forcing rural-urban migration (Karuaihe, 2019). With the changing climate and the agricultural sector under pressure, more people are migrating their business to trophy hunting and tourism (Stiftung, 2020; World Bank, 2020). There has been a decrease in extreme poverty over the past few years, but multi-dimensional poverty remains high (this includes health, education and related services). The recession of 2016 and the high unemployment rate has contributed to the growing informal economic sector that now makes up 40% of employment (Stiftung, 2020). The Namibian healthcare services are shared between the public and private sector. The private sector is found in urban areas, making it difficult for the rural population to access these services. The leading causes of deaths in Namibia are HIV/AIDS, diarrhoea, tuberculosis, pneumonia and malaria, and the country only has a life expectancy of 49 years (MET, 2011; GNR, 2015). HIV/Aids infections are approximately 15% of the total population, and the high number of tuberculosis and malnutrition in the country puts much strain on the hospitals (GNR, 2015). It is important to understand the socio-economic status of the country and the population structure to understand the impact ETEs can have on an already pressured healthcare system. The effects of ETEs on a country that rely heavily on tourism and the 40% of people living in rural areas can put extra strain on the economy.

Chapter 4: Methodology

4.1. Introduction

The main objective of the study is to assess the frequency and extent of ETEs in Namibia. This chapter outlines the methods and process which were followed to address the objective. Only quantitative data is used in this study in the form of meteorological data. Firstly, it will discuss the data needed for the study and how the data was collected and selected. After that, data quality and cleaning are discussed. Furthermore, the different types of indices and interpolation of the data are discussed and computed by different computer software.

4.2. Data collection and Station Selection

For this study, the daily maximum (TX) and minimum (TN) temperatures in (°C) were obtained from the Namibian Weather Network for the period 2008-2019. Unfortunately, some limitations were encountered with the collection of the data. Over ten years, some stations had months to years missing in the data sets. For the indices to be calculated, up to 25% of the data set missing is deemed to be acceptable, as by the standards set by the WMO. The above mentioned resulted in two of the originally selected stations being omitted from the analysis. Thus, the temperature indices for five sites spread out over Namibia were calculated.

4.3. Data quality and cleaning

Before any statistical analyses are performed, it is recommended that proper quality control be done to ensure reliable results (Klein Tank *et al.*, 2009; WMO, 2011; Fioravanti *et al.*, 2019). Therefore, the datasets selected were subject to quality control to identify any missing data and outliers that may have occurred due to failure of equipment or human error (Salameh *et al.*, 2018). In order to maintain consistency throughout, from the raw data to the results, a two-point decimal rounding was used from the raw data, and visible outliers were checked. Where possible, missing data of five consecutive days or less, the data was replaced with the 5-day running average (Alexander & Herold, 2016). These were also cross-checked with adjacent stations within a radius of 50km. Additional quality control was also conducted using the software packages used to determine the ET-SCI and ETCCDI. The ET-SCI uses the ClimPACT v2 (Alexander & Herold, 2016), while the ETCCDI uses RClimDex v1.9 (Zang *et al.*, 2018). These packages allow the user to set the threshold for outliers in terms of the standard deviation and will then warn the user if any occur. Furthermore, the user is then able to make the necessary changes. A default threshold of three standard deviations was used for each package (Zang *et al.*, 2018; Kruger & Nxumalo, 2017).

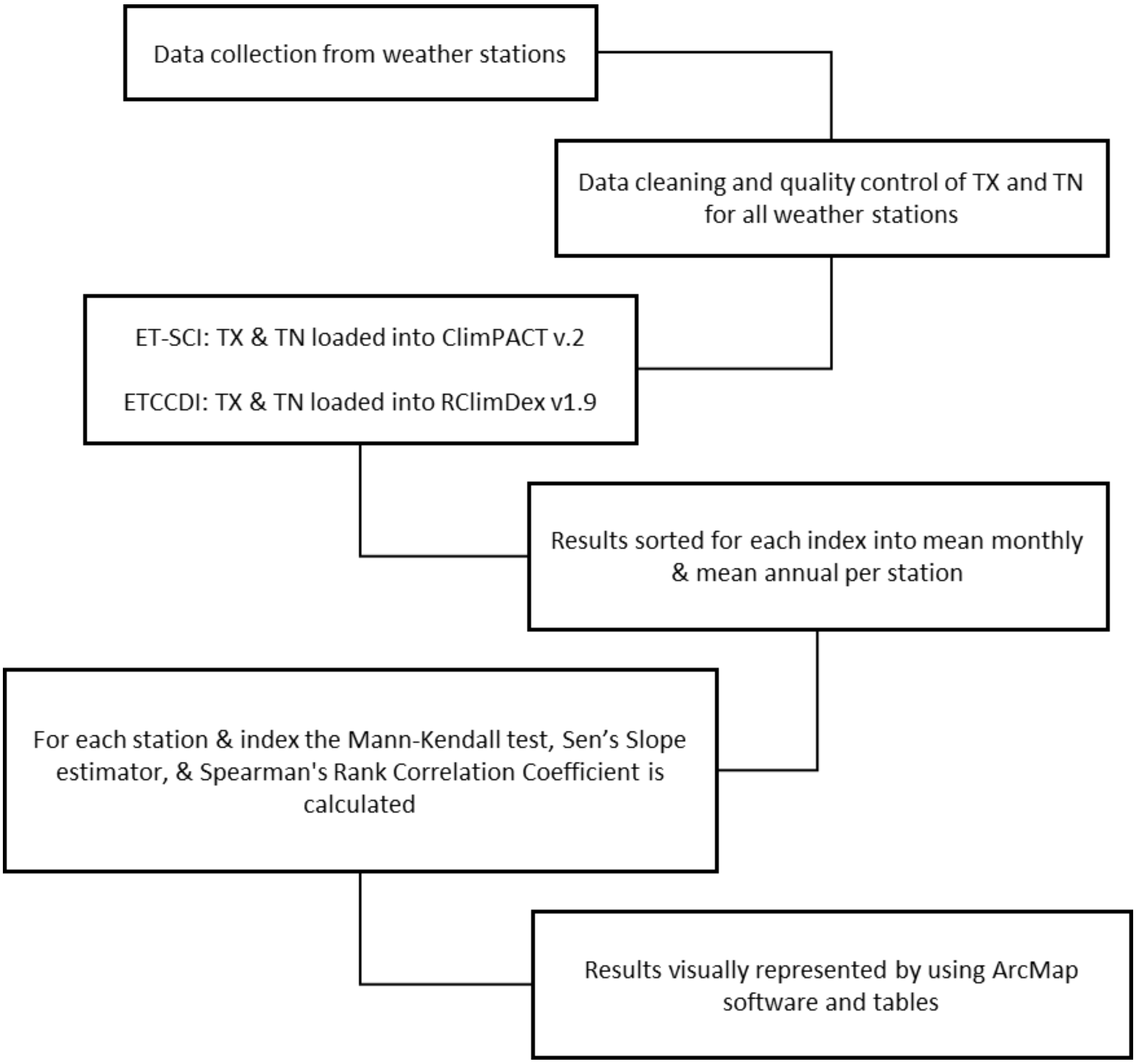


Figure 3: Method to determine extreme cold and warm temperature events.

4.4. Temperature Indices

4.4.1. ETCCDI

In 1996 the IPCC published the Second Assessment Report (SAR), and it was concluded that the available data and analyses were inadequate to make assessments on global climate changes (Anguilar, 2016). The focus was predominantly on short-term scales; thus, there was no long-term datasets record (Donat *et al.,* 2013; Anguilar, 2016). Subsequently, in 1999 a jointly sponsored team was created, now known as the ETCCDI (Anguilar, 2016). This team exits of the following organizations: the project on Climate Variability and Predictability (CLIVAR), the World Climate Research Programme (WCRP), World Meteorological Organization (WMO), the Commission for Climatology (CCl), the Joint WMO Intergovernmental Oceanographic Commission (IOC), the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the Technical Commission for Oceanography and Marine Meteorology (JCOMM; Peterson & Folland, 2001; Donat *et al.*, 2013; Anguilar, 2016). The ETCCDI have characterised and measure climate variability and change by coordinating internationally accepted indices for universal comparison (Karl *et al.,* 1999). 27 core indices measure temperature and precipitation and can be divided into four categories (Karl *et al.,* 1999; Zang *et al.,* 2018):

1. absolute indices;
2. threshold indices;
3. percentile indices; and
4. duration indices

These indices can be used for modelling or observations globally and on a regional scale (Anguilar, 2016; Alexander *et al.,* 2019). For this study, 12 indices were selected from the 27 main indices, which will be defined below in Table 3 and a summary of each below the table. (Karl *et al.*, 1999; Peterson & Folland, 2001; Zang *et al.,* 2018).

Table 3: ETCCDI indices used in the study (Zang et al., 2018).

ID	Name	Definition	Equation	Unit
FD	Frost Days	Annual number when TN<0°C	$TNij < 0℃$	Days
SU	Summer Days	Annual number when TX>25°C	$T\mathrm{X}ij < 25℃$	Days
TX_x	Maximum TX	Daily warmest TX	$TXij$=max $(TXij)$	°C
TX_n	Minimum TX	Daily coldest TX	$TXij$=min $(TXij)$	°C
TN_x	Maximum TN	Daily warmest TN	$TNij$=max $(TNij)$	°C
TN_n	Minimum TN	Daily coldest TN	$TNij$=min $(TNij)$	°C
TN10p	Cool Nights	Days when TN<10th percentile	$TNij < TNin10$	%
TN90p	Warm Nights	Days when TN>90th percentile	$TNij > TNin90$	%
TX10p	Cool Days	Days when TX<10th percentile	$T\mathrm{X}ij < T\mathrm{X}in10$	%
TX90p	Warm Days	Days when TX>90th percentile	$T\mathrm{X}ij > T\mathrm{X}in90$	%
WSDI	Warm Spell Duration Indicator	Annual number of days when TX>90th percentile (at least 6 consecutive days)	$TXij > TXin90$	Days
CSDI	Cold Spell Duration Indicator	Annual number of days when TN<10th percentile (at least 6 consecutive days)	$T\mathrm{N}ij < T\mathrm{N}in10$	Days

4.4.1.1. Summary of ETCCDI Indices

Frost Days (FD): The yearly number of days where the daily minimum is below 0°C (TN < 0°C). Let $TNij$ be the daily minimum temperature on day i in year j.

Summer Days (SU): The yearly number of days where daily maximum is above 25 °C (TX > 25°C). Let $T\mathrm{X}ij$ be the daily minimum temperature on day i in year j.

Maximum TX (TXx): The maximum daily maximum temperature for each month. Let $T\mathrm{X}ij$ be the daily maximum temperature on day i in year j.

Minimum TX (TXn): The minimum daily maximum temperature for each month. Let $TXij$ be the daily maximum temperature in month i, year j.

Maximum TN (TNx): The maximum daily minimum temperature for each month. Let $TNij$ be the daily minimum temperatures in month i, year j.

Minimum TN (TNn): The minimum daily minimum temperature for each month. Let $TNij$ be the daily minimum temperature in month i, year j.

Cool Nights (TN10p): The number of days where the minimum temperature is below the 10th percentile. Let $TNij$ be the daily minimum temperature on day i, in the year j and let $TNin10$ be the calendar day 10th percentile centred on a 5-day window.

Warm Night (TN90p): The percentage of warm nights where the minimum temperature is above the 90th percentile. Let $TNij$ be the daily minimum temperature on day i, in the year j and let $TNin90$ be the calendar day 90th percentile centred on a 5-day window.

Cool Days (TX10p): The number of days where the maximum temperature is below the 10th percentile. Let $T\mathrm{X}ij$ be the daily maximum temperature on day i, in the year j and let $T\mathrm{X}in10$ be the calendar day 10th percentile centred on a 5-day window.

Warm Days (TX90p): The percentage of warm days where the maximum temperature is above the 90th percentile. Let $T\text{X}ij$ be the daily maximum temperature on day i, in the year j and let $T\text{X}in90$ be the calendar day 90th percentile centred on a 5-day window.

Warm Spell Duration Indicator (WSDI): The yearly number of days with six or more consecutive days when the maximum temperature is more than the 90th percentile (TX >.90th percentile). Let $TXij$ be the daily maximum temperature on day i in the year j and let $TXin90$ be the calendar day 90th percentile centred on a 5-day window.

Cold Spel Duration Indicator (CSDI): The yearly number of days with six or more consecutive days, when the minimum temperature is less than the 10th percentile (TN <.10th percentile). Let $T\text{N}ij$ be the daily minimum temperature on day i in the year j and let $T\text{N}in10$ be the calendar day 10th percentile centred on a 5-day window.

4.4.2. ET-SCI

At the fifteenth session of the WMO Technical Commission for Climatology, it was decided that there was a need for sector-specific indices that will have a broader range of implementation (Alexander, 2015; Alexander & Harold, 2016; Mistry, 2019). Henceforth, The Expert Team on Sector-specific Indices (ET-SCI) had their first meeting in 2011 in Spain and established 34 core sets of indices developed in part with the core indices of ETCCDI (Perkins & Alexander, 2013; Alexander & Herold, 2016). The newly developed ET-SCI have sector-specific applications and were informed by experts in health, agriculture and water (Donat *et al.,* 2013; Alexander & Perkins, 2016; Mistry, 2019). Furthermore, the ET-SCI allows the user to define thresholds within specific indices. Additionally, it includes new heatwave and coldwave indices over a shorter period than those of ETCCDI (Donat *et al.,* 2013; Mistry, 2019). From the 34 core indices, seven were selected for this study and is discussed below (Table 4; Alexander & Herold, 2016):

Table 4: ET-SCI indices used in this study (Alexander & Herold, 2016).

ID	**Name**	**Definition**	**Equation**	**Unit**
SU35	Very Hot Days	Annual number of days when TX>=35°C	TX >= 35℃	Days
CSDI$_d$	User-defined Cold Spell Duration Indicator	Annual number of *n* consecutive days where TN<10th percentile	TN < 10^{th} percentile	Days
CWN	Cold Wave Number	Number of cold waves occurring each winter	$ECI_{sig} = \frac{T_i+T_{i+1}+T_{i+2}}{3} - T_{05}$, $ECI_{accl} = \frac{T_i+T_{i+1}+T_{i+2}}{3} - (T_{i-1} + \cdots + T_{i-30})/30$, $ECF = -ECI_{sig} \times \min(-1, ECI_{accl})$.	Number of events
CWD	Cold Wave Duration	Length of longest cold wave	Identified by the CWN	Days
WSDI$_d$	User-defined Warm Spell Duration Indicator	Annual number of *n* consecutive days where TX>90th percentile	$TX > 90^{th}$ percentile	Days
HWN	Heatwave Number	Number of heatwaves occurring each summer	$EHI(accl.) = \left[\frac{TM_i+TM_{i-1}+TM_{i-2}}{3}\right] - [(TM_{i-3} + \cdots + TM_{i-32})/30]$, $EHI(sig.) = \left[\frac{TM_i+TM_{i-1}+TM_{i-2}}{3}\right] - TM_{90}$.	Number of events
HWD	Heatwave Duration Days	Length of longest heatwave	Identified by the HWN	Days

4.4.2.1. Summary of ET-SCI Indices

Very Hot Days (SU35): The number of days where the maximum temperature (TX) is above 35°C.

User-defined Cold Spell Duration Indicator (CSDId): The yearly number of days contributing to events where d or more days where the minimum temperature (TN) is below the 10th percentile.

Cold Wave Number (CWN): The yearly number of cold waves defined by the Excess Cold Indices (ECI) and Factor (ECF).

Cold Wave Duration (CWD): The length of the longest cold wave identified by the CWN and defined by the ECF.

User-defined Warm Spell Duration Indicator (WSDId): The yearly number of days contributing to events where d or more days where the maximum temperature (TX) is above the 90th percentile.

Heatwave Number (HWN): The number of individual heatwaves that occur each summer (November to March in the southern hemisphere). A heatwave is defined as three or more days, where the Excess Heat Factor (EHF) is positive. The EHF is a combination of two excess heat indices (EHI).

Heatwave Duration Days (HWD): The length of the longest heatwave identified by the HWN, defined by the number of days.

4.5. Statistical Trend Analysis

Trend analyses have a wide variety of applications over a broad number of disciplines, including meteorology. Due to the popularity of trend analyses in climate research, several time series analyses have developed, including linear curve, accelerated increases, non-linear behaviour and non-parametric descriptions (Brown *et al.,* 2012; Sillmann *et al.,* 2013;

Mudelsee, 2019; Rathnayake, 2019). Although the linear regression is widely used, it is essential to note that it is prone to overestimating or underestimating the time series's slope (Onoz & Bayazit, 2003; Machiwal & Jha, 2008). One method that is considered the most appropriate in climatological trend analyses is the non-parametric Mann-Kendall trend test (Mann, 1945; Kendall, 1955; Onoz & Bayazit, 2003; Machiwal & Jha, 2008; Some'e *et al.*, 2013).

The Mann-Kendall test uses the time series data to determine a monotonic downward and upward trend of extreme temperature series (New *et al.,* 2006; Rehman, 2012; Blain, 2013; Abbas *et al.,* 2018; Rathnayake, 2019). The trend is determined by using the null hypothesis as no trend; thus, the alternative hypothesis is a positive or negative trend. This can be a linear or a non-linear trend, and therefore the Mann-Kendall test can be seen as a replacement for linear regression models (Rathnayake, 2019; Yosef *et al.,* 2019). Another reason why the test is popular in determining climate trends is that it does not require the data to be normally distributed, and therefore it is non-parametric (Onoz & Bayazit, 2003; Machiwal & Jha, 2008; Rathnayake, 2019). In conjunction with the Mann-Kendall, the Theil-Sen slope estimator is often used. This quantifies the magnitude of slopes and the median slope value (Sen, 1968; Davis *et al.,* 2016; Poudel *et al.,* 2020).

For this study, the Mann-Kendall test is used together with the Theil-Sen slope estimator to determine the trends in extremely warm and cold weather events. Furthermore, to cross-validate the Mann-Kendall test results, the Spearman's Rank correlation coefficient was calculated. Although both these methods are good in making long term analyses, the Mann-Kendall are seen as more interpretable (Şen, 2011; Rathnayake, 2019; Alemu & Dioha, 2020).

As stated above, the Mann-Kendall test uses a null hypothesis (H_0) as no trend evident. The latter is the alternative hypothesis (H_a), where there is a monotonical increase or decrease evident in the trends. Thus, the Mann-Kendall either rejects the H_0 or accepts the H_a (Mann, 1945; Kendall, 1975). The statistic S (Mann-Kendall test) is given by the following formula (Mann, 1945; Kendall, 1975; Rathnayake, 2019):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\, x(x_j - x_i)$$

1

where x_j and x_i are time series, and n is the number of data points in the time series. The "sgn" can be expressed as:

$$sgn(x_j - x_i) = \begin{cases} +1, > (x_j - x_i) \\ 0, = (x_j - x_i) \\ -1, < (x_j - x_i) \end{cases}$$

2

The Mann-Kendall variance is:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(i)\,(i-1)(2i+5)}{18}$$

3

where m is the number of tied groups, and t_i is the number of observations in the ith tied group. Where the sample size n > 10 the standard normal variable Z_c is computed:

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{Var\,(S)}}, & S > 0 \\ 0, & S = 0 \\ \frac{S+1}{\sqrt{Var\,(S)}}, & S < 0 \end{cases}$$

4

The Z_c value follows a normal distribution. When the Z_c value is negative; it shows a downward trend, whereas a positive Z_c value shows an upward trend. It is important to note that the Mann-Kendall test uses several assumptions (Rathnayake, 2019):

i. The data are identically distributed, and that the data is time-independent,
ii. The conditions at the observation times are assumed to be the actual conditions,
iii. The collection and handling of data occurred without any biased situation.

In the two-tailed test (at a given significance level α), the H_0 is rejected for an absolute value:

$$|Z| \geq Z_{1-\alpha/2}$$

5

Where the test for significance is performed at a 5% level (α = 0.005) (Phanda *et al.,* 2014; Yosef *et al.*, 2019; Poudel *et al.*, 2020).

The Theil-Sen estimator is used in conjunction with the Mann-Kendall to determine the slope's magnitude (Davis *et al.,* 2016; Poudel *et al.,* 2020). The estimator is resistant to extreme outliers like extreme lows and extreme highs (Wilcox, 2001). The slope can be calculated as follow (Sen 1968):

$$\beta = Median\left[\frac{x_j - x_i}{j - i}\right], \qquad for\ j < i$$

6

where β is Sen's slope estimate and, x_j are the time value at j and x_i are the time value at i. When $\beta > 0$ it indicates an upward trend in the time series.

Spearman's Rank correlation coefficient was also used to determine monotonic trends in the time series and determine the degree of correlation between two variables (Rauf *et al.,* 2016; Pohlert, 2020). This gives one a numerical value on the correlation or the degree of non-correlation (Spearman, 1904; Sneyers, 1990). It is calculated as follow:

$$\rho = 1 - \frac{6\sum_{i=1}^{n}[R(X_i - i)]^2}{n(n^2 - 1)}$$

7

where $R(X_i)$ si the rank in the ith observation X_i in the sample size of n.

The add-in software XLSTAT 2020.2.1 (ADDinSoft, 2020) was used to calculate the Mann-Kendal test, Sen's Slope estimator as well as Spearman's Rank correction Coefficient.

4.6. Conclusion

Extreme temperature events are becoming more frequent, and in areas where droughts and extreme temperatures are common, it can cause irreparable damage to the environment and its surrounding areas (GNR, 2011; Crawford & Terton; 2016; Grab & Zumthurm; 2018). Thus, there is a need to better understand extreme temperature events and have predictions for the future management of resources (Kuvare *et al.*, 2008; Angula and Menjono, 2014). For this study, the TX and TN daily temperatures were collected from the Namibian Weather Network (2019). These temperatures were collected over 24 hours and for the duration of 10 years. It was determined that only six of the eight stations had sufficient data. All the data from the selected stations had gone through quality control. The 12 ETCCDI indices and 10 ET-SCI indices were calculated using RClimDex v1.9 and ClimPACT v2.. This was also done on a seasonal scale, Summer (Dec/Jan/Feb), Autumn (Mar/Apr/May), Winter (June/July/August) and Spring (Sept/October/November). The results are presented *in Chapter 5*. All the above-mentioned statistical methods were used to address the aims and objectives (*Section 1.3*) of the study.

Chapter 5: Results

5.1. Introduction

This study aims to determine the extreme temperature events (ETEs) over Namibia using the ETCCDI and ET-SCI. This chapter presents the results of the different indices, starting with the mean temperature events. It is further separated between warm and cold events. Under each index, the average conditions are discussed, followed by the trends at each station for the period. Lastly, it will discuss the seasonal trends where applicable. It is important to note that the WMO requires at least 30 years of data for trend analysis to show climate change. The study only represents ten years of data. Trends presented are therefore tested for statistical significance. If there are statistically significant trends, it cannot be taken as evidence of climate change as the results may reveal trends within longer-term cyclicities. The interpretation of the different results is represented in *Chapter 6*.

5.2. Cold events

5.2.1. Mean minimum temperatures (TNMean)

The indices, TNMean, refers to the mean minimum temperature of a station. The timescale represented will be indicated at each description as either, for the period (2008-2018), year, or month. The TNMean conditions over Namibia range between 10.36°C and 13.17°C for the entire period with an average of 11.67°C. Windhoek experienced temperatures very close to the average TNMean. Swakopmund had the highest TNMean of 13.17°C and can be related to the fact that it is situated on the coast of Namibia. Hochfeld and Kalahari Farmhouse had the lowest TNMean of 10.36°C and 10.38°C, respectively. Namib Desert Lodge had the second-highest TNMean for the period, 12.87°C. There is an apparent increase in the TNMean from the western parts of the country towards the northeast and southeast of the country (Table 5).

Table 5:The average TNMean for 2008-2018.

Station	ETCCDI
	TNMean (°C)
Hochfeld	10.36
Kalahari Farmhouse	10.38
Namib Desert Lodge	12.87
Swakopmund	13.17
Windhoek	11.58

The majority of the stations (four of five) have increasing trends, with an overall rate increase of 0.13°C.y^{-1}. Swakopmund has no increasing trend for the ten years, while Namib Desert Lodge, Hochfeld and Kalahari Farmhouse all have an increasing trend. Windhoek is the only station with a decreasing trend of 0.03°C.y^{-1}. Namib Desert Lodge had an increasing trend of of 0.34°C.y^{-1} for TNMean(Supporting Table 1; Figure 4a). From the west coast towards the northeast and the southeast, there is an increasing pattern in the trend for TNMean. In summer, four of the five stations have an average increasing rate of 0.12°C and Swakopmund decreasing by 0.07°C.y^{-1} (Figure 5a). Hochfeld and Kalahari Farmhouse has the fastest increasing trend. During autumn, Hochfeld, Namib Desert Lodge and Windhoek are increasing at a rate of >0.22°C.y^{-1}. Kalahari Farmhouse and Swakopmund are both decreasing at a rate of >0.09°C.y^{1-}. Most stations have an increasing trend except for Swakopmund that has no trend for the period (Figure 5b). Desert Lodge has a statistically significant increasing trend of 0.42°C.y^{-1} for winter (Figure 5c). All the stations have an increase of >0.34°C.y^{1-} for spring, with Hochfeld having an increasing trend of 1.04°C for 2008-2018. Namib Desert Lodge is the only station for spring that has a statistically significant increase of 0.37°C.y^{-1} (Figure 5d). The central, northeast, southeast and southwestern part of the country has the fastest rate of increase in TNMean, while the west coast shows little to no increase.

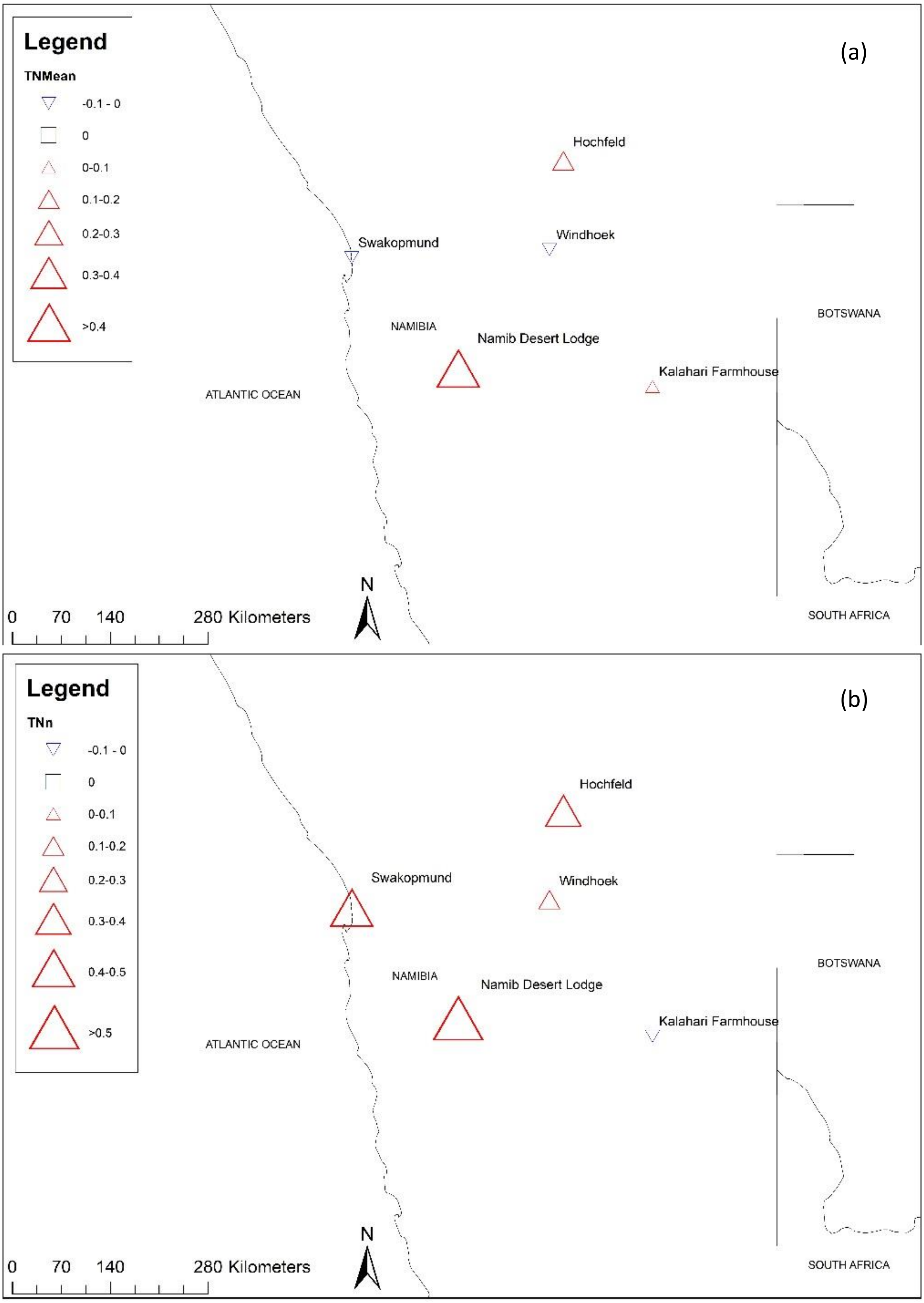


Figure 4: Trends of TNMean (a), and TNn (b). Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level

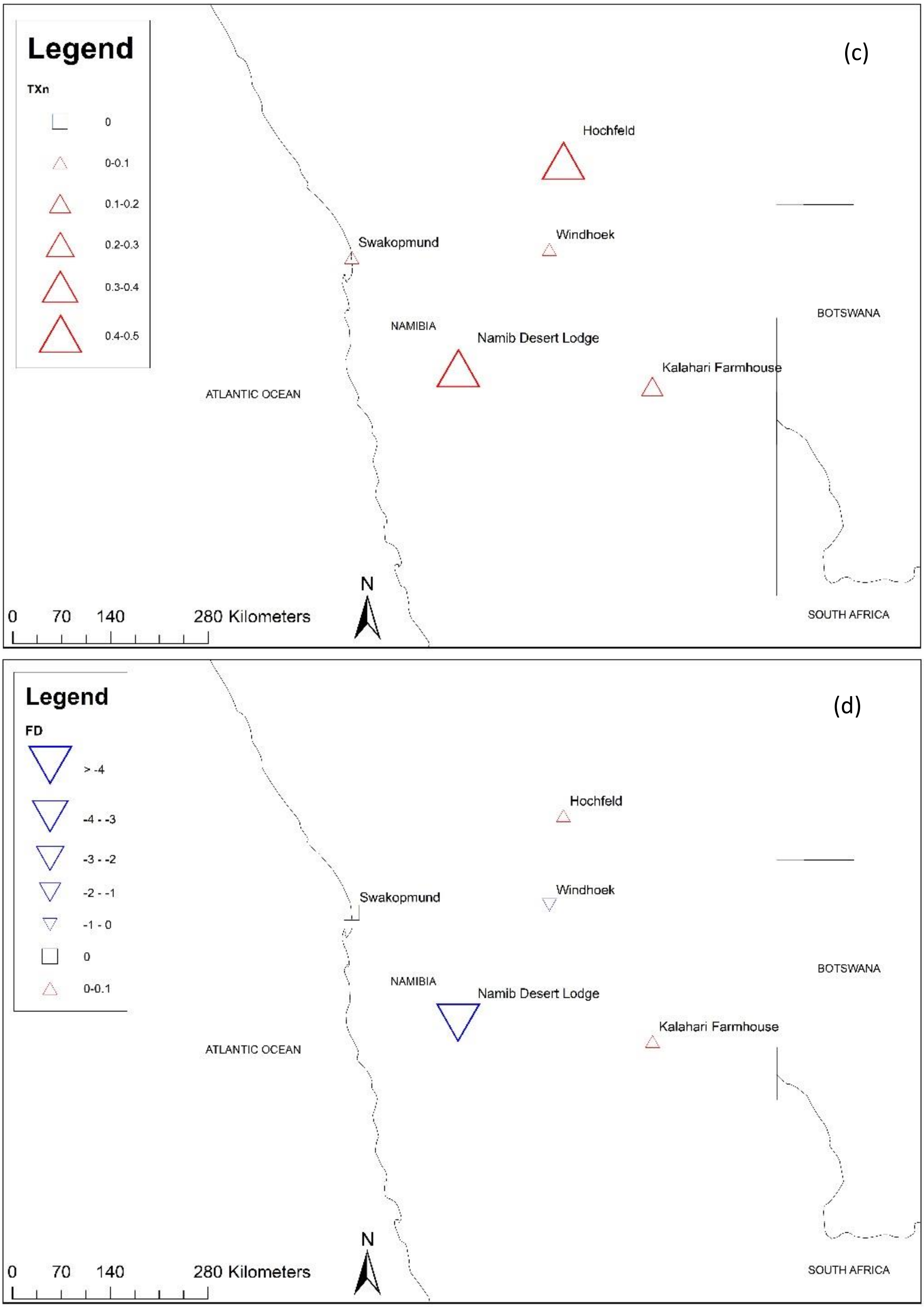


Figure 4: Trends of TXn (c), and FD (d). Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level.

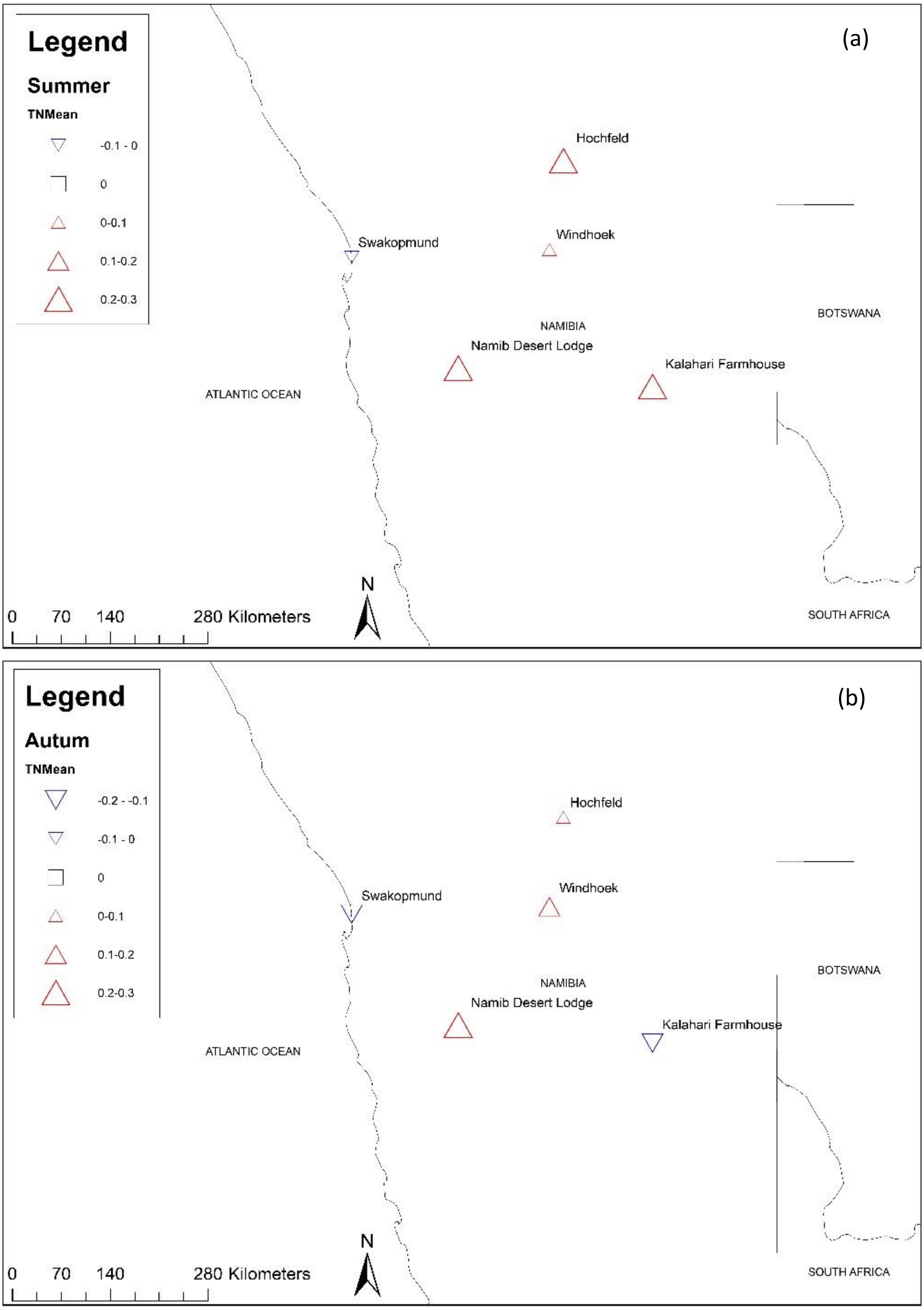


Figure 5: Seasonal trends of TNMean (a) Summer, and (b) Autumn. Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level.

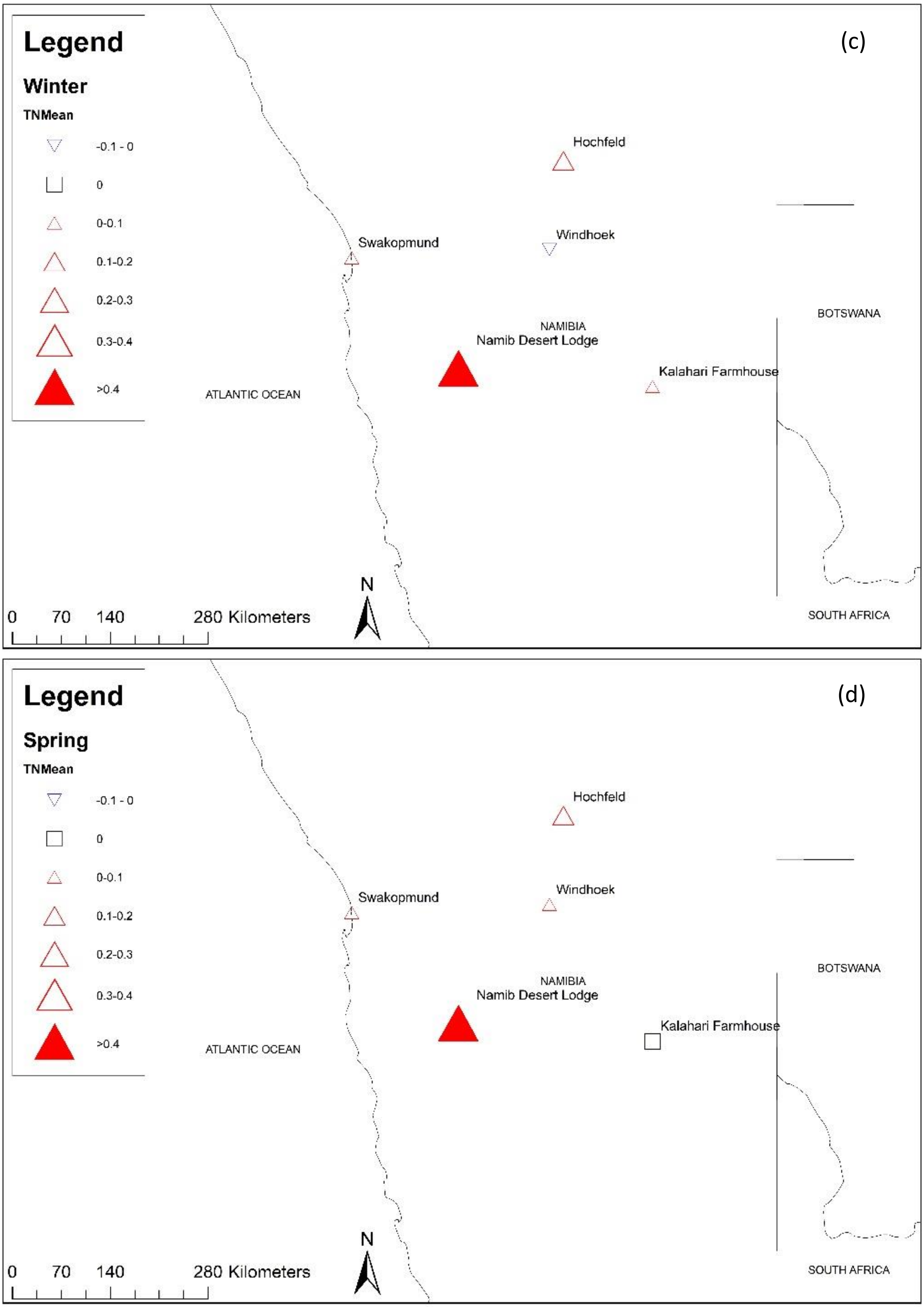


Figure 5: Seasonal trends of TNMean (c) Winter, and (d) Spring. Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level.

5.2.2. Coldest day (TXn), coldest night (TNn) and Frost days (FD)

The indices refer to the following: TXn, the maximum daily maximum temperature for each month, TNn, the minimum daily minimum temperature for each month and, FD, the yearly number of days where the daily minimum is below 0°C. The timescale represented will be indicated at each description as either, for the period (2008-2018), year, or month. The average TXn for Namibia was 19.09°C for 2008-2018, with almost all of the stations experiencing an average TXn of >19°C. Swakopmund is below the average TXn at 15.40°C for the period. The highest average TXn was recorded for Namib Desert Lodge, 22.26°C. Hochfeld, Kalahari Farmhouse and Windhoek all recorded a TXn slightly above 19°C. There is an increase in TXn moving from the west coast towards the southwest and eastern parts (Table 6). The average TNn experienced for all stations is <10°C with an average over Namibia of 6.16°C. Swakopmund recorded an average TNn of 9.93°C, and it is also the highest TNn measured for the period. The average TNn for Windhoek was 7.13°C and 6.07°C for Namib Desert Lodge. Hochfeld experienced an average TNn of 5.35°C, and Kalahari Farmhouse recorded the lowest average TNn of 4.57°C between 2008-2018. There is a decreasing trend in the TNn moving towards the country's southeast (Table 6). The average number of FD for the country is 3 days.y^{-1} with only two stations experiencing >1 FD per year. Swakopmund recorded no FD over the period, while Windhoek and Hochfeld recorded 0.09 and 0.22 days, respectively. An average of 2 days was recorded for Namib Desert Lodge and 12 days for Kalahari Farmhouse. There is an increase in FD towards the southeastern parts of the country (Table 6).

Table 6: The average TXn, TNn and FD for 2008-2018

Station	ETCCDI		
	TX_n (°C)	TN_n (°C)	FD (days)
Hochfeld	19.16	5.35	0.22
Kalahari Farmhouse	19.08	4.57	11.70
Namib Desert Lodge	22.26	6.07	2.11
Swakopmund	15.40	9.93	0.00
Windhoek	19.56	7.13	0.09

Almost all stations experienced an increasing trend over TXn, with an average increase of 0.08.y^{-1} for Namibia. Windhoek was the only station to experience a decrease of 0.11°C.y$^{-1,}$ with Swakopmund recording no trend over the period. Hochfeld and Kalahari Farmhouse recorded an increase of >0.05°C.y^{-1}. The fastest increasing trend was recorded in Namib Desert Lodge, and the station experienced an increase in TNx of 0.39°C.y^{-1} (Appendix 1.1; Figure 4c). Only one station experienced a decreasing trend in TNx and recorded a decrease of 0.02°C.y $^{-1}$ for Kalahari Farmhouse. Swakopmund and Windhoek recorded an increase of >0.05°.y^{-1} while Hochfeld recorded an increase of 0.31°C y^{-1}. The fastest recorded increase in trend was in the southeastern part of the country at Namib Desert Lodge, which experienced an increase of 0.34°C.y^{-1} for 2008-2018 (Appendix 1.1; Figure 4b). Only two of the five stations experienced any trend in FD over the period. Namib Desert Lodge experienced a decreasing trend of 0.55 days.y^{-1}, while Kalahari Farmhouse recorded an increase of 0.83 days.y^{-1} (Appendix 1.1; Figure 4d).

Only one station recorded a decreasing trend for TNn in summer. Windhoek experienced a decrease of 0.37°C.y^{-1}. Swakopmund experienced an increase of 0.09°C.y^{-1} while Hochfeld, Kalahari Farmhouse and Namib Desert Lodge all recorded an increase of >0.1°C.y^{-1} (Appendix 1.7; Figure 6a). During autumn, three stations experienced an increase in TNn. Namib Desert Lodge recorded an increase of 0.04°C.y^{-1} while Swakopmund and Windhoek recorded an increase of >0.1°C.y^{-1}. Swakopmund had an increasing trend in TNn of 0.18°C.y^{-1}. Hochfeld and Kalahari Farmhouse experienced a decreasing trend, with Kalahari Farmhouse experienced a decreasing trend of 0.14°C.y^{-1} (Appendix 1.7; Figure 6b). All the stations recorded an increasing trend of > 0.1°C.y^{-1} for winter. The slowest increase was recorded in Swakopmund, 0.13°C.y^{-1} and Kalahari Farmhouse, 0.27°C.y^{-1}. Windhoek and Hochfeld experienced increases of >0.3°C.y^{-1} while Namib Desert Lodge recorded a statistically significant increase of 0.64°C.y^{-1} (Appendix 1.7; Figure 6c). Kalahari Farmhouse was the only station to record a decreasing trend, 0.15°C.y^{-1}, in TNn for spring. Swakopmund and Windhoek experienced an increase of >0.01°C.y^{-1}, and Hochfeld and Namib Desert Lodge recorded an increase of 0.2°C.y^{-1}. The lowest recorded increase was in Windhoek, 0.01°C.y^{-1}. Hochfeld experienced an increasing trend of 0.71°C.y^{-1}. The northeast and southwest of the country experience the fastest increasing trends (Appendix 1.7; Figure 6d).

Four of the five stations experienced an increasing trend in TXn for summer. Windhoek was the only station to record a decrease in the trend of 0.2°C. y^{-1}. Swakopmund recorded the slowest increase in trend with only 0.27°C. y^{-1}. Both Kalahari Farmhouse and Hochfeld experienced an increase of > 0.4°C.y$^{-1,}$ and Namib Desert Lodge was the only station to record a statistically significant increase in TXn of 0.74°C.y^{-1} (Appendix 1.6; Figure 7a). All of the stations recorded an increase in the TXn trend for autumn. Swakopmund and Kalahari Farmhouse recorded an increase of < 0.1°C.y^{-1}, while Namib Desert Lodge, Windhoek and Hochfeld recorded an increase of > 0.5°C.y^{-1}. Hochfeld experienced the fastest increase in the TXn trend for autumn, 0.78°C.y^{-1}, and Swakopmund recorded the lowest increase, 0.05°C.y^{-1} (Appendix 1.1; Figure 7b). Almost all of the stations experienced an increasing TXn trend for winter, except Windhoek, which for which a decrease of 0.2°C.y^{-1}. Swakopmund was the station with the slowest trend of 0.05°C.y^{-1} while Namib Desert Lodge, Hochfeld and Kalahari Farmhouse experienced an increase of > 0.9°C.y^{-1}. Statistically significant trends are calculated for Namib Desert Lodge, with an increase of 0.91°C.y^{-1}, and Kalahari Farmhouse, with a increase of 1.15°C.y^{-1} (Appendix 1.6; Figure 7c). In spring, only Kalahari Farmhouse experienced a decrease in TXn of 0.16°C.y^{-1}. Namib Desert Lodge recorded an increase of 0.01°C.y$^{-1,}$ and Swakopmund recorded an increase of 0.1°C.y^{-1}. Hochfeld experienced an increasing trend of 1.74°C.y^{-1}. There is a stronger increase in trends from central Namibia towards the northeast of the country (Appendix 1.6; Figure 7d).

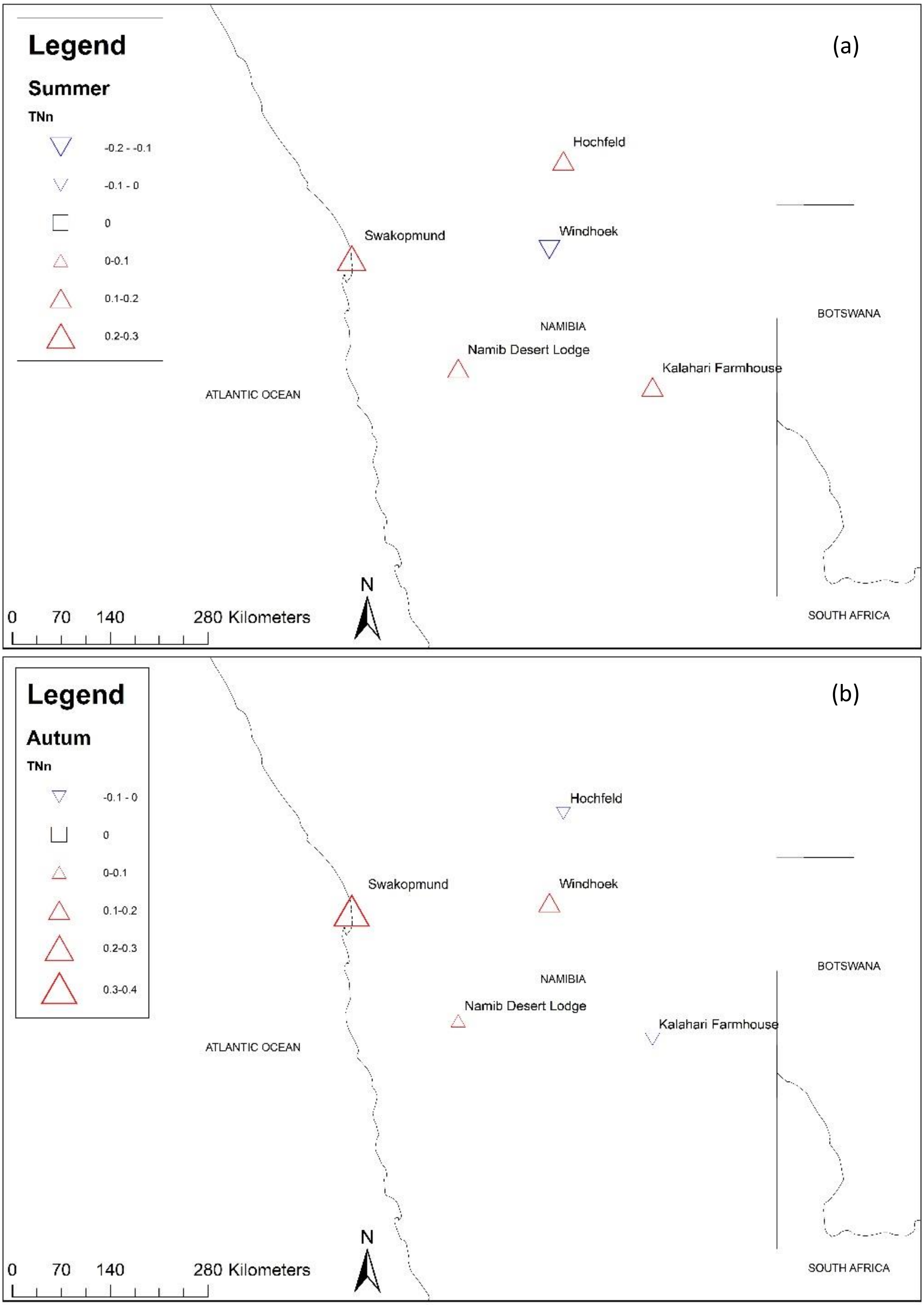


Figure 6: Seasonal trends of TNn (a) Summer, and (b) Autumn. Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level.

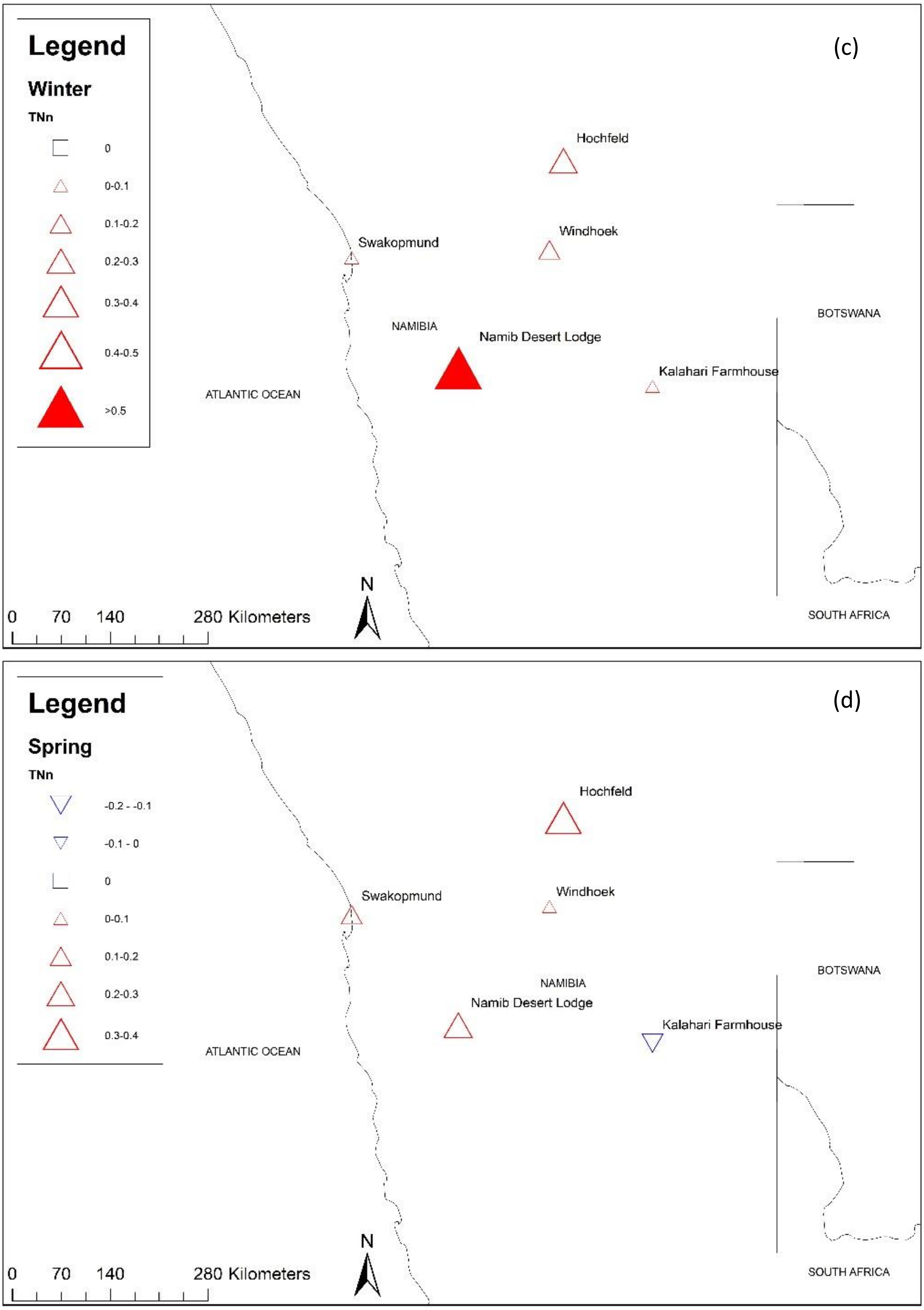


Figure 6: Seasonal trends of TNn (c) Winter, and (d) Spring. Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level.

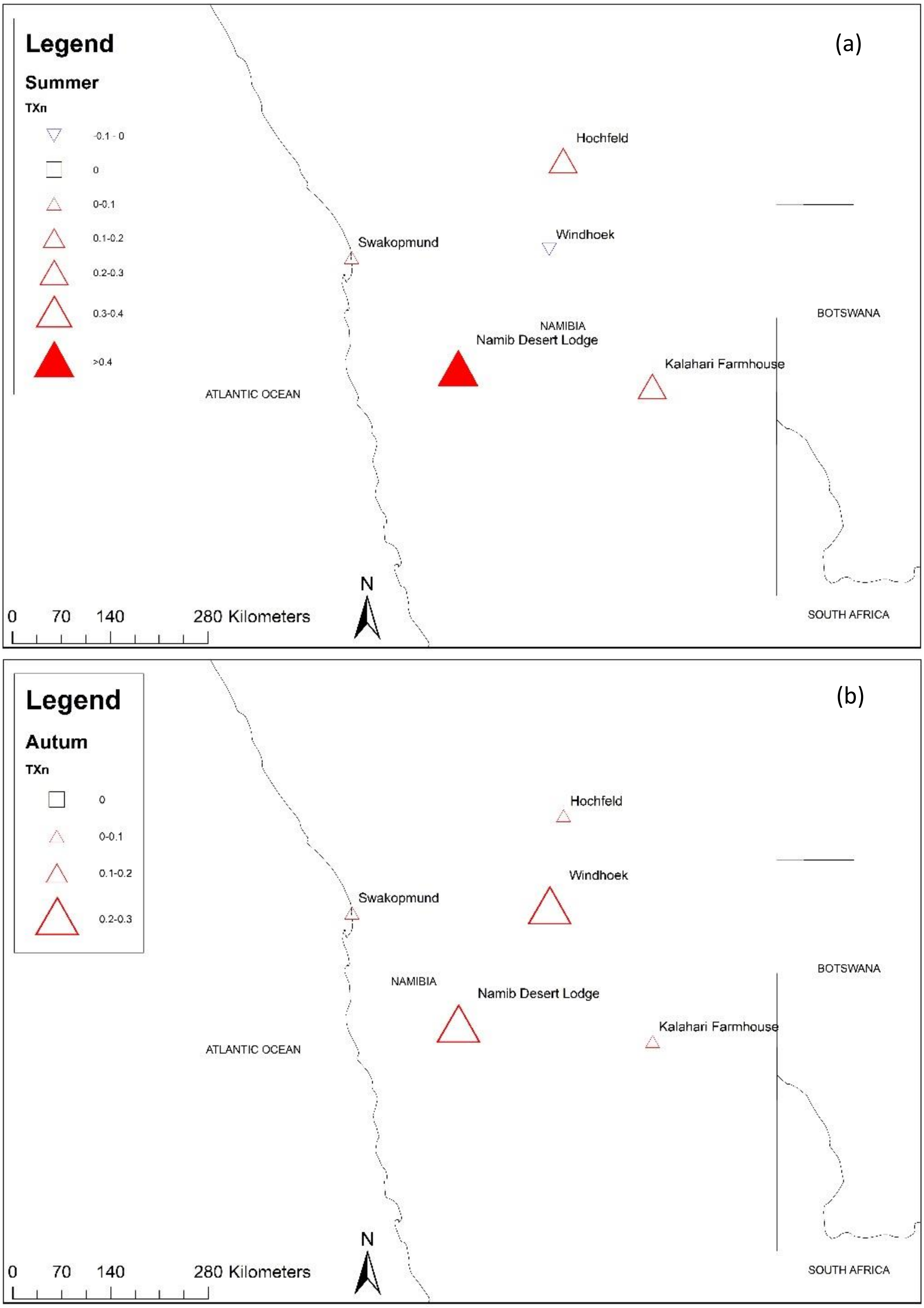


Figure 7: Seasonal trends of TXn (a) Summer, and (b) Autumn. Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level.

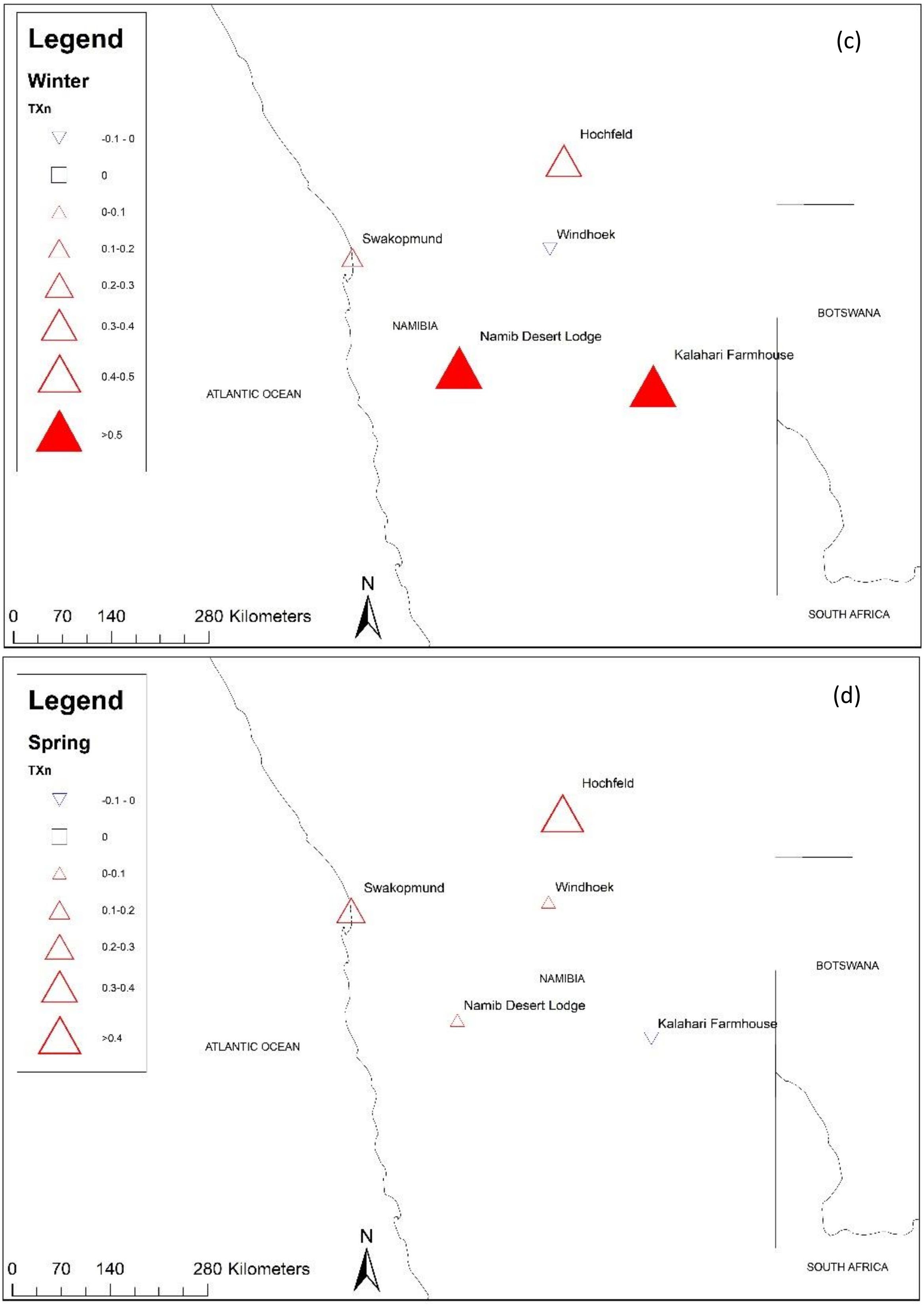


Figure 7: Seasonal trends of TXn (c) Winter, and (d) Spring. Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level.

5.2.3. Cold nights (TN10p) and cold days (TX10p)

The indices refer to the following: TN10p, the number of days where the minimum temperature is below the 10th percentile and, TX10p, the number of days where the maximum temperature is below the 10th percentile. The timescale represented will be indicated at each description as either, for the period (2008-2018), year, or month. Namibia experienced an average of 15.08% days of TN10p. All stations experienced a TN10p of >10%, with Kalahari Farmhouse experiencing the lowest percentage of 15.75%. Swakopmund recorded 11.01% and Namib Desert Lodge 13.43% of TN10p for 2008-2018. Windhoek experienced the highest percentage of TN10p, 24.46%. The TX10p is higher than TN10p with an average of 19.86%. Similar to the results of TN10p, Kalahari Farmhouse experienced the lowest percentage of TX10p, 10.84%. Namib Desert Lodge and Swakopmund recorded averages of > 12% and Hochfeld at 31.2%. Windhoek also experienced the highest percentage of TX10p with an average percentage of 32.14. There is an increase in TN10p and TX10p from central Namibia towards the northeast and southeast of the country, decreasing towards the west coast and the southeast (Table 7).

Table 7: The average TN10p and TX10p for 2008-2018

	ETCCDI	
Station	TN10p (%)	TX10p (%)
Hochfeld	15.75	31.20
Kalahari Farmhouse	10.75	10.84
Namib Desert Lodge	13.43	12.21
Swakopmund	11.01	12.89
Windhoek	24.46	32.14

There is an average decrease in the TN10p for Namibia of 1.04% days.y^{-1} from 2008-2018. The only station that recorded an increase was Kalahari Farmhouse, 0.2% days.y^{-1}. All the other stations experience a decrease of >0.3% days.y^{-1}. Hochfeld recorded a decrease in TN10p of 0.64% days.y^{-1} and Swakopmund a decrease of 0.35% days.y^{-1}. Windhoek recorded a decreasing trend of 2.26% days.y^{-1} while Namib Desert Lodge is the only station of statistical significance experiencing a decrease of 2.17% days.y^{-1} (Appendix 1.1; Figure 8a). All of the stations experienced a decrease in TX10p, with an average decrease of 1.73% days.y^{-1}. Swakopmund is the only station that recorded a decrease of < 1.0% days.y^{-1} with the slowest decrease of 0.37% days.y^{-1} while the other stations recorded a decrease of >1.4% days.y^{-1}. Namib Desert Lodge and Kalahari Farmhouse experienced a statistically significant decrease of 1.95% days.y^{-1} and 1.47% days.y^{-1} respectively. The fastest decrease in TX10p was recorded at Hochfeld at 2.99% days.y^{-1}. The decreasing trend becomes weaker when moving towards the west coast and stronger towards the north, east and southern parts of the county (Appendix 1.1; Figure 8b).

In summer, three of the five stations recorded a decrease in TN10p of > 0.4% days.y^{-1}. An increasing trend was recorded for Namib Desert Lodge, 0.37% days.y^{-1} and at Swakopmund, 0.12% days.y^{-1}. The weakest decreasing trend was recorded at Kalahari Farmhouse, of 0.41% days. y^{-1}. Hochfeld experienced a decreasing trend of 2.7% days.y^{-1} while Windhoek experienced a statistically significant decrease of 4.98% days.y^{-1} for 2008-2018. (Support Table 8; Figure 9a). Kalahari Farmhouse is the only station that recorded an increasing trend for TN10p of 1.11% days.y^{-1} during autumn. The other stations experienced a decreasing trend of > 0.3% days.y^{-1} with Windhoek recording the lowest decrease of 0.38% days.y^{-1}. Hochfeld and Swakopmund recorded a decrease of > 0.5% days. y^{-1}. The fastest decreasing trend was recorded at Namib Desert Lodge, 1.49% days.y^{-1} (Appendix 1.8; Figure 9b). During winter, Swakopmund was the only station to experience an increasing trend in TN10p of 0.31 % days.y^{-1}. Kalahari Farmhouse experienced no trend during 2008-2018. The slowest decreased trend was recorded in Hochfeld, 1.11% days.y^{-1} and Windhoek experienced a decreasing trend of 2.45% days.y^{-1} (Appendix 1.8; Figure 9c). All of the stations experienced a decreasing trend for spring for TN10p with an average of 1.1% days.y^{-1} for 2008-2018. Hochfeld recorded the slowest decrease of 0.32% days.y^{-1} while Kalahari Farmhouse and Swakopmund recorded a decrease of >0.6% days.y^{-1}. Windhoek had the second- fastest decrease of 1.23% days.y^{-1} and Namib Desert Lodge are of statistical importance with the fastest of 2.69% days.y^{-1}. An increasing trend towards the southeast of the country is prominent (Appendix 1.8; Figure 9d).

All five stations recorded a decrease of > 1.5% days.y^{-1} in the average TX10p for summer. The two stations with the slowest decrease were Swakopmund, 1.75% days.y^{-1} and Kalahari Farmhouse, 2.1% days.y^{-1}. Namib Desert Lodge and Windhoek experienced an increasing trend of > 3.2% days.y^{-1}. The fastest decrease in the trend was recorded in Hochfeld, 4.2% days.y^{-1}. Kalahari Farmhouse and Namib Desert Lodge are of statistical importance (Appendix 1.9; Figure 10a). In autumn, Swakopmund was the only station that experienced no trend in the TX10p for 2008-2018. Windhoek recorded a decreasing trend of 0.73% days.y^{-1} while Hochfeld and Kalahari farmhouse experienced a decrease of > 1.0% days.y^{-1}. Namib Desert Lodge experienced a decreasing trend of 3.15% days.y^{-1}(Appendix 1.9; Figure 10b). All the stations recorded an average decrease of 1.78% days.y^{-1} in the TX10p trend for winter. Swakopmund experienced the lowest decrease of 0.28% days.y^{-1} and Kalahari Farmhouse the second-lowest trend of 0.9% days.y^{-1}. A decrease of more than 1.5% days.y^{-1} was experienced by Namib Desert Lodge and Windhoek. The fastest decreasing trend was recorded for

Hochefeld, 3.27% days.y^{-1} (Appendix 1.9; Figure 10c). Only two stations recorded a decrease in the TX90p trend for spring. Swakopmund, 0.25% days.y^{-1} and Windhoek, 1.09% days.y^{-1}. Namib Desert Lodge had the lowest increase of 0.02% days.y^{-1} and Hochfeld experienced an increasing trend of 0.67% days. y^{-1}. The spatial patterns suggest a stronger decrease from the southwest to the northeast of the country (Appendix 1.9; Figure 10d).

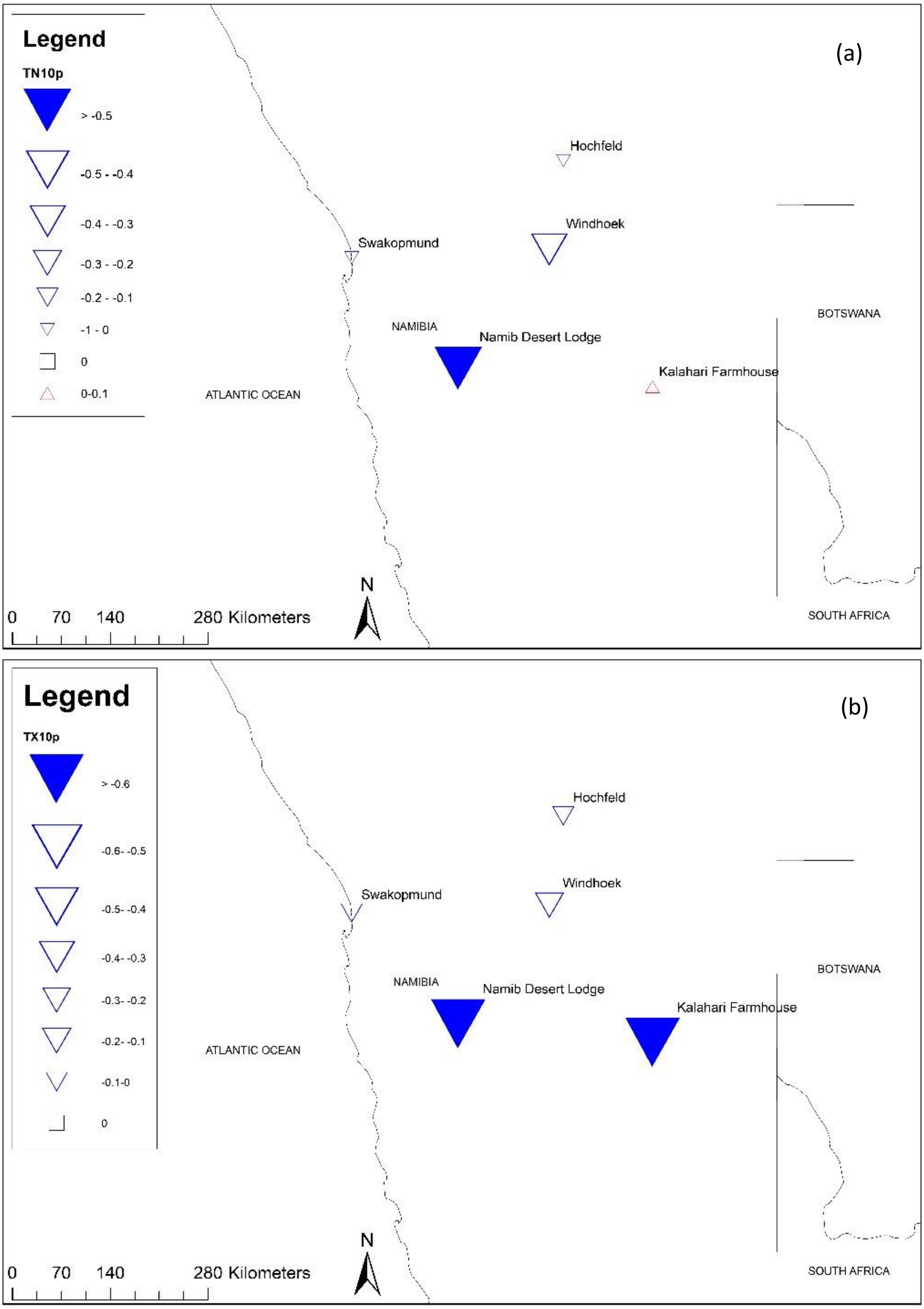


Figure 8: Trends of TN10p (a), and TX10p (b). Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level

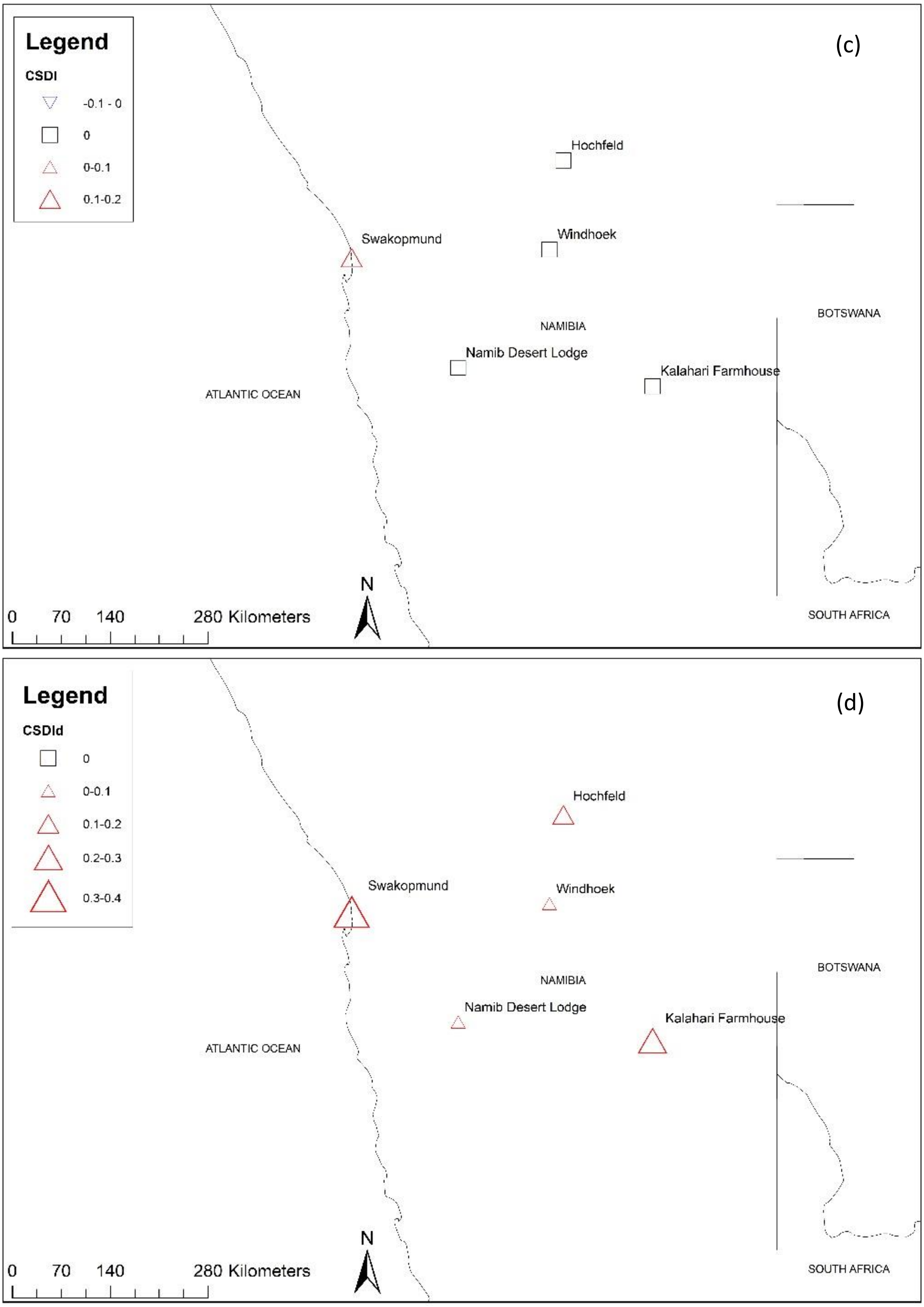


Figure 8: Trends of CSDI (c), and CSDId (d). Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level.

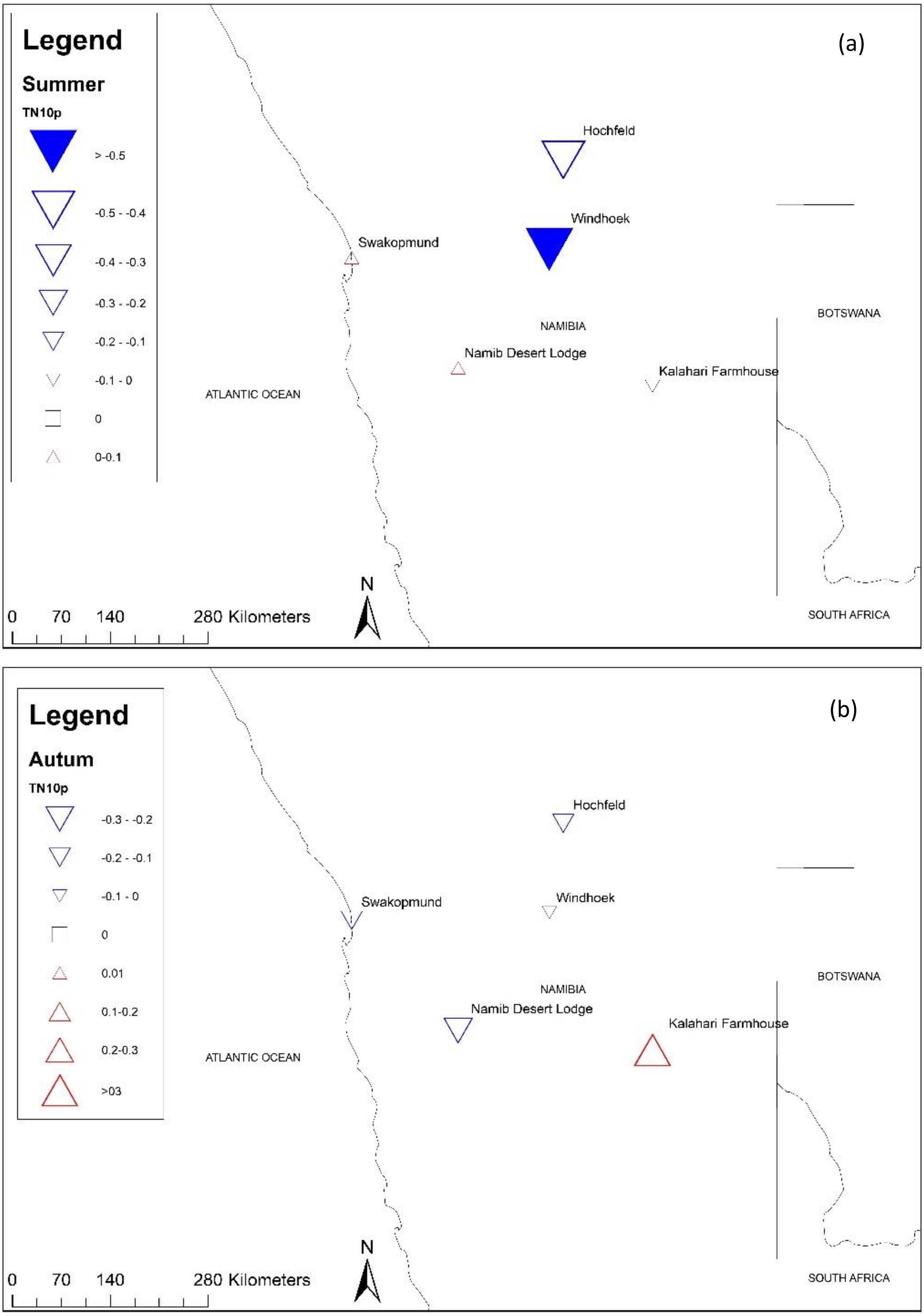


Figure 9: Seasonal trends of TN10p (a) Summer, and (b) Autumn. Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level

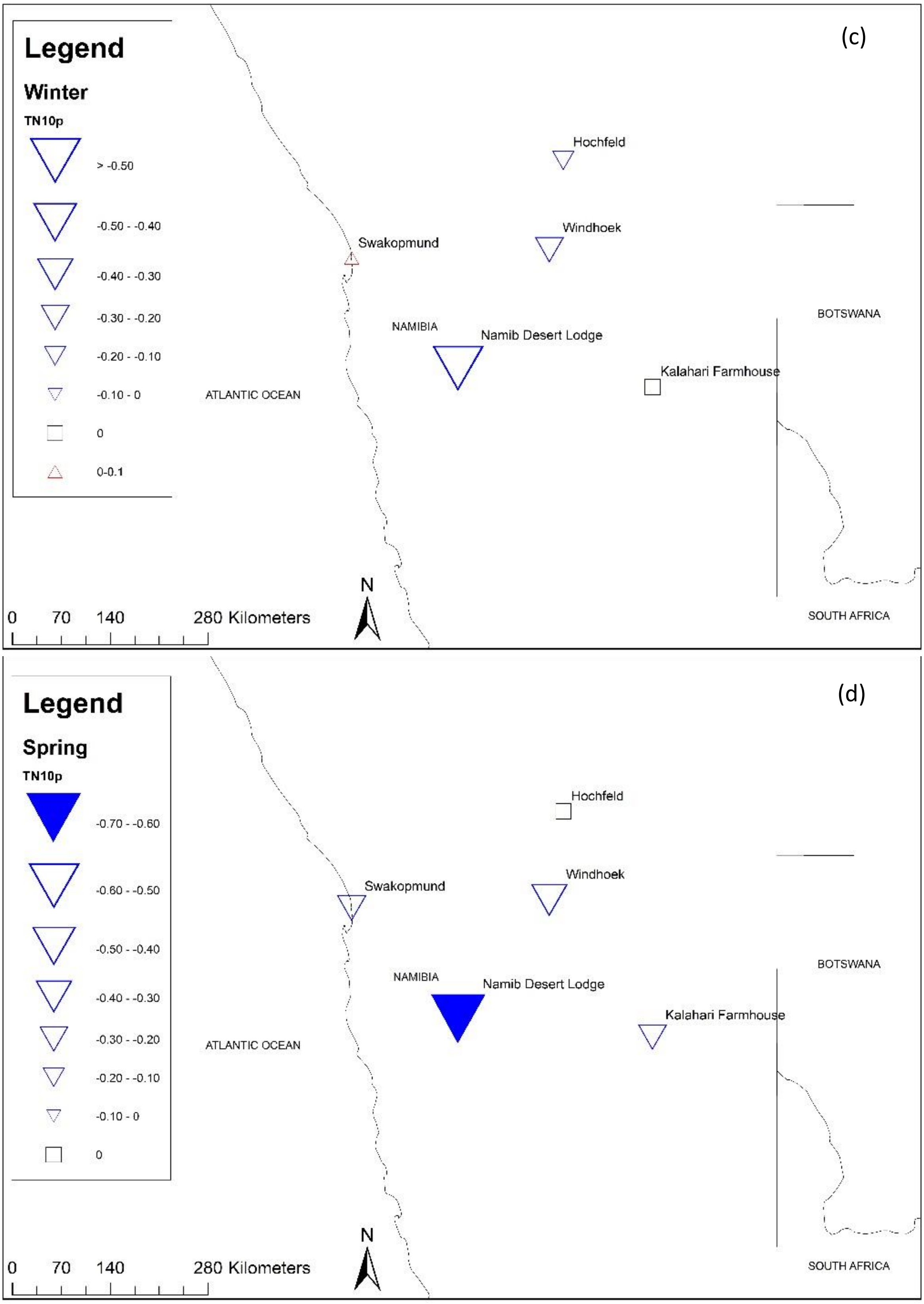


Figure 9:Seasonal trends of TN10p (c) Winter, and (d) Spring. Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level.

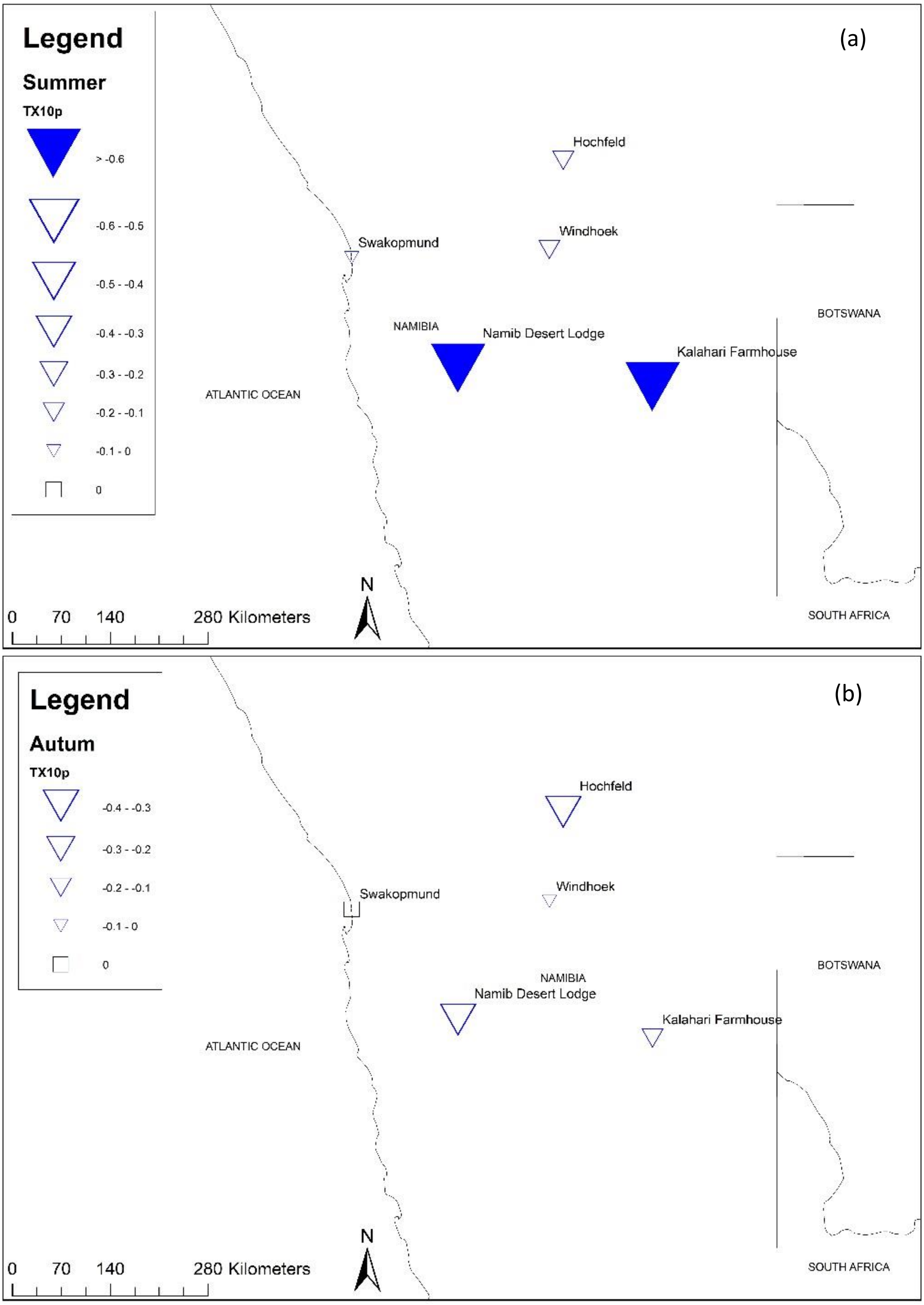


Figure 10: Seasonal trends of TX10p (a) Summer, and (b) Autumn. Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level.

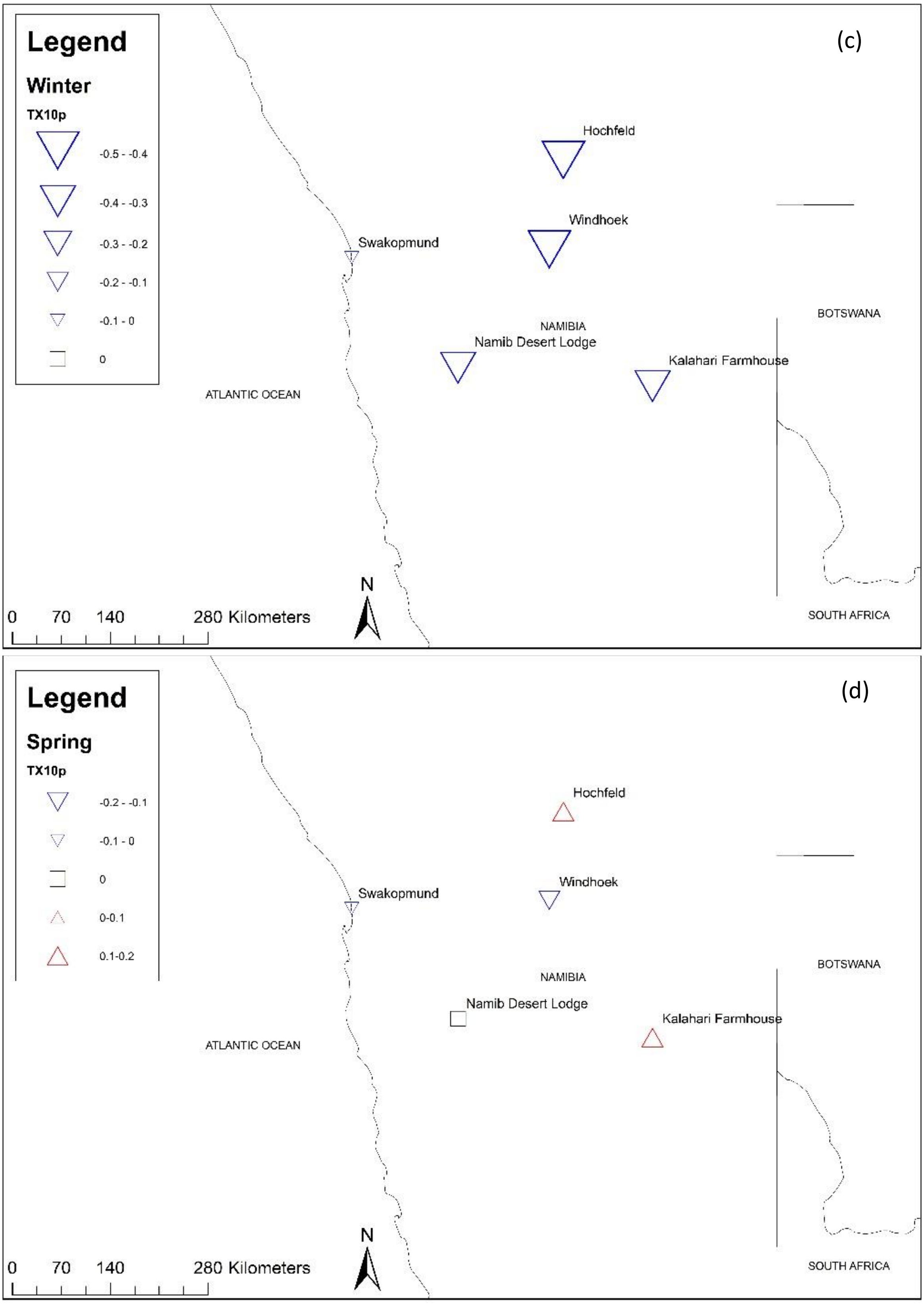


Figure 10: Seasonal trends of TX10p (c) Winter, and (d) Spring. Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level.

5.2.4. Cold spells (CSDI and CSDI$_d$)

The indices refer to the following: CSDI, the yearly number of days with six or more consecutive days, when the minimum temperature is less than the 10th percentile and, CSDId, the yearly number of days contributing to events where d or more days where the minimum temperature (TN) is below the 10th percentile. The timescale represented will be indicated at each description as either, for the period (2008-2018), year, or month. The CSDI is calculated over six days, and only one station experienced a cold spell during the period 2008-2018. Swakopmund has an average of 0.67 days of CSDI. The CSDI$_d$ is calculated over three days. A significant difference in the number of cold spells between CSDI and CSDI$_d$ is evident. On average, Namibia experienced 4.86 CSDI days. Swakopmund and Hochfeld experienced the least number of cold spells, with an average of 3.42 days and 4.47 days for each station. An average of 5.2 days was calculated for Windhoek and 5.6 days for Namib Desert Lodge and Kalahari Farmhouse. There is an increase in the number of cold spells from the west coast towards the country's eastern side (Table 8).

Table 8: The average CSDI and CSDId for 2008-2018

	ETCCDI	ET-SCI
Station	CSDI (days)	CSDI$_d$ (days)
Hochfeld	0.00	4.47
Kalahari Farmhouse	0.00	5.60
Namib Desert Lodge	0.00	5.60
Swakopmund	0.67	3.42
Windhoek	0.00	5.20

None of the stations had any trend for CSDI for 2008-2018 (Appendix 1.1; Figure 8c). Although there was an apparent increase in the number of days for CSDI$_d$ little to no trends were calculated for the study period. The only station that did show a trend was Swakopmund, with an increase of 0.3 days.y^{-1} (Appendix 1.2; Figure 8d).

5.2.5. Cold waves (CWN and CWD)

The indices refer to the following: CWN, the yearly number of cold waves and, CWD, The length of the longest cold wave identified by the CWN. The timescale represented will be indicated at each description as either, for the period (2008-2018), year, or month. For the period 2008-2018, there has been an average of 2 cold waves over Namibia. Hochfeld and Swakopmund are the two stations with the least CWN and had an average of 1 and 2 CWN. Windhoek had an average of 2 cold waves and Kalahari Farmhouse, 2. The station with the highest number of cold waves was Namib Desert Lodge. The average cold wave over Namibia spanned over 4.59 days. Hochfeld had an average CWD of 3.56 days. Swakopmund and Windhoek experienced, on average, 4.65 and 4.33 days of CWD. Namib Desert Lodge had the longest duration of cold waves, 5.3 days. There is a larger duration and number of cold waves to the south of the country (Table 9).

Table 9: The average CWN and CWD for 2008-2018

	ET-SCI	
Station	CWN (number)	CWD (days)
Hochfeld	1.44	3.56
Kalahari Farmhouse	2.20	5.10
Namib Desert Lodge	2.50	5.30
Swakopmund	1.75	4.33
Windhoek	2.05	4.65

Almost all of the stations recorded a decrease in the trend for CWN over the period. The only station that did not experience a decrease was Swakopmund, which had no trend. The other four stations experienced a decrease of > 0.2.y^{-1}. Kalahari Farmhouse experienced a decrease in the trend of 0.25.y^{-1}. The decreasing trend for Hochfeld and Windhoek were calculated at

0.27.y^{-1} and 0.29.y^{-1}. The station with the fastest decrease in the trend for CWN was Namib Desert Lodge at 0.31.y^{-1} (Appendix 1.2; Figure 11a). Only one station experienced an increase in the duration of cold waves. Swakopmund experiences an increase of 0.1 days.y^{-1} for CWD. The other stations experienced a decrease in the trend of CWD of >0.6 days.y^{-1}. A decrease of 0.67 days.y^{-1} were calculated for Kalahari Farmhouse and 0.83 days.y^{-1} for Namib Desert Lodge. Windhoek experienced a decreasing trend of 0.95 days.y^{-1}, and Hochfeld experienced a decreasing trend of 1 days.y^{-1}. There exists a stronger decreasing trend in the central and eastern side of the country and an increasing trend towards the west coast (Appendix 1.2; Figure 11a).

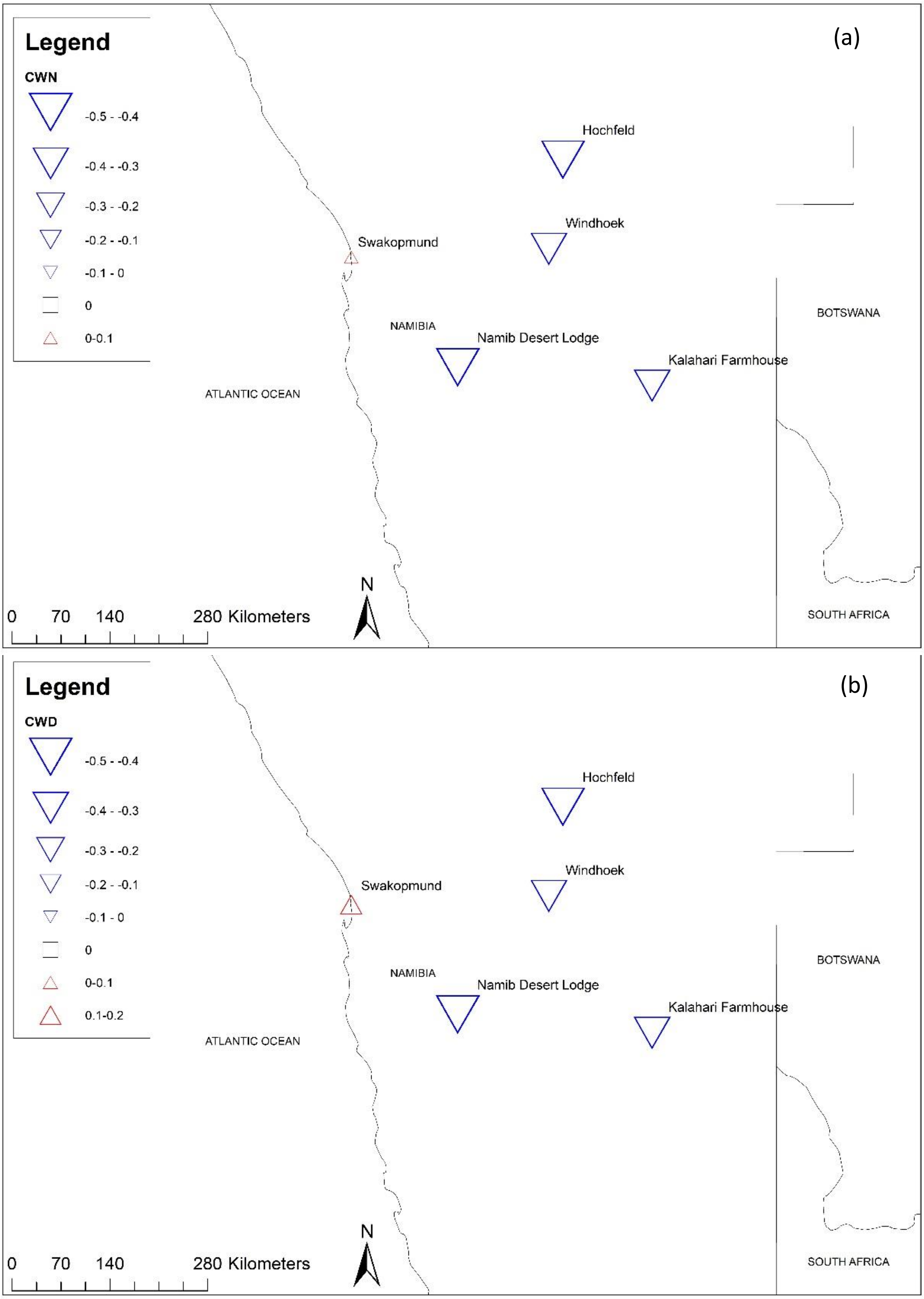


Figure 71: Trends of CWN (a) and CWD (b). Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level.

5.3. Warm events

5.3.1. Mean Maximum temperatures (TXMean)

The indices, TXMean, refers to the mean maximum temperature of a station. The timescale represented will be indicated at each description as either, for the period (2008-2018), year, or month. The average TXMean over Namibia is 24.62°C for the period 2008-2018. TXMean conditions over Namibia range between 25.91°C and 19.15°C. Windhoek experiences temperatures close to the average TXMean, 24.49°C. Swakopmund had the lowest TXMean of 19.15°C. Hochfeld and Kalahari Farmhouse experienced average temperatures of 24.12°C and 25.91°C, respectively. Namib Desert Lodge had the highest TXMean for the period, 29.42°C. There is an apparent increase in the TXMean from the western parts of the country towards the northeast and southeast of the country (Table 10)

Table 10: The average of TXMean for 2008-2018

Station	ETCCDI
	TNMean (°C)
Hochfeld	24.12
Kalahari Farmhouse	25.91
Namib Desert Lodge	29.42
Swakopmund	19.15
Windhoek	24.49

The majority of the stations have increasing trends, with an overall rate increase of 0.13°C.y^{-1}. Windhoek is the only station with a decreasing trend in TXMean, 0.21°C.y^{-1} for the ten years. Swakopmund experienced the slowest increase in trend over the period with 0.04°C.y^{-1}. The TXMean for Hochfeld is calculated at 0.14°C.y^{-1} and 0.32°C.y^{-1} for Namib Desert Lodge. Kalahari Farmhouse experienced an increasing trend in TXMean of 0.39°C.y^{-1} (Appendix 1.3; Figure 12a). From the west coast towards the northeast and the southeast, there is an increasing pattern in the trend for TXMean.

In summer, four of the five stations are increasing in TXMean and have an average increasing rate of 0.29°C.y^{-1}. Windhoek is calculated to have had no trend throughout the ten years. Hochfeld and Namib Desert Lodge have the fastest increasing trend. Hochfeld experienced an increasing trend of 0.54°C.y^{-1} and Namib Desert Lodge an increase of 0.46°C.y^{-1}. Swakopmund has the lowest rate of increase at 0.07°C.y^{-1} (Appendix 1.10; Figure 13a). During autumn, Hochfeld, Namib Desert Lodge and Windhoek increased at a rate of >0.10°C.y^{-1}. Swakopmund is decreasing at a rate of 0.10°C.y^{1-}. Namib Desert Lodge experienced an increasing rate of 0.36°C.y^{-1}, while Windhoek experienced an increase of 0.22°C.y^{-1} (Appendix 1.10; Figure 13b). Swakopmund was the only station to have a negative trend of 0.07°C.y^{-1} during winter. The rest of the stations increased at an average rate of 0.22°C.y^{-1}. Kalahari Farmhouse has a statistically significant increasing trend of 0.58°C.y^{-1} (Appendix 1.10; Figure 13c). All the stations experienced an average increase of 0.45°C.y^{1-} for spring, with Hochfeld having the fastest rate of increase, 1.86°C for 2008-2018. The other stations did not experience an increase of> 0.2°C.y^{-1} (Appendix 1.10; Figure 13b). Namib Desert Lodge had the lowest increase in trend of 0.02°C.y^{-1}. The fastest increase in trends is towards the southeast and northeastern parts of Namibia.

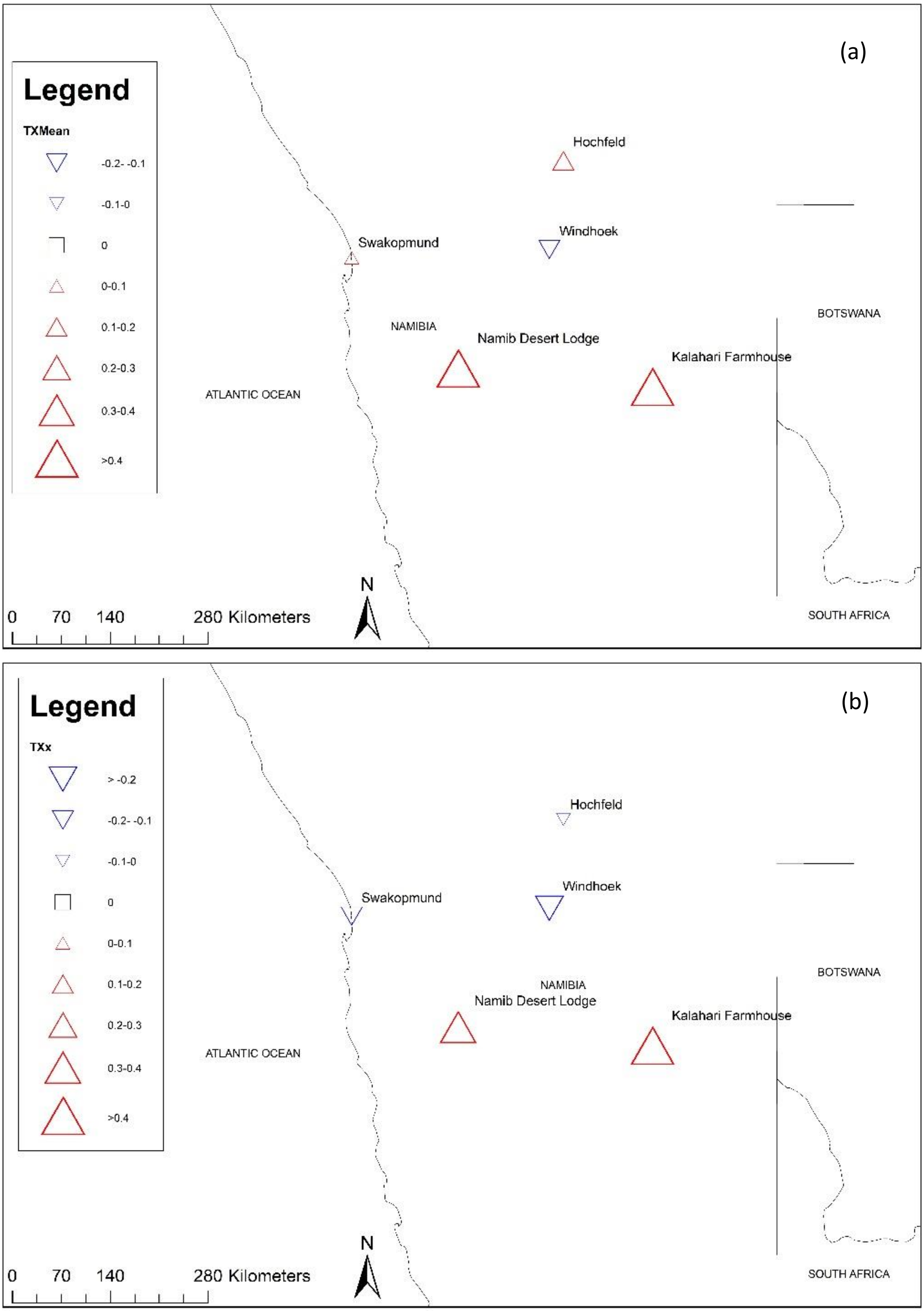


Figure 12: Trends of TXMean (a), and TXx (b). Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level

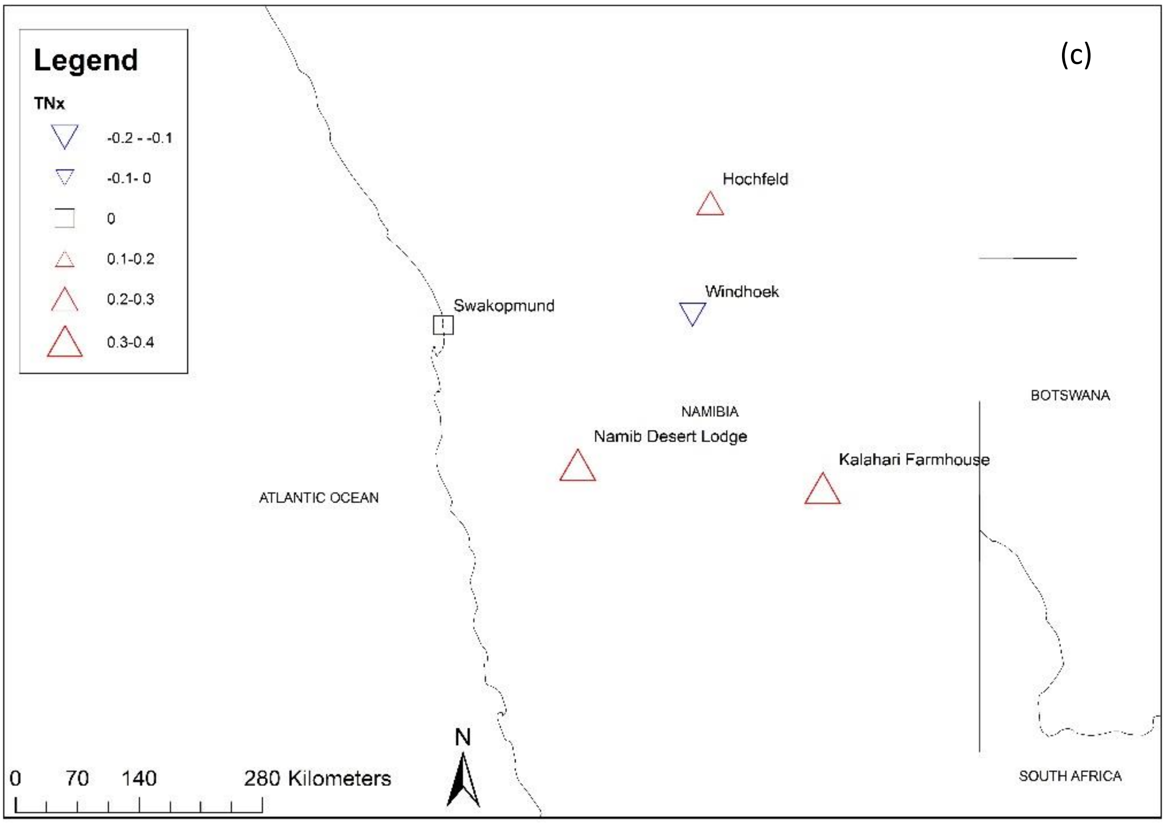


Figure 12: Trends of TXMean TNx (c). Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level.

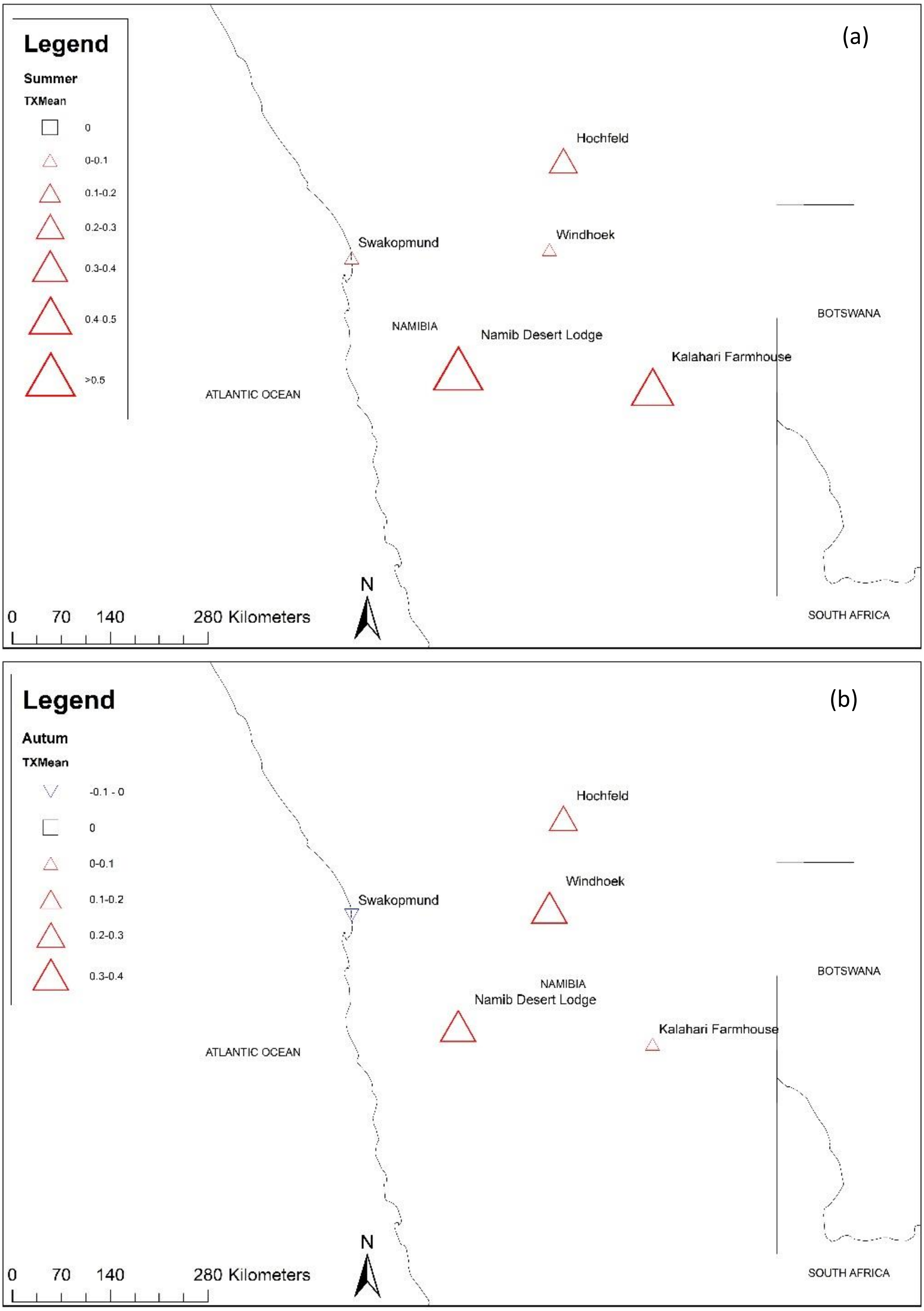


Figure 13: Seasonal trends of TXMean (a) Summer, and (b) Autumn. Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level

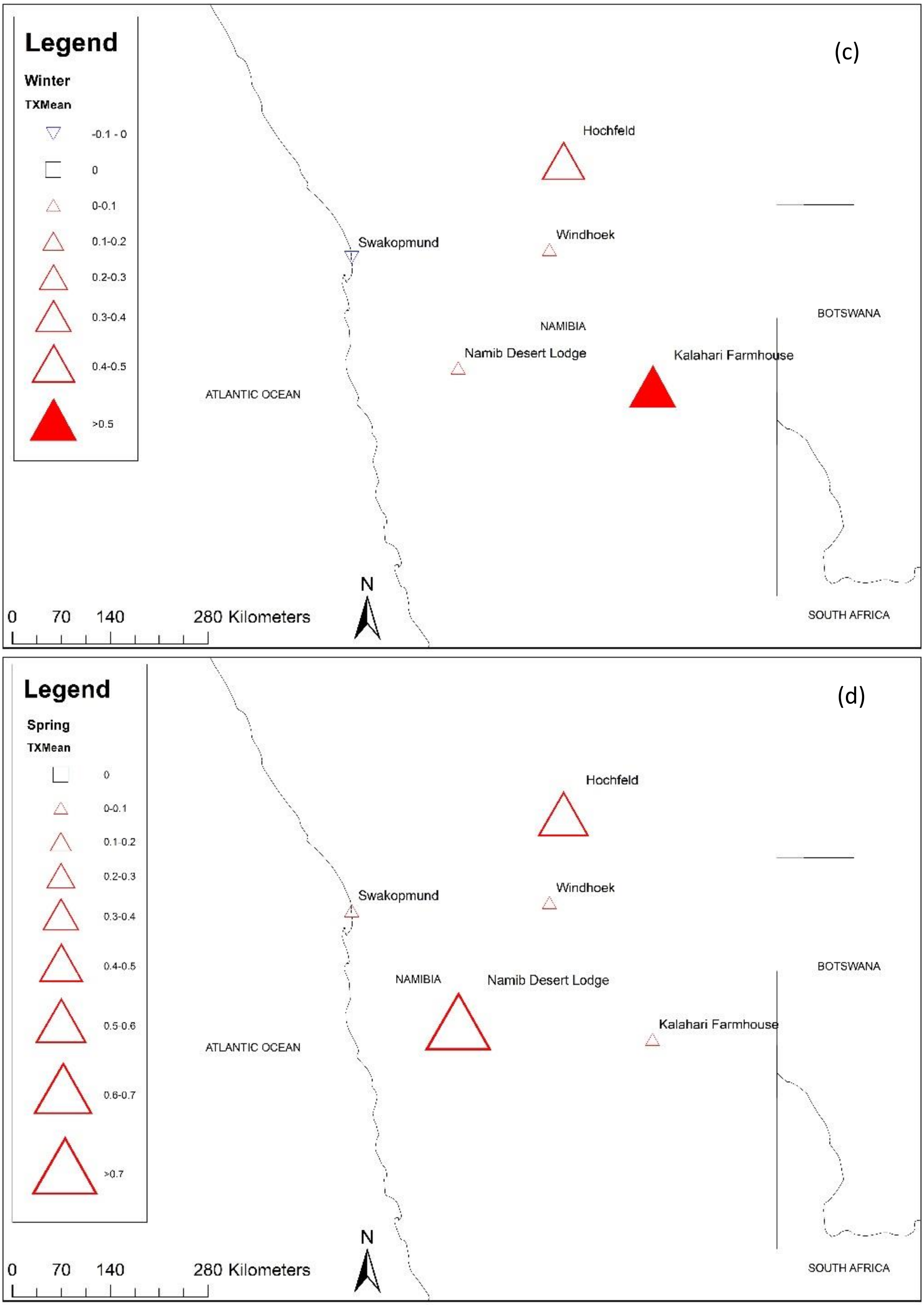


Figure 13: Seasonal trends of TXMean (c) Winter, and (d) Spring. Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level.

5.3.2. Warmest day (TXx) and Warmest night (TNx)

The indices refer to the following: TXx, the maximum daily maximum temperature for each month, and TNx, the minimum daily maximum temperature for each month. The timescale represented will be indicated at each description as either, for the period (2008-2018), year, or month. The average TXx for Namibia was 29.03°C for 2008-2018, with all of the stations experiencing an average TXx of >26°C. Swakopmund is below the average TXx at 26.39°C for the period. The highest average TXx was recorded for Namib Desert Lodge, 33.82°C. Hochfeld, and Windhoek recorded similar TXx, 27.51°C and 27.43°C. The average TXx for Kalahari Farmhouse was 29.99°C. The average TNx experienced by the stations were all >14°C with an average over Namibia of 16.66°C. Hochfeld recorded the lowest average TNx of 14.64°C. The average TNx for Windhoek was 15.27°C and 16.36°C for Kalahari Farmhouse. Swakopmund experienced an average TNx of 16.64°C, and Namib Desert Lodge recorded the highest average TNx of 20.38°C between 2008-2018. There is an increasing trend in the moving towards the country's southeast (Table 7).

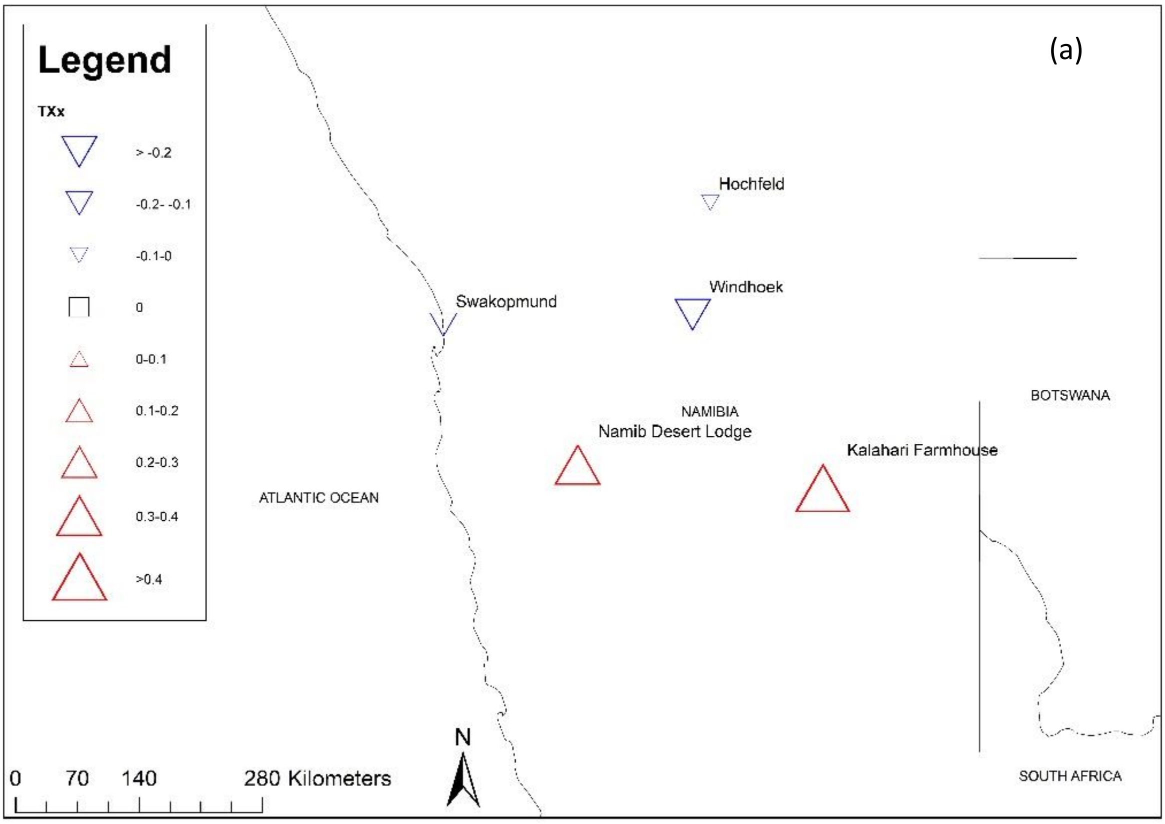
Table 11: The average of TXx and TXn for 2008-2018

Station	ETCCDI	
	TX_x (°C)	TN_x (°C)
Hochfeld	27.51	14.64
Kalahari Farmhouse	29.99	16.35
Namib Desert Lodge	33.82	20.38
Swakopmund	26.39	16.64
Windhoek	27.43	15.27

Almost all stations experienced an increasing trend over TXx, with an average increase of $0.07.y^{-1}$ for Namibia. Windhoek and Swakopmund were the only stations to experience a decrease of 0.30°C.y^{-1} and 0.08°C.y^{-1} with Windhoek recording the fastest decreasing trend over the period. Hochfeld recorded the lowest increasing trend of 0.01°C.y^{-1}, and Namib Desert Lodge recorded an increase of 0.27°C.y^{-1}. The fastest increasing trend was recorded in Kalahari Farmhouse, and the station experienced an increase in TNx of 0.43°C.y^{-1} (Appendix 1.3; Figure 14a). Only three of the five stations experienced an increase in the TNx trend, with an average over Namibia of 0.08°C.y^{-1}. Only one station experienced a decreasing trend in TNx and recorded a decrease of 0.11°C.y $^{-1}$ for Windhoek. Swakopmund recorded no trend in the TNx, while Hochfeld recorded an increase of 0.05°C y^{-1}. The recorded increase in the trend for Kalahari Farmhouse was 0.07°C.y^{-1}. The fastest recorded increase in trend was in the southeastern part of the country at Namib Desert Lodge, which experienced an increase of 0.39°C.y^{-1} for 2008-2018 (Appendix 1.3; Figure 14b).

Only one station recorded no trend for TXx for summer. Windhoek recorded no trend for the ten years. Swakopmund experienced an increase of 0.12°C.y^{-1} while Hochfeld, Kalahari Farmhouse and Namib Desert Lodge all recorded an increase of >0.4°C.y^{-1}. Similar TXx were experienced in Namib Desert Lodge and Kalahari Farmhouse. Hochfeld recorded an increase in TXx trend at 0.51°C.y^{-1} (Appendix 1.11; Figure 15a). During autumn, four stations experienced an increase in TXx. Namib Desert Lodge and Windhoek recorded an increase of 0.39°C.y^{-1} and 0.26°C.y^{-1}. Kalahari Farmhouse recorded an increase of 0.08°C.y^{-1}, which is the lowest over the ten years. (Appendix 1.11; Figure 15b). Namib Desert Lodge was the only station to record a decreasing trend of 0.02°C.y^{-1} in TXx for winter. Swakopmund experienced an increase of 0.08°C.y$^{-1,}$ and Windhoek experienced no trend for the period. Hochfeld recorded an increase of 0.11°C.y$^{-1,}$ and Kalahari Farmhouse recorded an increase of 0.59°C.y^{-1} (Supporting Table 11; Figure 15c). All the stations recorded an increasing trend with an average over Namibia of 0.48°C.y^{-1} for winter. The slowest increase was recorded in Swakopmund, 0.06°C.y^{-1} and Namib Desert Lodge, 0.1°C.y^{-1}. Windhoek and Kalahari Farmhouse experienced increases of 0.12°C.y^{-1} and 0.11°C.y^{-1}. Hochfeld recorded an increase in TXx of 2.02°C.y^{-1} (Appendix 1.11; Figure 15d). The northeast and southwest of the country experience the fastest increasing trends.

During Summer, four of the five stations experienced an increasing trend in TNx. Swakopmund was the only station to record a decrease in the trend of 0.02°C. y^{-1}. Namib Desert Lodge recorded an increase in trend with only 0.04°C. y^{-1}. Kalahari Farmhouse and Hochfeld experienced an increase of 0.07°C.y^{-1} and 0.15°C.y^{-1}. The fastest increase in TNx trend was recorded in Windhoek, 0.2°C.y^{-1} (Appendix 1.12; Figure 16a). Four of the stations recorded an increase in the TNx trend for autumn. Swakopmund was the only station with a decrease of 0.27°C.y^{-1}. Windhoek recorded an increase of 0.09°C.y^{-1}, while Hochfeld experienced an increase of 0.24°C.y^{-1}. Kalahari Farmhouse recorded an increase of 0.42°C.y^{-1}. Namib Desert Lodge experienced the fastest increase in the TXn trend for autumn, 0.63°C.y^{-1} (Appendix 1.12; Figure 16b). Three of the five stations experienced an increase in the TXn trend for winter. Windhoek and Namib Desert Lodge recorded a decrease of 0.21°C.y^{-1} and 0.15°C.y^{-1}. Kalahari Farmhouse was the station with the slowest increasing trend of 0.03°C.y^{-1} while Hochfeld recorded an increase of 0.48°C.y^{-1} (Appendix 1.12; Figure 16c). In spring, only Windhoek experienced a decrease in TNx of 0.0°C.y^{-1}. Namib Desert Lodge recorded an increase of 0.2°C.y$^{-1,}$ and Swakopmund recorded an increase of 0.12°C.y^{-1}. Hochfeld experienced the an increase in the trend, with 1.38°C.y^{-1}. There is a stronger increase in trends from central Namibia towards the northeast of the country (Appendix 1.12; Figure 16d).



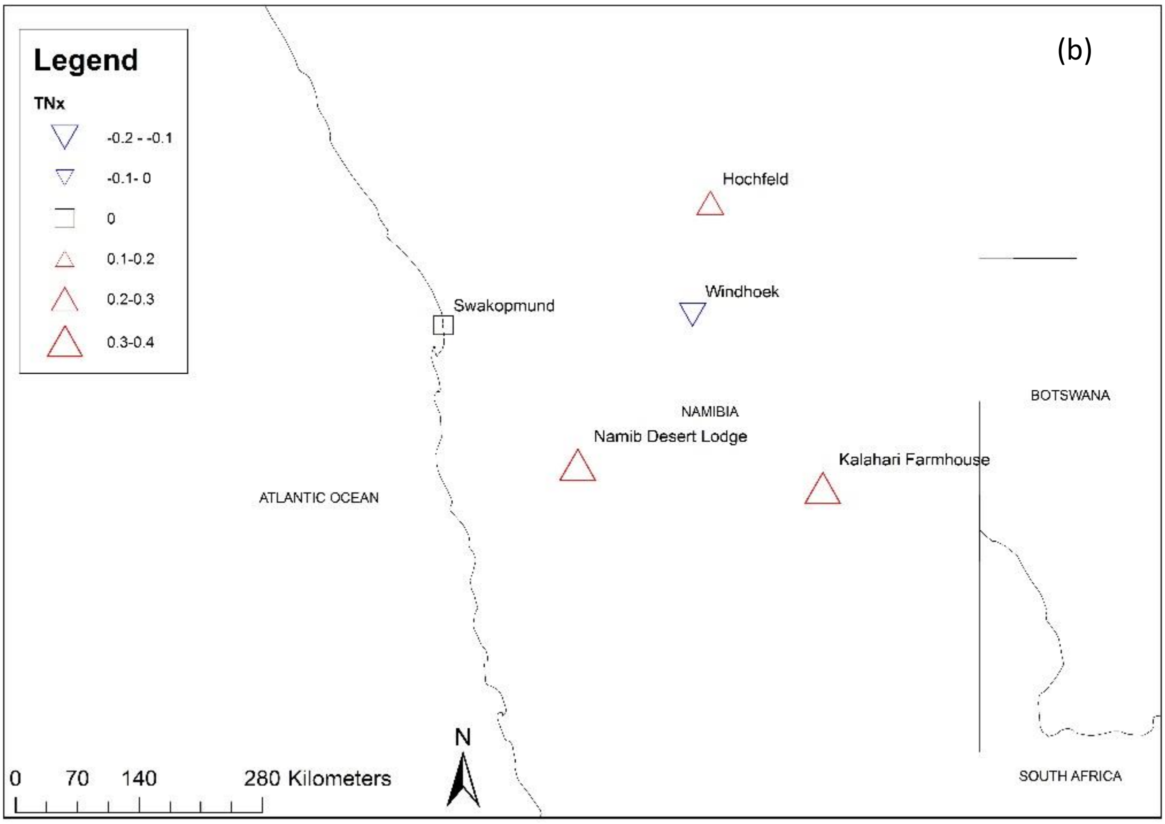


Figure 14: Trends of TXx (a), and TNx (b). Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level

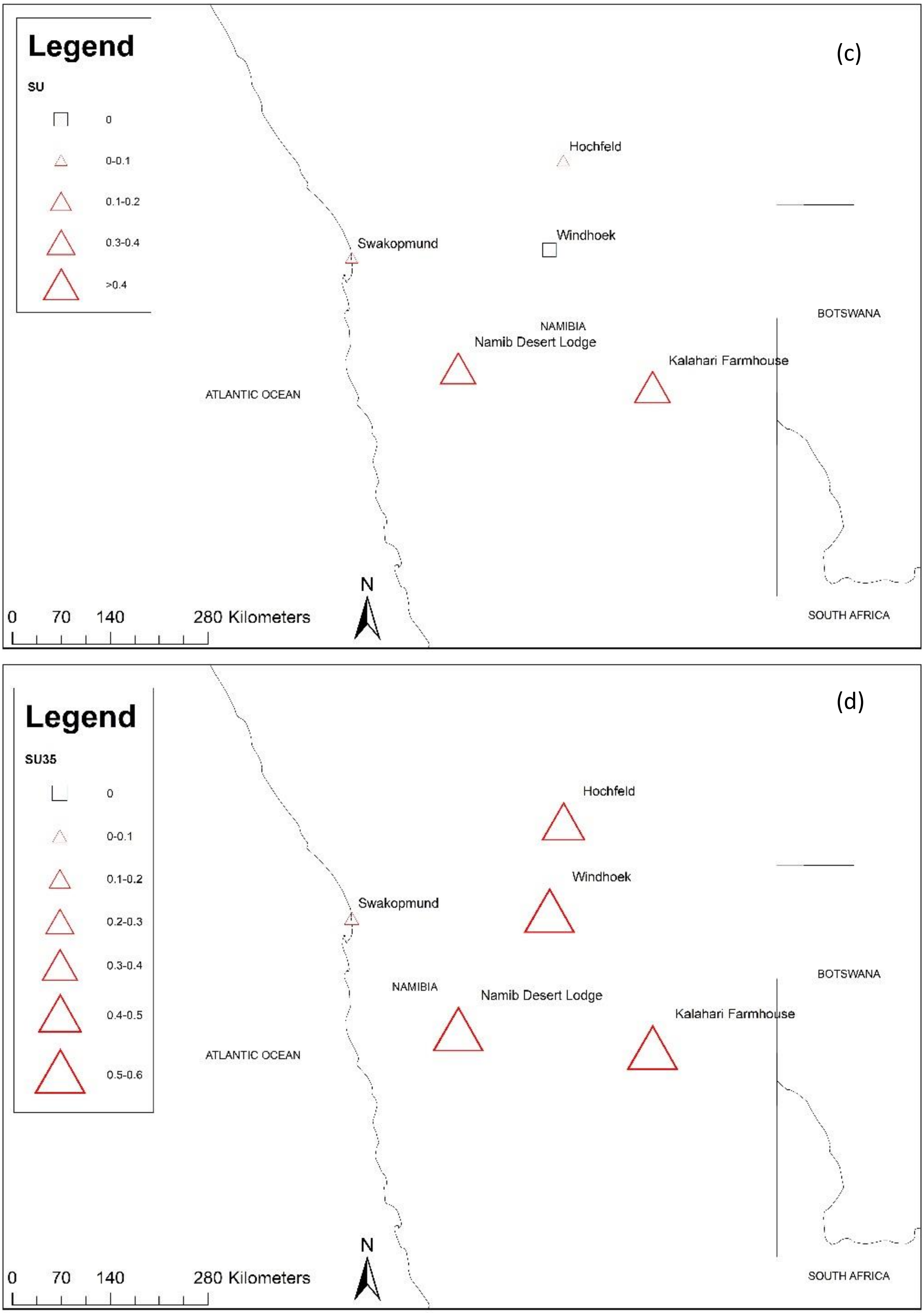


Figure 14: Trends of SU (c), and SU35 (d). Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level.

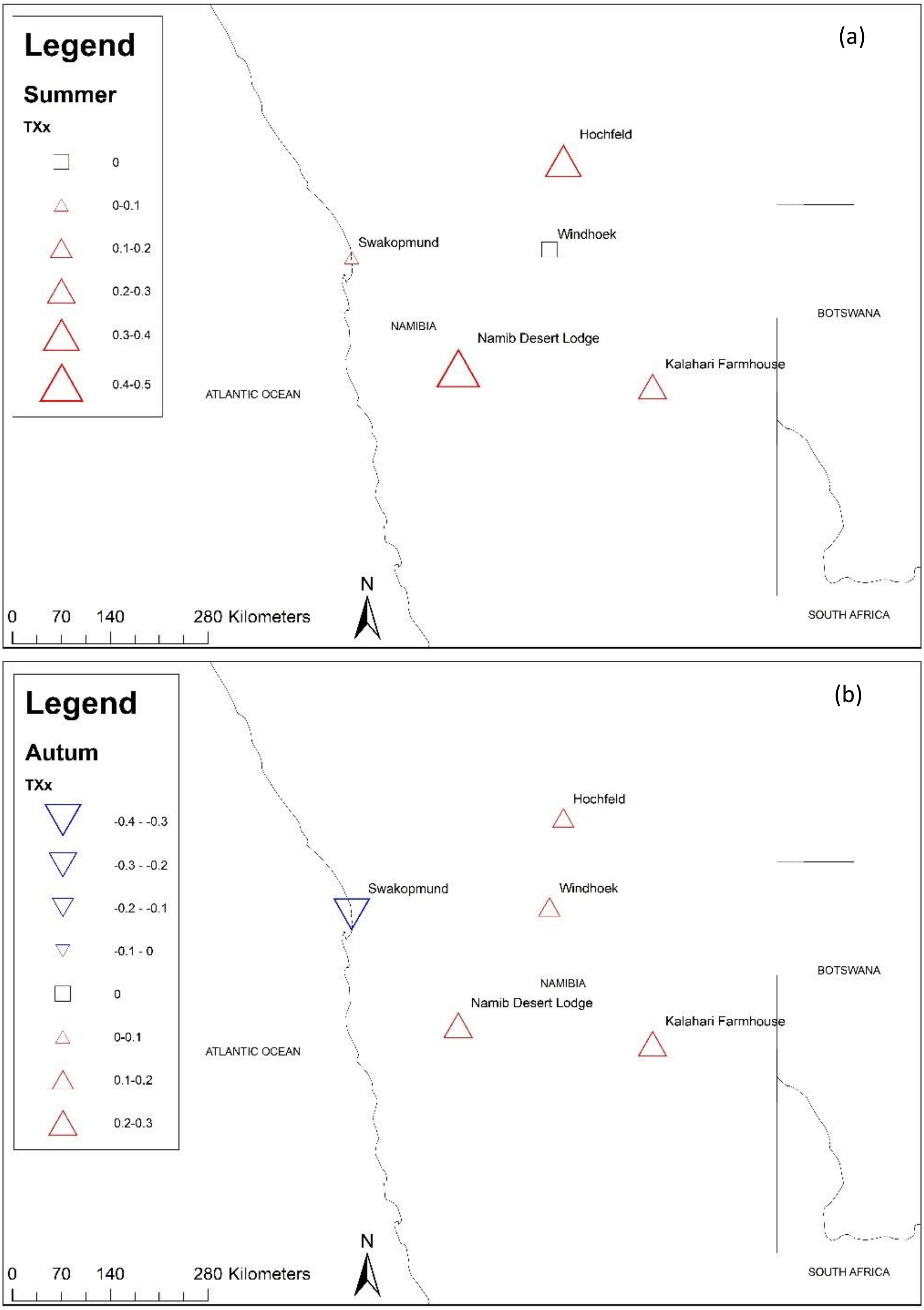
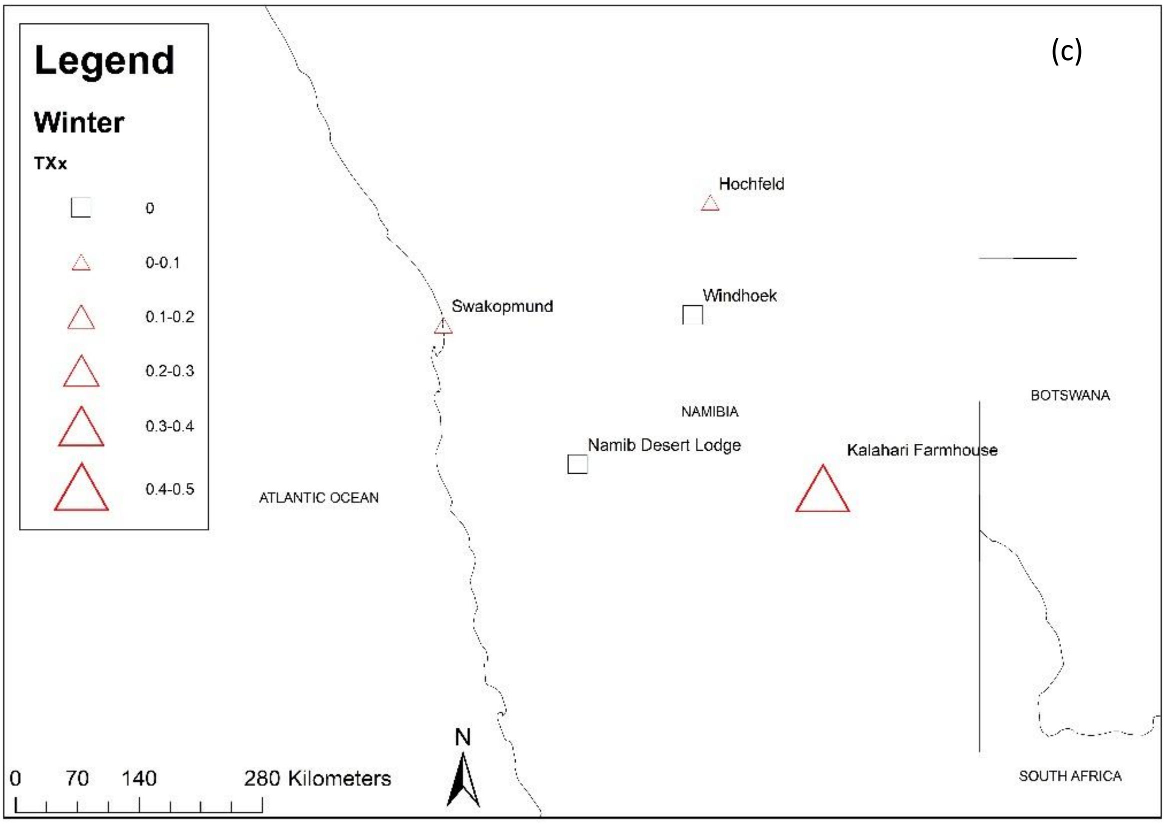


Figure 15: Seasonal trends of TXx (a) Summer, and (b) Autumn. Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level



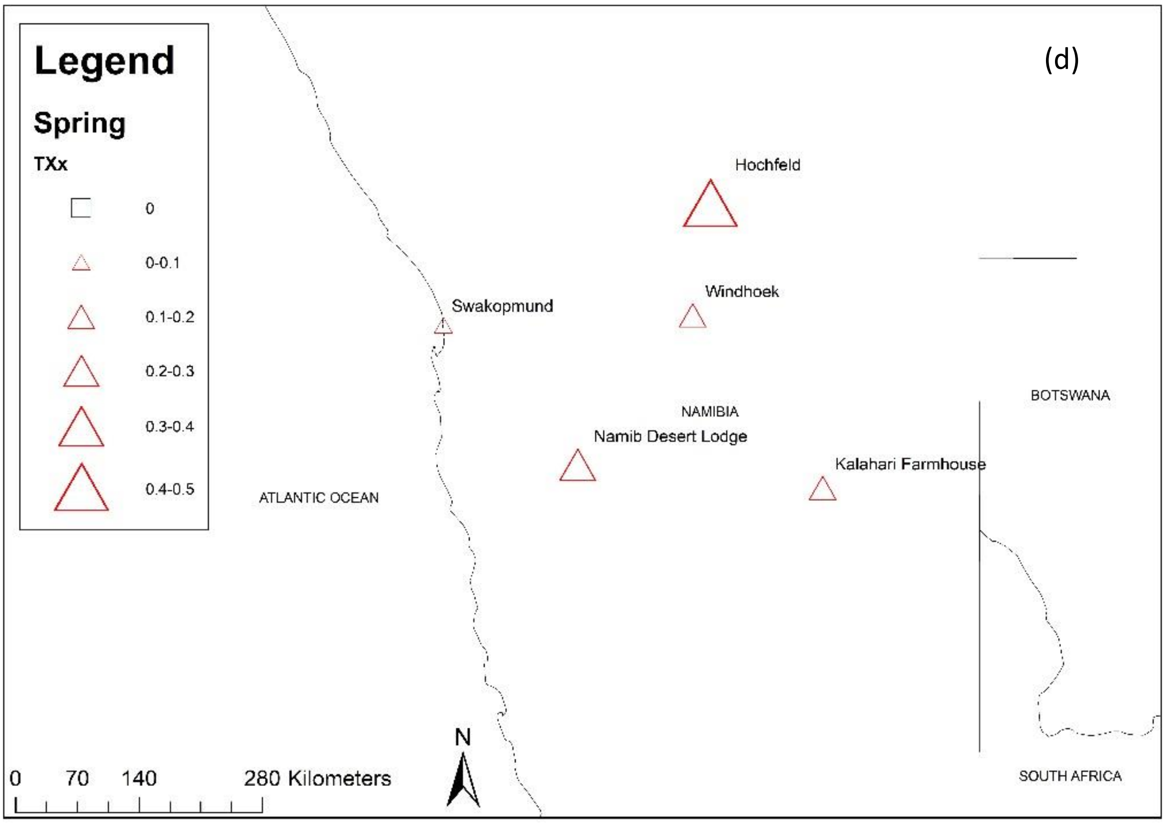


Figure 15: Seasonal trends of TXx (c) Winter, and (d) Spring. Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level.

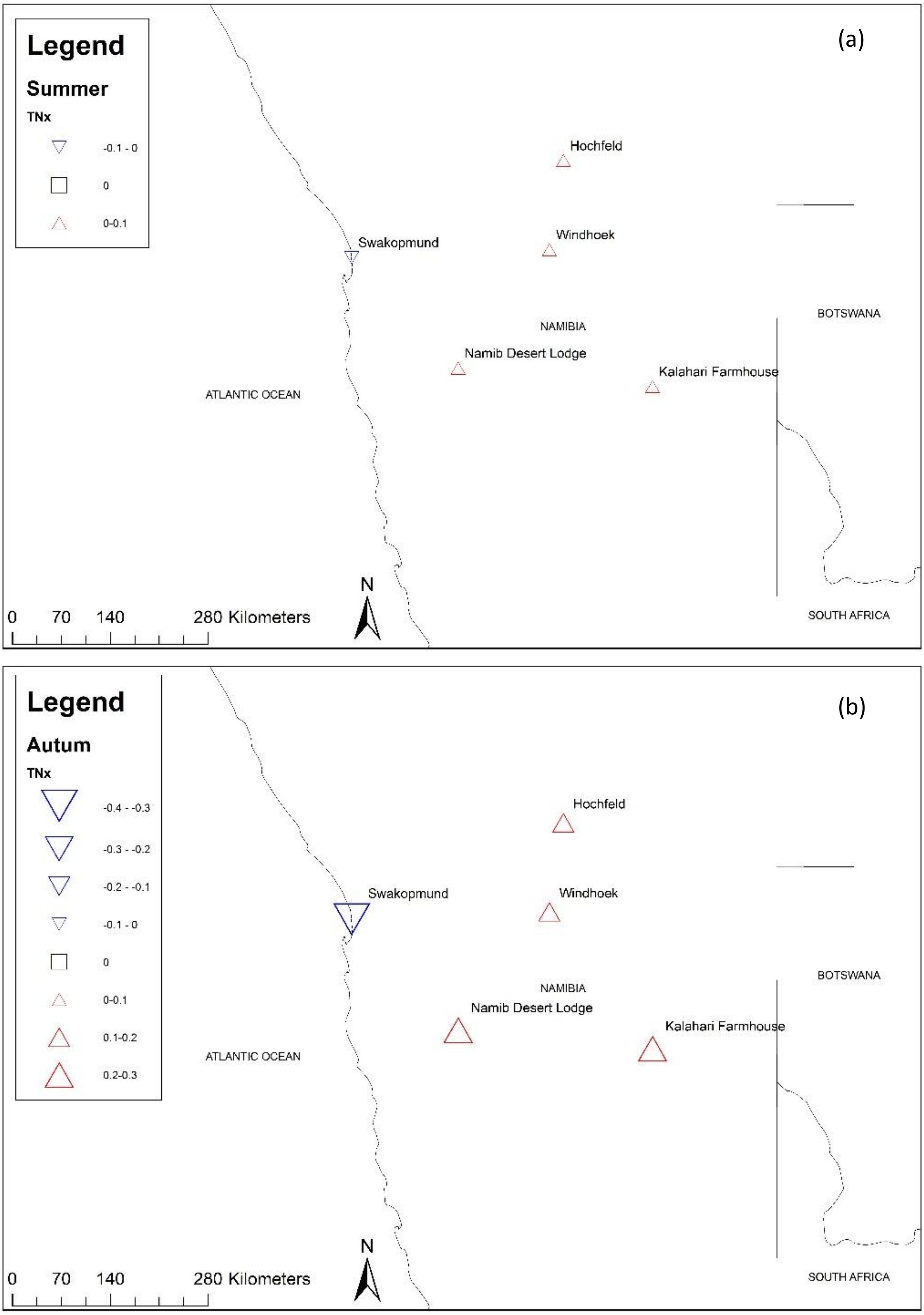


Figure 16: Seasonal trends of TNx (a) Summer, and (b) Autumn. Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level

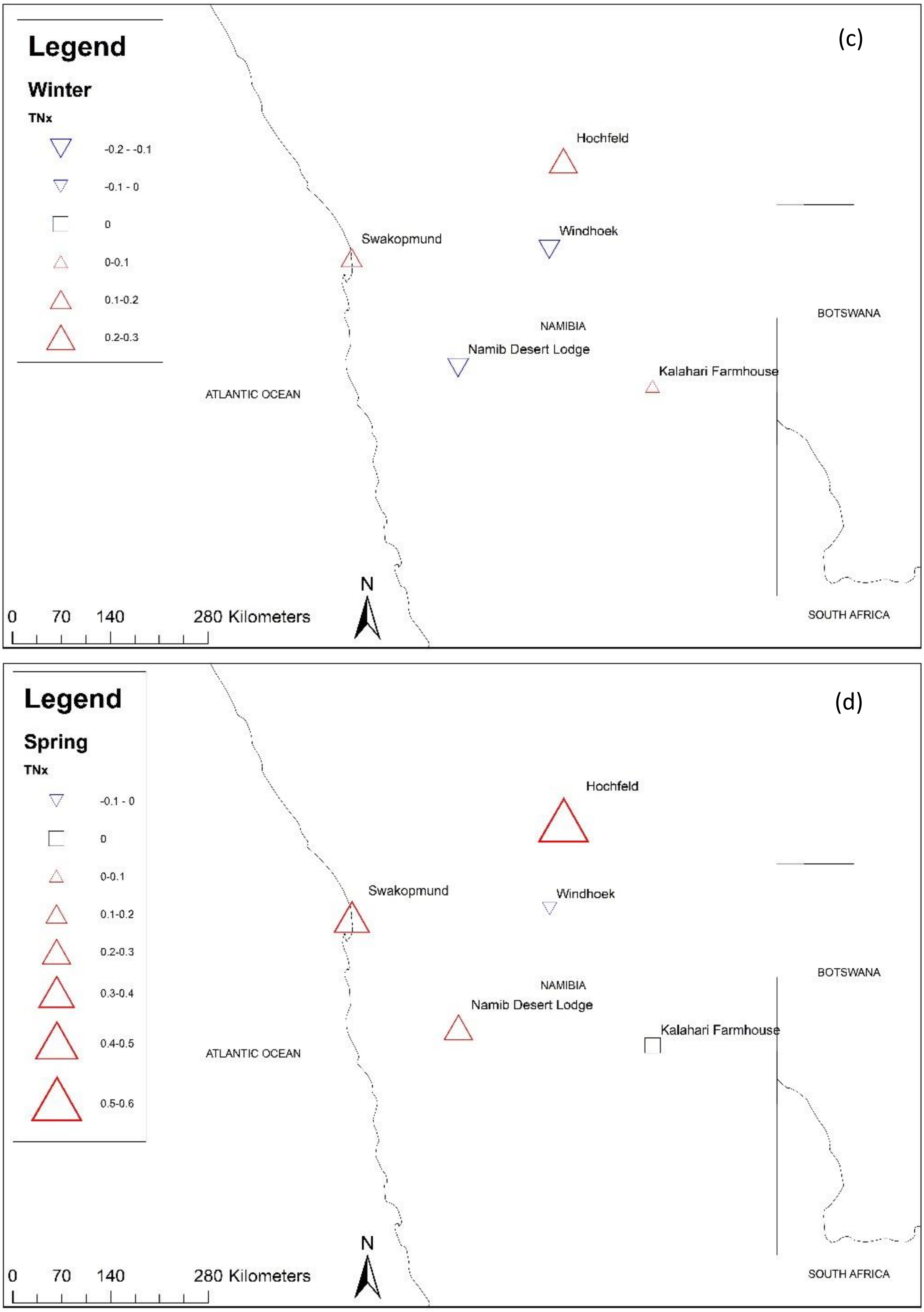


Figure 16: Seasonal trends of TNx (c) Winter, and (d) Spring. Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level.

5.3.3. Summer Days and very hot days (SU and SU35)

The indices refer to the following: SU, the yearly number of days where daily maximum is above 25 °C, and SU35, the number of days where the maximum temperature (TX) is above 35°C. The timescale represented will be indicated at each description as either, for the period (2008-2018), year, or month. Namibia experienced 99 SU days on average for the ten year study period. Swakopmund had an average of 15 days, and Windhoek an average of 25 days. An average of 32 SU days was experienced in Hochfeld. Kalahari Farmhouse had 183 days and is the second- highest of the stations. The Station with the most SU days were Namib Desert Lodge, with an average of 241 days. The average number of SU35 days for Namibia is 48, with only 3 days of SU35 in Swakopmund. Hochfeld experienced 62 days of SU35, and Namib Desert Lodge Had the highest number of SU35 at 68 days (Table 12).

Table 12: The average of SU and SU35 for 2008-2018

	ETCCDI	ET-SCI
Station	SU (days)	SU35 (days)
Hochfeld	32.00	62.44
Kalahari Farmhouse	182.90	47.40
Namib Desert Lodge	241.22	67.50
Swakopmund	15.25	3.33
Windhoek	25.27	59.11

Only two of the five stations had any trend over the study period for SU. Windhoek, Swakopmund and Hochfeld experienced no trend, while Namib increased 2.67 days.y^{-1}. Kalahari Farmhouse experienced an increasing trend of 11.12 days.y^{-1} (Appendix 1.3; Figure 14c). All of the stations had an increasing trend for SU35, with an average of 5.52 days.y^{-1}. The stations that had the lowest increasing trend was Swakopmund with 0.14 days.y^{-1}. Hochfeld and Namib Desert Lodge had an increase of 5.38 days.y^{-1} and 5.5 days.y^{-1}. Windhoek experienced an increase of 7.35 days.y^{-1} and Kalahari Farmhouse experienced an increasing trend of 9.23 days.y^{-1} (Appendix 1.4; Figure 14d). There is an overall increasing trend across the stations, with the fastest trends seen in Namibia's central, northeast and southeastern parts.

5.3.4. Warm days (TX90p) and warm night (TN90p)

The indices refer to the following: TX90p, the percentage of warm days where the maximum temperature is above the 90th percentile, and TN90p, the percentage of warm nights where the minimum temperature is above the 90th percentile. The timescale represented will be indicated at each description as either, for the period (2008-2018), year, or month. Namibia experienced an average of 13.45% days of TX90p. All stations experienced a TX90p of > 10%, with Swakopmund experiencing the lowest percentage of 10.66%. Kalahari Farmhouse recorded 10.74% and Namib Desert Lodge 13.20% of TX90p for 2008-2018. Hochfeld experienced the highest percentage of TX90p, 17.19%. The TN90p is higher than TX90p with an average of 15.86%. Similar to the results of TX90p, Kalahari Farmhouse experienced the lowest percentage of TN90p, 10.55%. Namib Desert Lodge and Swakopmund recorded averages of > 11% and Windhoek at 20.22%. Hochfeld also experienced the highest percentage of TN90p with an average percentage of 23.81%. There is an increase in TN90p and TX90p from central Namibia towards the northeast and southeast of the country, decreasing towards the west coast and the southwest (Table 13).

Table 13: The average of TX90p and TN90p for 2008-2018.

Station	ETCCDI	
	TX90p (%)	TN90p (%)
Hochfeld	17.19	23.81
Kalahari Farmhouse	10.74	10.55
Namib Desert Lodge	13.20	12.80
Swakopmund	10.66	11.92
Windhoek	15.47	20.22

There is an average increase in the TX90p for Namibia of 1.10% days.y^{-1} from 2008-2018. All the stations experience an increase. Hochfeld recorded the an increase in TX90p of 2.25% days.y^{-1} and Swakopmund the lowest increase of 0.02% days.y^{-1}. Windhoek recorded an increase of 1.25% days.y^{-1} while Namib Desert Lodge was experiencing an increase of 0.69% days.y^{-1}. Kalahari Farmhouse is the only station that had a statistically significant increase of 1.29% days.y^{-1} (Appendix 1.3; Figure 17a). The average increase in TN90p for Namibia was 1.36% days.y^{-1}. Only Swakopmund experienced a decrease in TN90p of 0.71% days.y^{-1}. Namib Desert Lodge experienced a statistically significant increase of 1.79% days.y^{-1}. Windhoek and Kalahari Farmhouse had an increase of >1.1% days.y^{-1} while Hochfeld experienced an increase of 3.03% days.y^{-1}.The fastest decrease in TX90p was recorded at Hochfeld. The decreasing trend becomes weaker when moving towards the west coast and stronger towards the north, east and southern parts of the county (Appendix 1.3; Figure 17b).

For summer, four of the five stations recorded an increase in TX90p of > 0.8% days.y^{-1}. An increasing trend was recorded for Namib Desert Lodge, 0.97% days.y^{-1} and at Windhoek, 0.81% days.y^{-1}. Swakopmund was the only station that experienced a decrease in TX90p of

0.02% days.y^{-1}. Kalahari Farmhouse had an increase of 1.24% days.y^{-1}. Hochfeld experienced an increasing trend of 2.59% days.y^{-1} (Appendix 1.13; Figure 18a). Swakopmund is the only station that recorded a decreasing trend for TX90p of 0.26% days.y^{-1} during autumn. The other stations experienced an increasing trend of > 0.6% days.y^{-1} with Windhoek recording the lowest decrease of 0.61% days.y^{-1}. Kalahari Farmhouse and Namib Desert Lodge recorded an increase of > 0.8% days.y^{-1}. The fastest increasing trend was recorded at Hochfeld, 1.42% days.y^{-1} (Appendix 1.13; Figure 18b). All stations experienced an increasing trend for winter for TX90p with an average of 1.09% days.y^{-1} for 2008-2018. Hochfeld recorded an increase of 2.39% days.y^{-1} while Kalahari Farmhouse and Swakopmund recorded a decrease of >0.5% days.y^{-1}. Namib Desert Lodge had the lowest increase of 0.39% days.y^{-1} and Windhoek had an increase of 1.43% days.y^{-1} (Appendix 1.13; Figure 18c) During spring, only Windhoek and Hochfeld experienced an increase in the TX90p of 1.68% days.y^{-1} and 3.78% days.y^{-1}. Swakopmund had a decrease of 0.02% days.y^{-1}. Namib Desert Lodge decreased by 0.2% days.y^{-1} while Kalahari Farmhouse decreased with the most by 0.6% days.y^{-1} (Appendix 1.13; Figure 18d). An increasing trend towards the northeast and southeast of the country is prominent.

In summer, Swakopmund was the only station to experience a decrease in the TX90p trend for 2008-2018. Windhoek recorded an increasing trend of 1.44% days.y^{-1} while Hochfeld and Namib Desert Lodge experienced an increase of > 1.3% days.y^{-1}. Kalahari Farmhouse experienced an increasing trend 1.89% days.y^{-1}(Appendix 1.14; Figure 19a). Only four stations recorded an increase in the average TN90p for autumn. The only station with a decreasing trend was Swakopmund, 0.9% days.y^{-1}. The two stations with the slowest increase were Namib Desert Lodge, 1.03% days.y^{-1} and Kalahari Farmhouse, 1.21% days.y^{-1}. Windhoek experienced an increasing trend of 1.46% days.y^{-1}. The fastest increase in the trend was recorded in Hochfeld, 3.4% days.y^{-1}. (Appendix 1.14; Figure 19b). All the stations recorded an average increase of 1.41% days.y^{-1} in the TN90p trend for winter. Kalahari Farmhouse experienced the lowest increase of 0.17% days.y^{-1} and Swakopmund the second-lowest trend of 0.38% days.y^{-1}. An increase of 0.69% days.y^{-1} was experienced in Windhoek. The fastest increasing trend was recorded for Hochefeld, 2.97% days.y^{-1}. Namib Desert Lodge experienced a statistically significant increase of 2.59% days.y^{-1} (Appendix 1.14; Figure 19c). In spring, all the stations increased the TN90p with an average trend of 1.49% days.y^{-1}. Only two stations recorded an increase >1% days.y^{-1} for spring. Swakopmund, 0.52% days.y^{-1} and Kalahari Farmhouse, 0.91% days.y^{-1}. Hochfeld experienced an increase of 3.12% days.y^{-1}. The spatial patterns suggest a stronger decrease from the southwest to the northeast of the country (Appendix 1.14; Figure 19d).

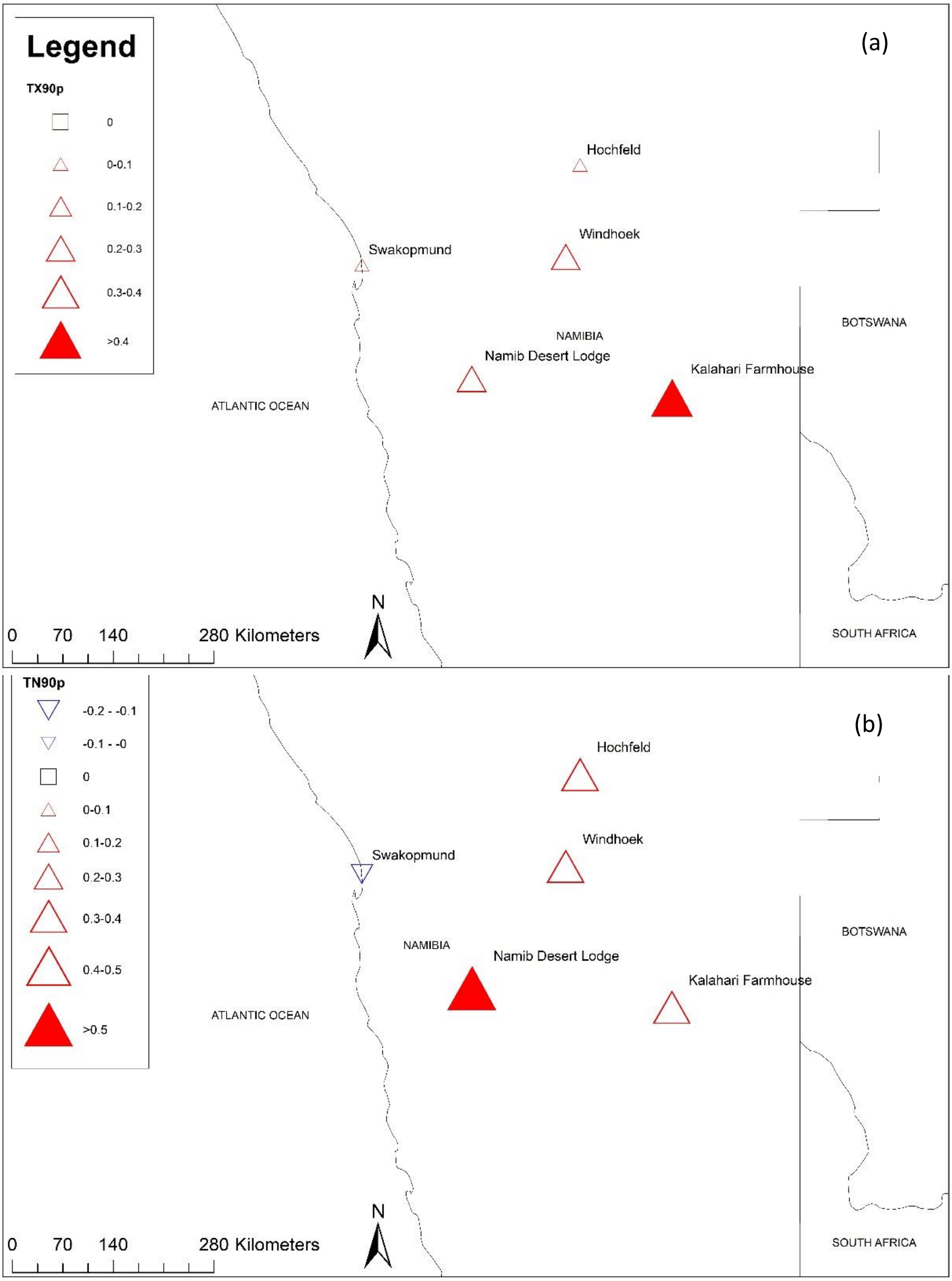


Figure 17: Trends of TX90p (a) and TN90p(b). Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level.

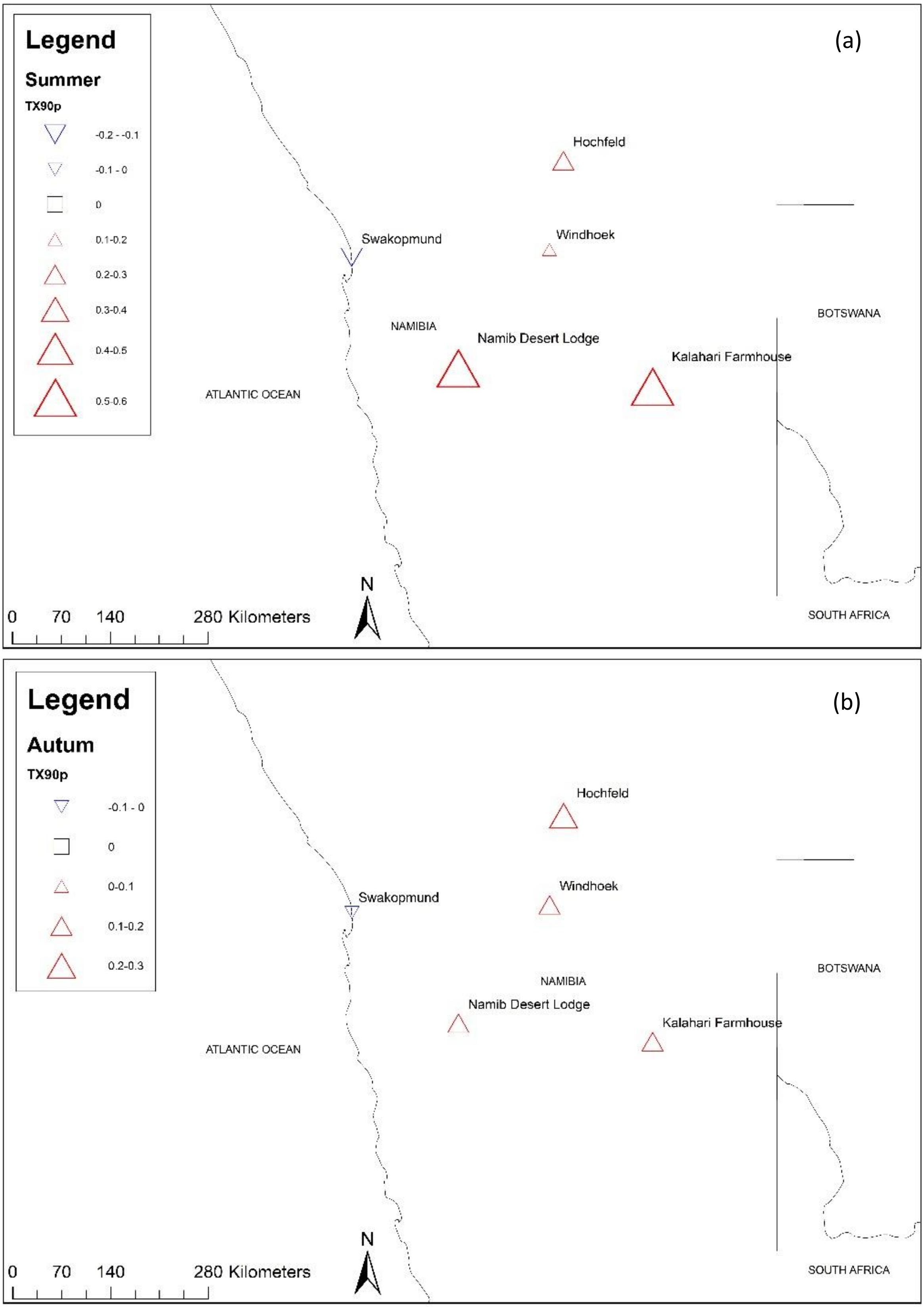
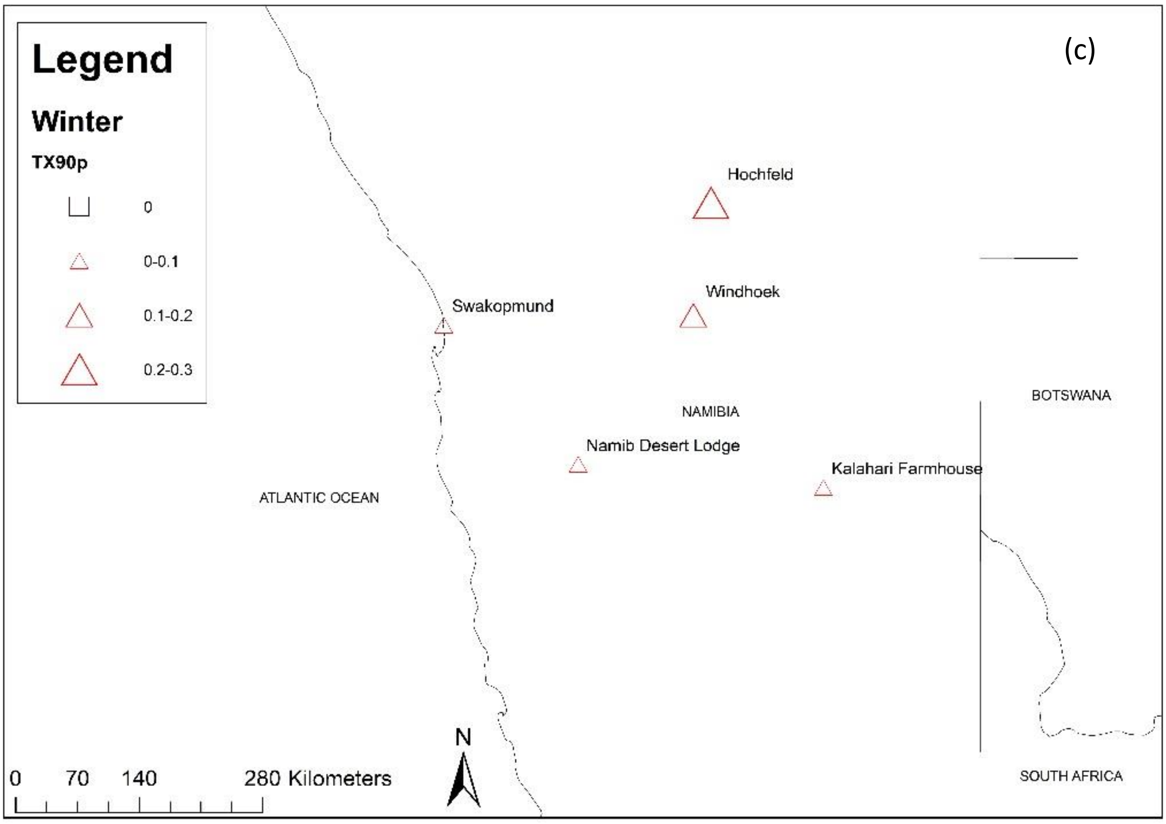


Figure 18: Seasonal trends of TN90px (a) Summer, and (b) Autumn. Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level.



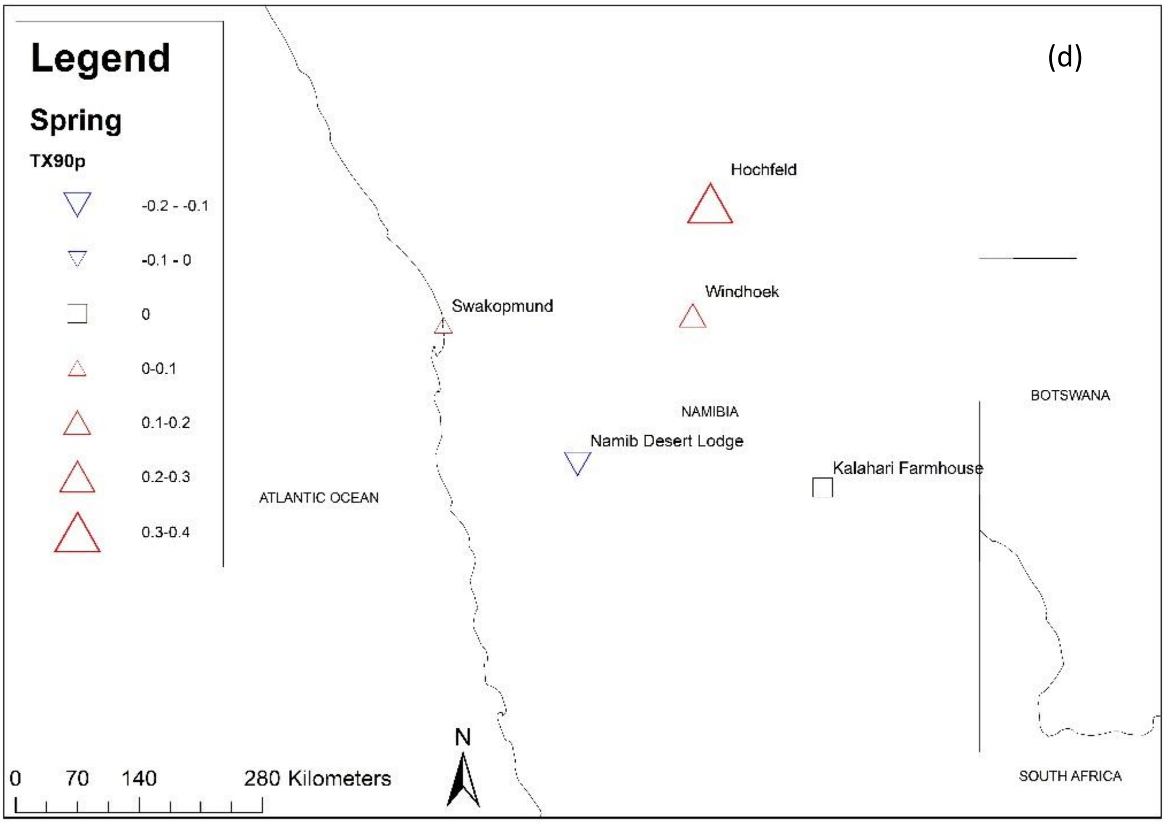
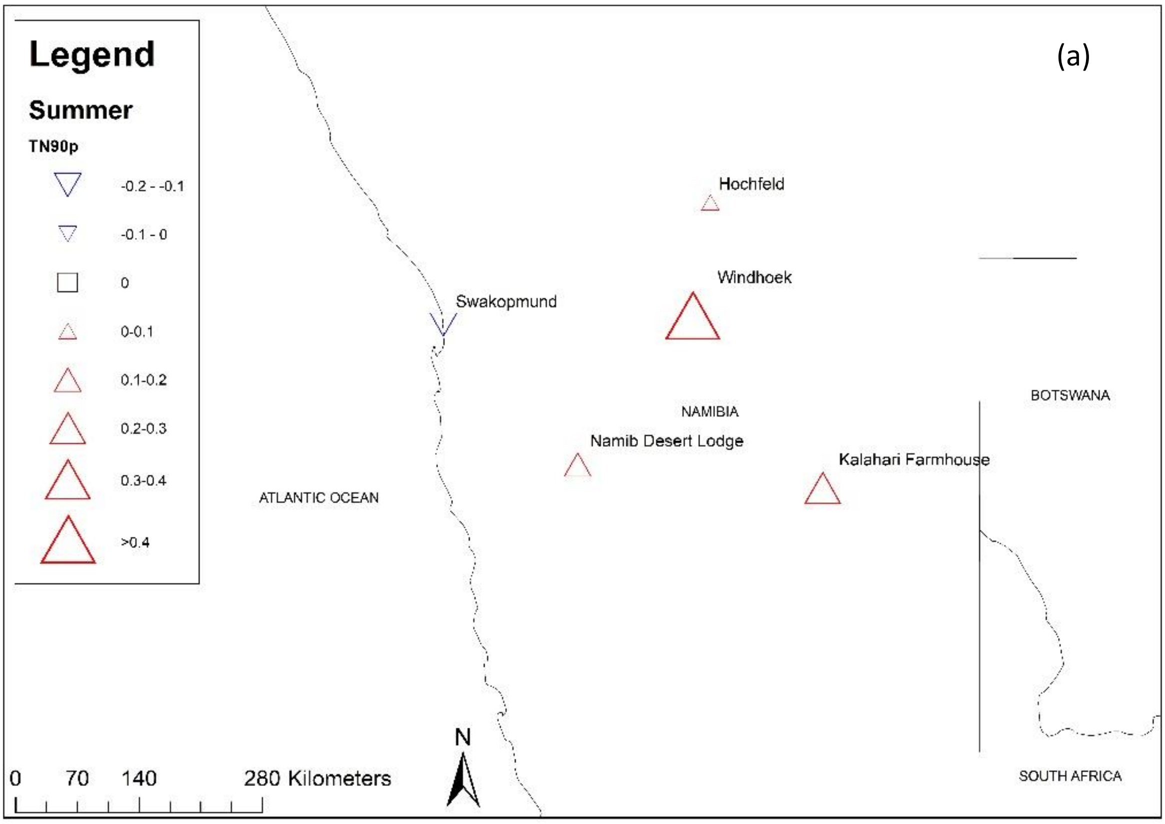


Figure 18: Seasonal trends of TN90p (c) Winter, and (d) Spring. Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level.



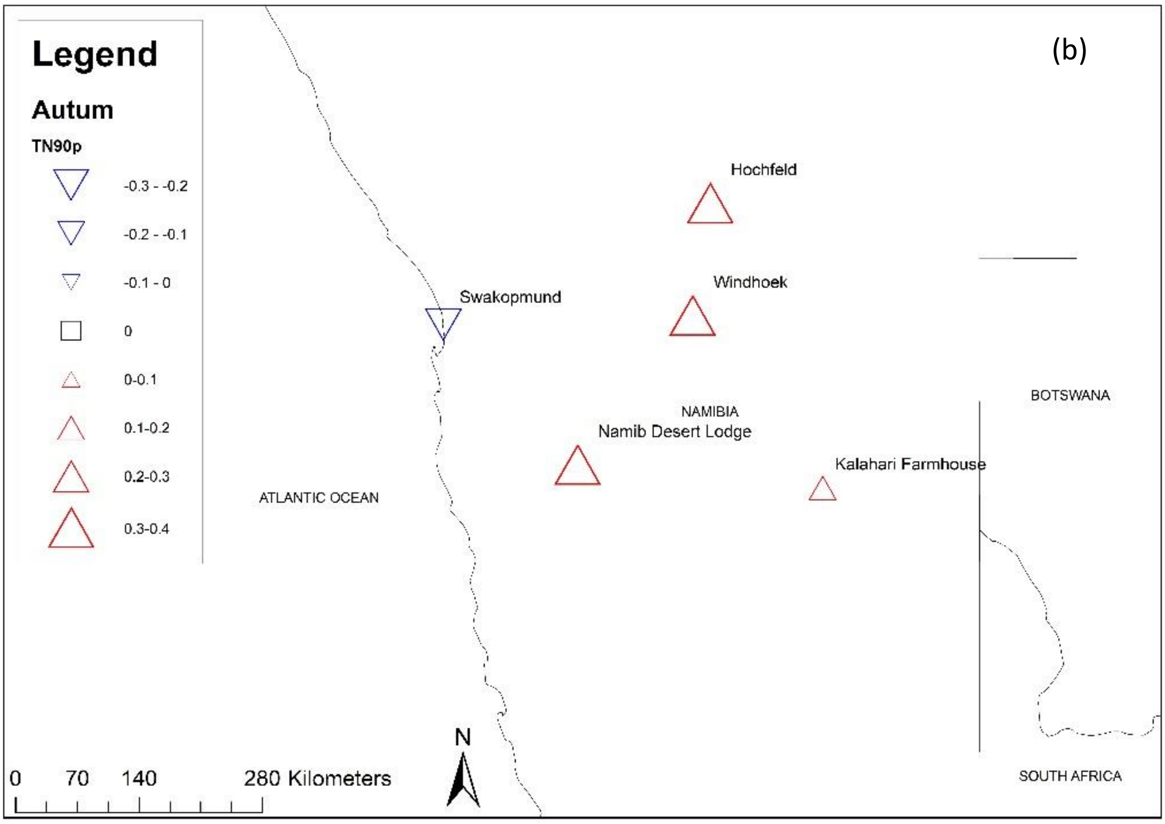
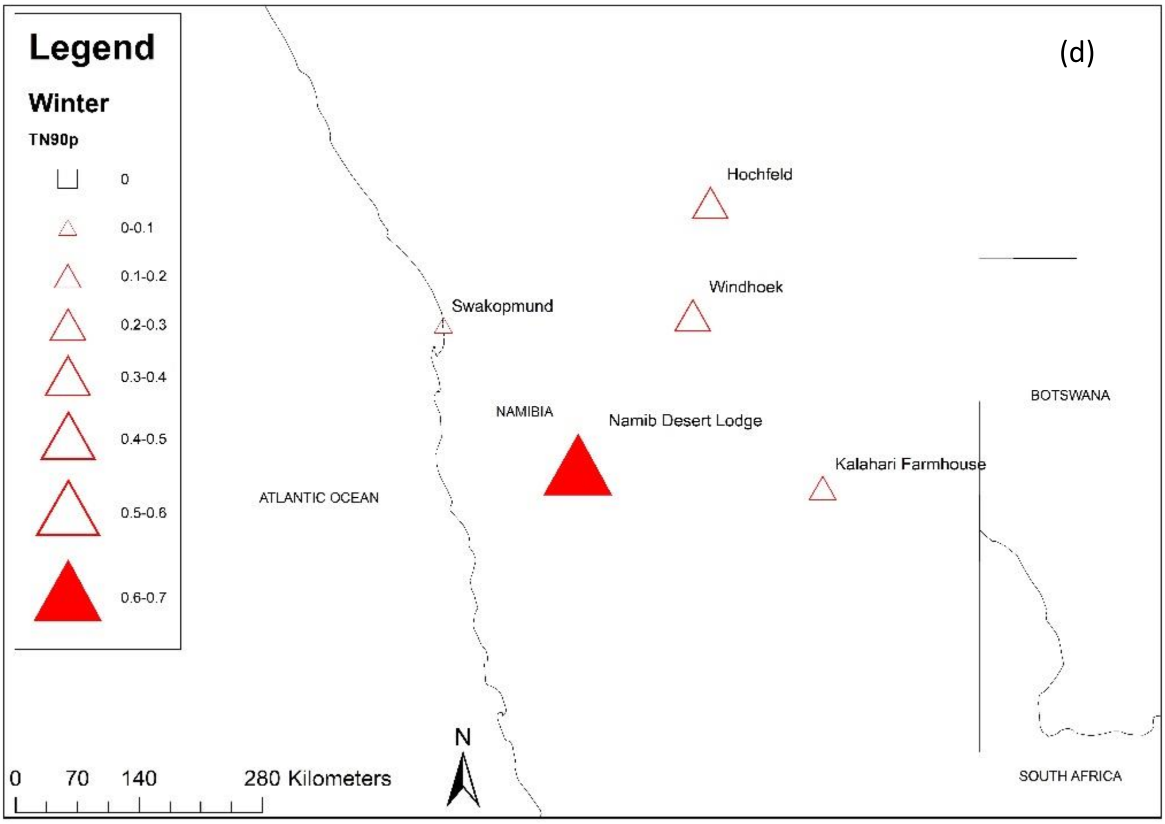


Figure 19: Seasonal trends of TNx (a) Summer, and (b) Autumn. Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level.



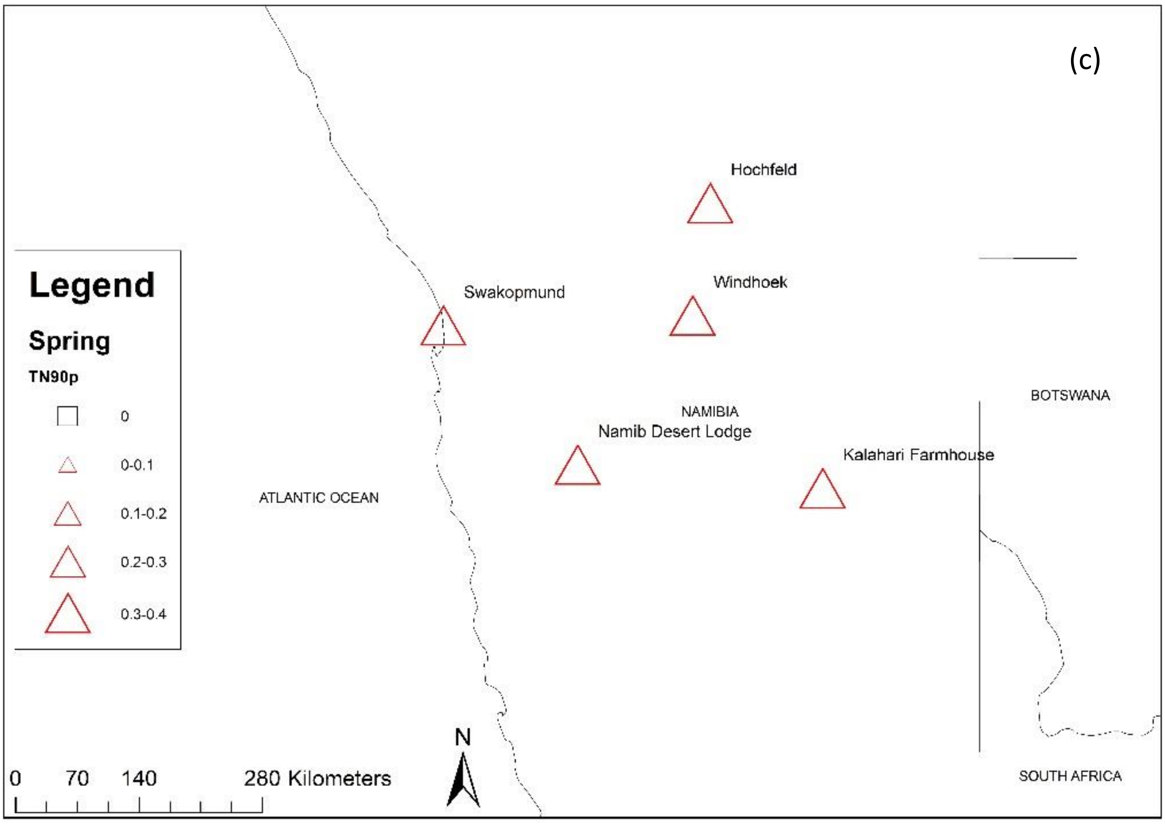


Figure 19: Seasonal trends of (c) Winter, and (d) Spring. Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level.

5.3.5. Warm spells (WSDI and WSDI$_d$)

The indices refer to the following: WSDI, the yearly number of days with six or more consecutive days when the maximum temperature is more than the 90th percentile and, WSDId, the yearly number of days contributing to events where d or more days where the maximum temperature (TX) are above the 90th percentile. The timescale represented will be indicated at each description as either, for the period (2008-2018), year, or month. The WSDI is calculated over six days, and only three stations experienced a warm spell during the period 2008-2018. Swakopmund has an average of 1 day of WSDI, Namib Desert Lodge has an average of 1 day, and Kalahari Farmhouse has an average of 6 days. The total average over Namibia for WSDI is 0.67 days. The WSDI$_d$ is calculated over three days. A significant increase in the number of warm spells between WSDI and WSDI$_d$ is evident. On average, Namibia experienced 8 WSDI$_d$ days. Swakopmund and Kalahari Farmhouse experienced the least number of warm spells, with an average of 6 days for each station. An average of 8 days was calculated for Windhoek and 10 days for Namib Desert Lodge, and 8 days for Hochfeld. There is an increase in the number of warm spells from the west coast towards the country's eastern side (Table 14).

Table 14: The average WSDI and WSDId for 2008-2018

	ETCCDI	ET-SCI
Station	WSDI (days)	WSDI$_d$ (days)
Hochfeld	0.00	7.89
Kalahari Farmhouse	0.60	6.20
Namib Desert Lodge	1.33	9.70
Swakopmund	1.42	6.00
Windhoek	0.00	7.95

None of the stations had any trend for WSDI for 2008-2018 (Appendix 1.3; Figure 20a). There is an average increase in $WSDI_d$ across Namibia of 0.39 days.y^{-1}. Swakopmund experienced no trend. An increase of 0.38 days.y^{-1} is calculated for Windhoek with 0.28 days.y^{-1} for Namib Desert Lodge. Kalahari Farmhouse experienced 0.5 days.y^{-1} increase, and Hochfeld had the fastest increase of 0.79 days.y^{-1} (Appendix 1.4; Figure 20b). There is a clear spatial pattern from the west coast towards the central and northeastern parts of the country.

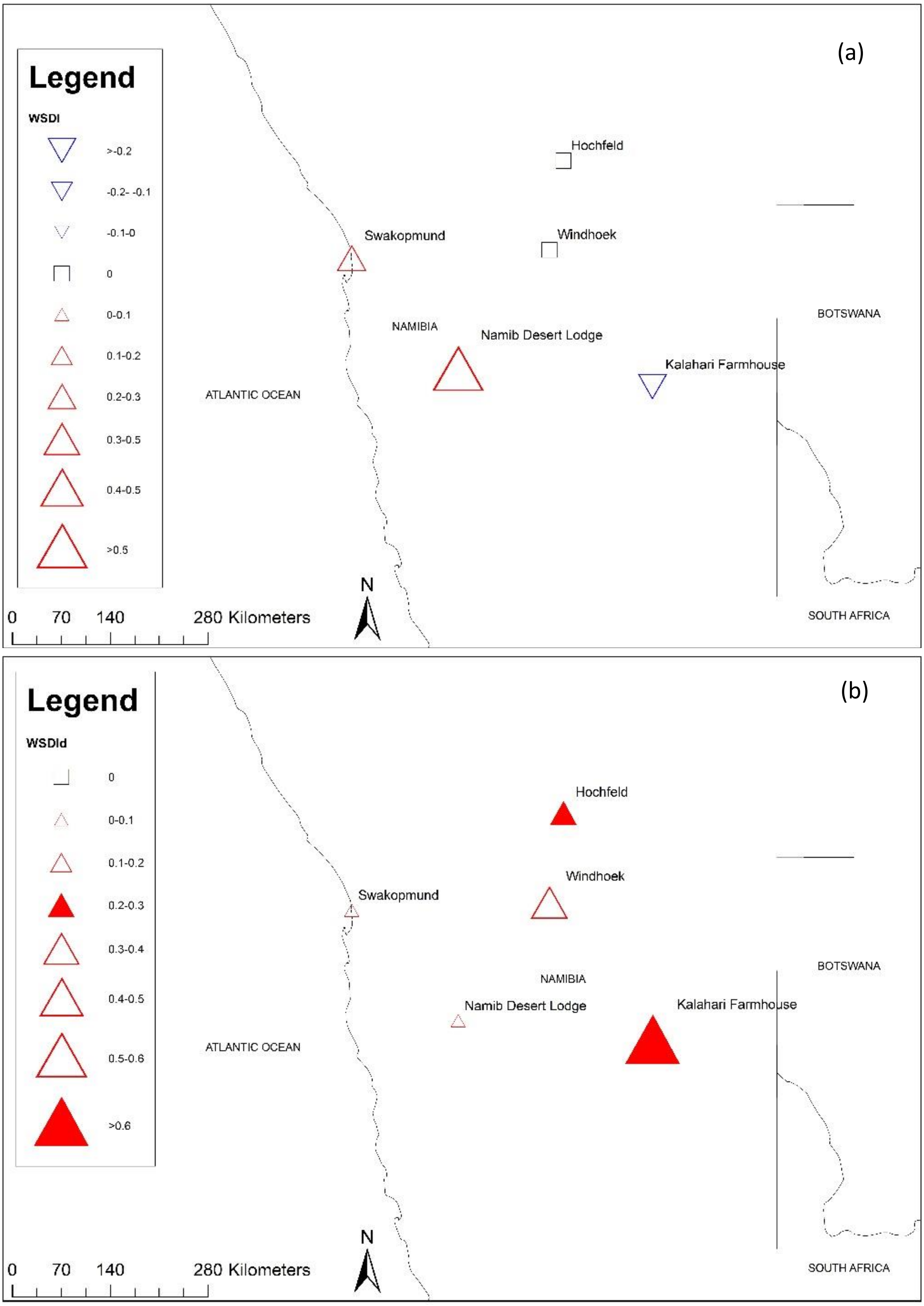


Figure 20: Trends of WSDI (a), and WSDId (b). Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level

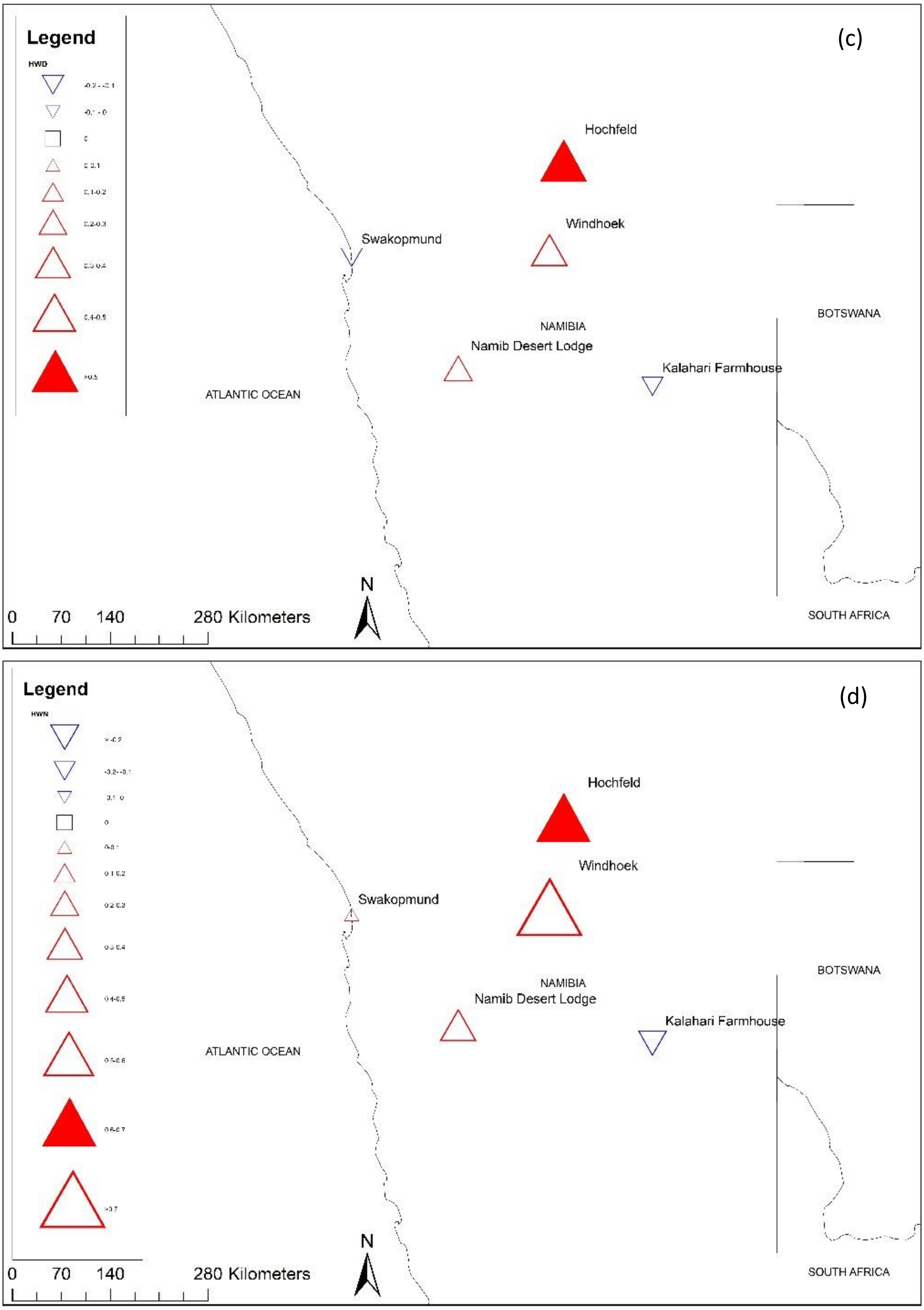


Figure 20: Trends of HWN (c), HWD (d). Open downward and upward triangles indicate negative and positive trends. Squares indicate no trend. Solid downward and upward triangles indicate trends that are statistically significant at the 5% level.

5.3.6. Heatwaves (HWN and HWD)

The indices refer to the following: HWN, the number of individual heatwaves that occur each summer (November to March in the southern hemisphere) and, HWD, the length of the longest heatwave identified by the HWN. The timescale represented will be indicated at each description as either, for the period (2008-2018), year, or month. For the period 2008-2018, there has been an average of 1.60 heatwaves over Namibia. Namib Desert Lodge is the stations with the least HWN and had an average of 1.30. Windhoek had an average of 1.63 heatwaves and Kalahari Farmhouse, 1.7. The station with the highest number of heatwaves was Kalahari Farmhouse. The average heatwave over Namibia spanned over 3 days. Hochfeld had an average HWD of 8 days. Swakopmund and Windhoek experienced, on average, 3 and 4 days of HWD. Namib Desert Lodge experienced heatwaves, for an average of 3 days (Table 15).

Table 15: The average HWN and HWD for 2008-2018

Station	ET-SCI	
	HWN (number)	HWD (days)
Hochfeld	1.67	2.78
Kalahari Farmhouse	1.70	3.40
Namib Desert Lodge	1.30	3.10
Swakopmund	1.67	3.50
Windhoek	1.68	3.23

Almost all of the stations recorded an increase in the trend for HWN over the period. The only station that experienced a decrease was Kalahari Farmhouse, which had a trend of 0.33 days.y^{-1}. Swakopmund had no trend for the year. Windhoek experienced an increase of 0.54 days.y^{-1} and Namib Desert Lodge an increase of 0.35 days.y^{-1}. Hochfeld experienced a statistically significant increase of 0.67 days.y^{-1}. (Appendix 1.4; Figure 20c). Only one station experienced a decrease in the duration of heatwaves. Kalahari Farmhouse experienced a decrease of 0.21 days.y^{-1}. Swakopmund experiences no trend for HWD. The other stations experienced an increase in the trend of HWD of >0.6 days.y^{-1}. An increase of 0.6 days.y^{-1} were calculated for Namib Desert Lodge and 0.78 days.y^{-1} for Windhoek. Hochfeld experienced a statistically significant increase of 0.80 days.y^{-1}. There exists a stronger decreasing trend in the central and northeastern side of Namibia (Figure 20d).

5.4. Conclusion

Although the data only represents ten years and not 30 years as suggested by the WMO to identify trends in a dataset, it was still possible to identify whether any climate extreme events occurred within the dataset and determine whether there were any increases or decreases in the number of events. The average temperature of cold nights and days increased while the temperature of warm nights and days increased. There was also an apparent decrease in the percentage of days in the 10th percentile while the percentage for days in the 90th percentile increased. Cold spells and cold waves were present but fewer compared to the warm spells and heatwaves. Only two sites were identified where frost days occurred. A large number of days throughout the year experience summer days and very hot days with temperatures above 35°C. Although no long-term trends can be drawn from the dataset, it is clear that the general trend suggests overall warming and an increase in heat-related events. The majority of change in the trends are from Hochfeld, Kalahari Farmhouse and Namib Desert Lodge. Swakopmund experiences minimal changes and minor extreme condition and can be linked to the fact that has a maritime climate.

Chapter 6: Discussion

6.1. Introduction

The primary purpose of this study is to explore the frequency of ETEs in Namibia and assess their impact on the country. The trend analysis to determine the cold and warm indices is the first known study in Namibia. To determine the ETEs, ETCCDI and ET-SCI were applied for the period 2008-2018. The need to understand the frequency, duration and impacts of ETEs is outlined in *Chapter 2,* including the current research gaps. Policymakers in the country first need to know whether there are ETEs and the extent to which these events occur before they can make informed decisions and implement policies. The study has addressed this in *Chapter 2,* and the effects of the results are assessed in this chapter. The chapter will mainly discuss the implication and application of the results. To do this, the chapter will first discuss the presence of ETEs and specifically in Namibia. Secondly, the chapter will look at the different impacts of the ETEs in the current climate on the health, environmental, and socioeconomic sectors. Lastly, the chapter will discuss the limitations of the research.

6.2. Extreme Temperature Events

The research is one of the first studies in Namibia to use the ETCCDI and ET-SCI to investigate the frequency of high-temperature events, and it covers the period 2008-2018. On an annual and seasonal time scale, the ETCCDI and ET-SCI results show an overall warming trend (trends do not represent long-term trend analyses) and an increase in the intensity and duration, extremely warm weather events over the study period (Chapter 5.3). These results are consistent with rising global mean temperature patterns (Yatim *et al.*, 2019; NOAA, 2020), rises in extremely warm temperatures, and an increase in the frequency of hot days, with a decrease in cooler temperatures (Hartmann *et al.* 2013; Mueller *et al.* 2016). Factors, such as local and region synoptic circulation and ENSO and the IOD, will influence the type and timing of extreme temperature events (Baudoin *et al.,* 2017). Over all seasons, ENSO has a significant impact on the climate distribution across Namibia (Tyson and Preston-Whyte, 2000). During the austral winter and spring, the Indian Ocean Basin Mode (IOBM), an ENSO-induced heat flux anomaly, affects Namibia’s climate (Stander, 2013). Namibia is located at the crossroads of many climate systems. The country's climate is primarily affected by its proximity to the Benguela current's northward flow, associated with cooler temperatures on its western shores (Baudoin *et al.,* 2017). In contrast, the northern part of the country is influenced by the intersection of warm tropical winds from Angola and the Benguela current from the southwest (Landman *et al.,* 2017). The country's southern region is located at the Mid-Latitude High-Pressure Zone and the Temperate Zone. Studies also suggest that anthropogenic forces play a role in the changes associated with ETEs (Yatim *et al.*, 2019; NOAA, 2020). However, less research is being done to better understand the relationships between extreme events and large-scale modes of climate variability and synoptic trends (NOAA, 2020).

Localised temperature variations can occur because of the station's proximity to the ocean and the stations' elevation (Yatim *et al.*, 2019). Colder sea surface temperatures along the west coast due to the cold Benguela, combined with westerly movement, lead to cold air advection over the coast (Tyson and Preston-Whyte, 2000; Landman *et al.,* 2017). Higher elevations have been known to be colder than lower elevations (NOAA, 2020). Due to the urban heat island effect, built-up areas can be warmer than rural areas (Scott *et al.*, 2018). Cold events are caused mainly by cold cut-off lows and cold fronts of mid-latitudinal cyclones, which primarily occur during the winter (Engelbrecht *et al.,* 2012; Abiodun *et al.,* 2016; Lennard, 2019).

6.2.1. ETEs in Namibia

6.2.1.1. Cold events

The majority of the cold waves (Chapter 5.2.5) in Namibia are located in the central, northeast and southeast of the country. The least number of cold waves are found along the west coast. The spatial pattern identified are similar to those of South Africa (Van der Walt & Fitchett, 2020). The duration of the cold waves follows the same pattern as CWN for the study period. These patterns of CWN and CWD are in line with work done across southern Africa and in Namibia (Reid *et al.,* 2008; Perkinds-Kirkpatrick & Lewis, 2020; Miller *et al.,* 2020). When assessing the frequency and intensity of cold waves, it is more effective to use the ET-SCI indicators, such as $CSDI_3$, CWN and CWD, instead of ETCCDI's CSDI (Panda *et al.,* 2014). The CSDI assess periods of six consecutive days and rarely occur. Whereby $CSDI_3$ is assessed on a three day period. An average of 1.99 cold wave events per year was identified using CWN that lasts for an average of 4.59 days using the CWD. Comparing the CSDI and $CSDI_3$, only Swakopmund showed any days of CSDI, and the $CSDI_3$ identified an average of 4.86 days per year.

Overall, there is an increase in the TN of Namibia across all the stations. The majority of the cold indices shows an increasing trend in the cooler temperatures of Namibia with the majority of the statistically significant trends occurring in these indices. In other words, Namibia’s minimum temperatures are rising. The warming coincides with research done in the past that shows a warming trend in cooler temperatures in adjacent South Africa (Kruger and Sekele 2013; Mackellar *et al.* 2014; Kruger and Nxumalo 2017). A general decrease in the frequency of cold events varies significantly across the region. The trend is apparent in the review of the seasonal $CSDI_3$, CWN and CWD. The only station that shows an increase in the duration of cold waves is Swakopmund for the period. The results suggest that cold events are present, but there is a decline in the overall events, although stations show an increase in the TNx, TXn and TXMean. The season variability is most present during Winter and Spring and can result from changes in the season from Winter to Summer. The more prominent events and changes are present in the country's interior, with the coastal area being less volatile.

6.2.1.2. Warm events

The number of heatwaves identified is similar across all the stations. As with cold events, WSDI is less effective in classifying warm events. Using the $WSDI_{3,}$ HWN and HWD is a more effective way of determining warm events (Perkins *et al.*, 2012; Panda *et al.*, 2014). The WSDI only identified an average of 0.67 days of warm spells per year, where the $WSDI_3$ identified an average of 7.55 days. Similarly, there are no trends identified with the WSDI, but with $WSDI_{3,}$ there is an increasing trend at all stations of which Hochfeld and Kalahari Farmhouse is statistically significant. This implies that there is a strong increasing trend for the stations mentioned. An average of 1.6 days per year in the number of HWN was identified, spanning over 3.2 days. The only station that has a decrease in the trend of HWN and HWD is Kalahari Farmhouse. The finding on HWN and HWD are in line with other studies done across southern Africa (Niange *et al.,* 2014; Miller *et al* 2020). The study also assessed the number of days over 25°C (SU) and days over 35°C (SU35). The annual average number of SU days is 99.33, with Namib Desert Lodge showing the highest average of 241.22 days per year. There are fewer

SU35 days identified per year, with an average of 47.96 days. Only two stations show an increase in the number of SU, but all the stations show an increase in SU35 days. In terms of a positive anomaly, these events may be a valuable predictor of heat stress severity. Compared to coastal stations, most interior stations observed a statistically significant increase in the frequency of warm days and warm spells duration days. The reason for the difference can be because of the elevation between the stations inland, the heating capacity of water versus land and humidity differences between inland and coastal stations (Kruger and Sekele, 2013; Kruger *et al.,* 2019). The differences can also be due to the stations and this dissimilarity happens as a result of topographic variation and geographical location of the station. When comparing Windhoek to the other inland stations, it is not warming as fast. Although it is warming, the slower rate of increase can be due to factors such as, urbanisation (heat island effect), location of the weather station and the distance of the station from the ocean. Another factor that can influence the rate of increase is the elevation of the station. These spatial trends are consistent with recent forecast studies that show a noticeable rise in the duration of warm spells (Kruger *et al.*, 2019).

It is apparent that there is an increase in the TX of Namibia throughout all the stations. The warming coincides with research done in the past that shows a warming trend in warm temperatures (Kruger and Sekele 2013; Mackellar *et al.* 2014; Kruger and Nxumalo 2017). The importance of observations on a seasonal timescale cannot be overstated. Due to an unprepared population, unseasonably warm temperatures can increase heat stress risk (Lee 2014; Founda *et al.* 2019). Seasonal temperature changes can trigger shifts in the onset and duration of growing seasons (Thorton *et al.*, 2014) and reduce crop yields (Araujo *et al.*, 2016; Landman *et al.*, 2017b). Warmer temperatures can cause seasonal phenological events to be delayed or advanced (Wang *et al.,* 2016). The TN90p and TX90p show a general increase for the period of the study except for Swakopmund. It suggests that the overall temperatures for night and daytime are increasing. This can pose a problem due to the human body using the lower nighttime temperatures to recuperate (Chersich and Wright 2019). An important factor to look at is the adaptive capacity of the people in Namibia. Although households in the urban areas of Namibia have instruments to help with adaption, like air conditioners, the problem lies at rural communities. These communities do not always have electricity for these instruments and the money to afford it. The increase in nighttime temperature might not influence the urban communities as much as it may influence the rural communities (Davis *et al.,* 2013). Different adaptive capacities can have an positive impact on the management of the warming trends in the country.

6.3. Effect of ETEs on Namibia

6.3.1. Health hazard

Extreme temperatures have a more significant impact on human health than any other climatic condition, with the most significant risk of affecting the elderly (Gaffen & Ross, 1998). The increase in cooler temperatures can have a positive effect, especially in rural areas where adaptive capacity to cold temperatures is limited. This will reduce injuries related to cold temperatures (Davis *et al.,* 2013). The increase of warmer temperatures will in return have a negative effect. Heat stress is a condition where the human body is at risk of overheating (Havenith, 2001). It includes different symptoms, from headaches to loss of life. Young children, the elderly and people with existing medical problems are at higher risk (Harvard Medical School, 2019). People are affected worldwide and in all aspects of their everyday life (Hulme *et al.*, 2001). Through a decrease in productivity, to loss of life for, example the heatwaves in 2003, 2010, and 2015 in Europe where over 70,000 people lost their life due to heat-related health problems (Barriopedro *et al.*, 2011; Ikäheimo 2014; Yu and Li, 2015; Orth *et al.*, 2016). People with pre-existing respiratory disease and other chronic disease are especially vulnerable in developing countries, with urban populations projected to be more negatively impacted than rural populations in developed countries (Ayres *et al.*, 2009). Many rural residents have less access to medical care than their urban counterparts, making them more susceptible to the effects of heat stress. The number of SU and SU35 days and the HWN and HWD can pose a problem with the above mentioned. The extreme temperatures and general increase in the mean temperature can cause more severe and frequent droughts that will further impact Namibia's people since they are already a water scarcity country (von Oertzen, 2009). Changes in the climate are especially concerning when coping with populations already weakened by poverty, malnutrition, and the consequences of systemic illnesses and a high disease burden (Hansen *et al.,* 2008; con Oertzen, 2009). The effects of ETEs, significantly increased climatic variability, would increase the pressure on human health and health-related aspects and the overall disease burden in most Namibian communities. Current vulnerabilities are likely to be exacerbated by an increase in ETEs in general and a rise in temperatures in particular, in cases of pre-existing medical conditions and severe poverty (Husain & Chaudhary, 2008; NNHA, 2008). Such effects are also likely to create additional and sometimes unforeseen problems for Namibia's already overburdened public health system. Increased heat stress, dehydration, and a decreased capacity to cope with other stressors and diseases are likely to be the key consequences that Namibians will experience as temperatures rise in the future (von Oertzen, 2009; NNHA, 2008).

ETEs may also have long-term health consequences, such as chronic respiratory disorders and heart dysrhythmias; they may also impair thermoregulation, allowing sepsis-related hypothermia during the summer months (Scott, 2015). ETEs have been linked to various diseases, categorised as distantly related health problems and impacts. During ETEs, mental health issues, memory loss, increased risk of miscarriages, increased Kawasaki disease cases, and civil unrest has been recorded (Scott, 2015; Rossati, 2017; Chan *et al.*, 2019; Kanner *et al.*, 2020). In addition to the above-mentioned potential health consequences, research shows that a population's susceptibility to ETEs is linked to its exposure as well as its ability to adjust and react to such ETEs over long or short periods (McGregor, 2017; Le Roux *et al.*, 2017). Demographic, health, physical, socioeconomic, and institutional variables all play a role in determining vulnerability (von Oertzen, 2009). These determinants can illustrate disadvantaged populations. The population's physiology plays a significant role in demographic determinants, with older people being more vulnerable to extreme temperatures than younger people (McGregor, 2000; von Oertzen, 2009). This will affect the permanent residents of the country and immigrants and tourists (McGregor, 2017).

6.3.2. Environmental and Socioeconomic impact

Shorter cold events (two or three days) can significantly impact many industries, particularly agriculture, as it can affect the growth of crops and livestock (Panda et al., 2014). The effect of warmer minimum temperatures can have a positive impact on crops. This allows for a longer growing period, thus increasing yields. Furthermore, this allows for grazing fields to have longer growing periods. The longer fields have to grow the more time animals have to use the nutrients within the grass (Panda et al., 2014). As soon as temperatures drop to low, the nutrient content drops dramatically. Similarly, it can also be beneficial to poultry farmers as they will use less electricity to heat the broiler houses (Mangani *et al.*, 2018). Although there are some positive effects to the agricultural community, it can also be negative by disrupting and reducing crop yields when they experience ETEs (Mangani *et al.*, 2018). Increases in cold events could affect the environment (Leriorato and Nakamura 2019), altering plant and animal distributions and delaying seasonal phenological events (Wang et al. 2016), as well as a result in livestock losses (Muirhead 2002). It may cause irreversible damage to regions that sustain extensive livestock farming (Lötter 2017) and communities that rely solely on subsistence farming for a living. Heatwaves also affect ecosystems; according to one report, heatwaves cause fitness costs in birds, which harm their nesting success (Malherbe *et al.*, 2016; Van Wilgen *et al.*, 2016). Extreme heat can also lead to and intensify wildfires, as in Australia of 2019-2020. (Ebbs, 2020). Electricity use is directly affected by the outdoor temperature. A working trend in winter can allow for less electricity being used for heating homes and offices. It will also influence the amount of electricity used in water heaters. The reduction in electricity use will have a positive effect on utility bills. Nevertheless, heat waves could devastate energy systems because as the temperature rises, so does electricity demand to power air conditioners and fans (Lubega *et al.*, 2018).   The Identified number of CWN and CWD in the study night cause problems in the agricultural sector and the tourism sector of the country.

Heatwaves affect tourism as well; temperatures have been found to play a significant role in outdoor tourism and tourist activities (Noome and Fitchett 2019). Tourism tend be more active with moderate temperatures. This means that during winter times, with an increase in temperature, more tourists may be encountered which is good for the economy. The latter might be true, but tourists, who are not often used to such hot weather, prefer to remain indoors during heatwaves (David *et al.,* 2013; Fitchett and Hoogendoorn 2018). One adaptive measure described by the government of Namibia is to move from livestock farming to wildlife farms. This is because wild animals tend to be more capable in dealing with temperature changes than what domestic animals are. The adaptive measure can also increase tourism in the country (David *et al.,* 2013). Given Namibia's historical labour regime, traditional roles of women, especially in rural communities, the high prevalence of HIV/AIDS, and other factors, the availability of food in rural Namibia is most likely to be adversely affected by climate change. Higher temperatures, more significant climatic variability, shorter rainy seasons, and a longer dry season would lead to lower crop yields, and a growing global population will put conventional food sources under increased strain (IPCC, 2014). This impact is also expected to increase the risk of household food insecurity and the likelihood of increased malnutrition. Malnutrition weakens human disease defences and increases mortality in the general population, with vulnerable groups, including babies and children under five years, becoming particularly vulnerable (WHO, 2003; Brown *et al.*, 2008; Brown, 2009). Chronic and acute infant malnutrition, low birth weights, inadequate breastfeeding, and increased disintegration of traditional society and family cohesion are all well-documented consequences of human malnutrition in general. These effects can also hasten society and family members' decision to migrate in search of more secure food supplies (Black *et al.*, 2008). Food insecurity is predicted to be exacerbated by ETEs (Cohen *et al.*, 2008). The international race for agricultural land for biofuels has shown what could happen if vast tracts of land traditionally used for conventional food supplies were inaccessible. Millions of citizens in Sub-Saharan Africa still eat calorie-deficient diets, and any weakening or disruption of the food chain – whether caused by climate change or not – would exacerbate malnutrition and reduce food protection (von Oeltzen, 2009). According to recent studies, without adequate adaptation measures, southern Africa is likely to experience crop reductions and an overall decrease in food crops such as maise, millet, and sorghum (Lobell *et al.*, 2008). Increased frequency of ETEs and changing trends of plant and livestock diseases and pest infestations are likely to result in lower income from animal products, lower crop yields, and increased fire risk. These factors would harm food production in general, reducing food security. Namibia's most vulnerable people, who have historically lived in rural areas, are the most likely to be harmed by such shifts and are also likely to face an increased disease burden linked to increased food insecurity (DRFN, 2008).

Although there are a number of concerning effects of increasing ETEs and warming of the climate, Namibia has implemented a number of adaptive measures (David *et al.,* 2013). Comparing Namibia with other countries that has a similar climate, like Iran, Namibia's adaptive measure are successful in that it is helping the country on a grass root level (Turpie *et al.,* 2010; David *et al.,* 2013). Measures implemented by the government is land-use planning, adaptive livestock management, wildlife management, tourism and conservation, promotion of biodiversity products, water conservation, fire management, and improved warning systems (Reid *et al.,* 2007; Dirkx *et al.,* 2008; Turpie *et al.,* 2010). All the above-mentioned measurements were explained to the rural and urban communities, especially those most vulnerable to the change in temperature. The country has made one of its main focus points, the awareness and education of the people in Namibia (David *et al.,* 2013). One problem with the education of people is that the scientific information from climatologist and meteorologist is of such a standard that it is often misunderstood in some rural communities (Turpie *et al.,* 2010). The negative impacts do outweigh the positive impacts when assessing the ETEs in Namibia. The main problem is that the positive impacts are very location specific, thus understanding the socioeconomic impact in Namibia is vital in understanding the impacts.

6.4. Limitations

This study, like all research projects, had limitations. The nature of access to meteorological data for developing regions is a significant limitation of this study. Uninterrupted, continuous measurements of each component needed for calculating the ETEs are one of the primary limitations for research in developing countries such as Namibia (Nicholson *et al.*, 2012; Hoogendoorn and Fitchett, 2016). Another restriction is the lack of free online meteorological data. These limitations in analyses should be noted because they could affect the quality of data used in future studies. In the collected dataset, there were several limitations with the climate variables for calculating ETEs. Because of the data gaps and outliers, this project cannot make conclusions about climate change trends because it lacks the necessary 30-year data span (IPCC, 2007; WMO, 2013). Outliers are often likely to occur due to natural human and defective equipment failures for a variety of reasons (Schulze, 2007). The final ETCCDI and ET-SCI are estimated over a 10-year data cycle in this study. If the data has intra-annual and inter-annual variability, interpolated values run the risk of being deceptive.

The gaps in the data resulted in two stations being omitted. The analysis is limited to looking at ETEs for a small number of destinations, with only five weather stations, Hochfeld, Kalahari Farmhouse, Namib Desert Lodge, Swakopmund, and Windhoek, having sufficient data on the Namibia Weather Network. The Namibia Weather Network's inability to provide adequate spatial and temporal data is a constraint because it limits research on climate change's effects in Namibia. On the other hand, the spatial distribution limitations are minor because a finescale resolution was not needed to meet the objectives of the research project. Because of high poverty levels, local government financial resources, expertise, and technology, developing countries' capacity to survive climate change is lower than developed countries (Tervo-Kankare *et al.*, 2018). Furthermore, data shortages are a serious and fundamental issue because they hinder the government's ability to investigate the possible effects of climate change worldwide. It is argued that a constructive attitude and well-structured preparation are needed for successful adaptation to the impacts of climate change through government agencies' comprehensive resource management (Amelung and Nicholls, 2014). The ETCCDI/ET-SCI indices are often specified on annual timescales, but some are also defined on monthly timescales. The current collection of monthly/annual indices may be less useful for some sectoral applications (e.g., agriculture and energy), as climate anomalies must be measured over various timescales. The results can thus be misleading to policymakers.

Chapter 7: Conclusion

7.1. Synopsis

This research is one of the first to measure ETEs. The ETCCDI and the ET-SCI indices yielded results; however, the ET-SCI is more practical and can be applied to a wide range of Namibian industries. These results have far-reaching consequences for both the natural environment and culture, and they set the stage for potential shifts in extreme events as a result of continued anthropogenic global warming. Furthermore, the outcomes of extreme temperature events are critical in framing mitigation and adaptation strategies to mitigate the effects of climate change in a country that is already vulnerable. When looking at long-term patterns (e.g., a higher number of hot days), the value of ETEs becomes more noticeable than isolated observations of particular short-lived events, which are often difficult to detect (Davis-Reddy and Vincent 2017). These results add to our understanding of the existence of extreme events in Namibia, given that these events will continue to occur in the face of rising mean temperatures. As a result, decision-makers must understand extreme warm and extreme cold events while planning infrastructure and alert systems.

7.2. Achievement of study aims

The primary aim of this research was to investigate the incidence of extreme temperature events over Namibia over the period 2008-2019. To address this research's primary aim, the specific objectives of this research are listed below and how they were achieved.

1. *Determine the frequency of occurrence of monthly, annual and seasonal warm temperature events over the period 2008-2019.*

Trend analyses had to be done for each of the selected ETCCDI and ET-SCI on all the selected stations for the study period. The frequency and intensity of the cold temperature events were identified using the selected ET-SCI and ETCCDI temperature indices, together with the trend analysis (Mann-Kendall, Spearman’s Rank correlation coefficient and Sen’s slope). The results of the ETCCDI and ET-SCI are present under *section 5.2.1, 5.2.2, 5.2.3, 5.2.4, and 5.2.5*. The data source, data quality, station placement, trend analysis, and importance (i.e. Mann-Kendall, Spearman's Rank correlation coefficient, and Sen's slope) behind this objective were all recorded under *sections 4.2, 4.3, 4.4* and *4.5*. The discussions of these results are presented under Section 6.2.1.1. In short, this research paper provides the first know application of the ETCCDI and ET-SCI in Namibia. The findings contribute to the nature of cold events in Namibia.

2. *Determine the frequency of occurrence of monthly, annual and seasonal cold temperature events over the period 2008-2019.*

Trend analyses had to be done for each of the selected ETCCDI and ET-SCI on all the selected stations for the study period. The frequency and intensity of the warm temperature events were identified using the selected ET-SCI and ETCCDI temperature indices, together with the trend analysis (Mann-Kendall, Spearman’s Rank correlation coefficient and Sen’s slope). The results of the ETCCDI and ET-SCI are present under *section 5.3.1, 5.3.2, 5.3.3, 5.3.4, 5.3.5* and *5.3.6*. The data source, data quality, station placement, trend analysis, and importance (i.e. Mann-Kendall, Spearman's Rank correlation coefficient, and Sen's slope) behind this objective were all recorded under *sections 4.2, 4.3, 4.4* and *4.5*. The discussions of these results are presented under *Section 6.2.2.1*. In short, this research paper provides the first know application of the ETCCDI and ET-SCI in Namibia. The findings contribute to the nature of warm events in Namibia.

7.3. Avenues for future work

The future research avenues identified in the study will be discussed below. These avenues will serve to build on the aims and objectives of the study. The first avenue comes from the limitations experienced with the short term data set. Namibia can benefit from a study that will identify long-term trends to help with future adoptions within the country. Future research may aid in the widespread adoption of the ET-SCI in Namibia and Africa as a whole. It could also promote the use of sector-specific climate indices and draw attention to the variability and patterns of ETEs of particular interest to health, agricultural and socioeconomic sectors. It may also aid in the identification of climate vulnerability in various sectors and regions in Namibia, as well as adaptation strategies.

The discovery and study of comfort indices, such as the ET-SCI and ETCCDI, is linked to the next avenue of research. There is a need to research comfortability indices such as the UTCI (Blaejcyk et al., 2013; Napoli et al., 2018). The UTCI aims to investigate thermal comfort measures of ETEs by combining temperature with a broader range of meteorological parameters such as humidity and wind speed. These comfort indices allow ETEs to be categorized based on biometeorological impacts without necessarily resulting in deaths, providing a standardized classification system and standardisation for the healthcare system (Napoli *et al.,* 2018). The fourth avenue is to perform a study in which synoptic features are investigated as ETE drivers throughout Namibia. Changes and variability in the frequency and length of synoptic features and how this correlates with the frequency and occurrence of both types of ETEs across the world can be the subject of such research. Teleconnection forcing mechanisms (e.g., ENSO, IOD, SAM, the North Atlantic Oscillation (NOA), the Arctic Oscillation (AO), and the Pacific Decadal Oscillation (PDO)) have been linked to ETEs in different regions, according to several studies. (e.g. Nicholls et al., 2012; You et al., 2013; Ning and Bradley, 2015; Matsueda & Takaya et al., 2015; He et al., 2017; Loikith et al., 2017; Liu et al., 2018). Few studies in Africa, especially in Namibia, have investigated the attribution of extreme climatic events, particularly the impact of large-scale drivers on ETEs (e.g. Otto et al., 2015; Abatan et al., 2018).

Reference List

Abatan, A.A., Aboidun, B.J., Lawal, K.A. and Gutowski, W.J. 2019. Trends in extreme temperature over Nigeria from percentile-based threshold indices. *International Journal of Climatology,* 36, 2527-2540.

Abatan, A.A., Osayomi, T. Akade, S.O., Abiodun, B.J. and Gutowski, W.J. 2018. Trends in mean extreme temperatures over Ibadan, Southwest Nigeria. *Theoretical and Applied Climatology,* 131, 1261-1272.

Abbas, F., Rehman, I., Adrees, M., Ibrahim, M., Saleem, F., Ali, S., Rizwan, M. and Salik, M.R. 2018. Prevailing trends of climate extremes across Indus-Delta of Sindh-Pakistan, *Theoretical and Applied Climatology*, 131, 1101-1117.

Addinsoft. 2020. XLSTAT statistical and data analysis solution. New York, USA. [Software] Available from: https://www.xlstat.com.

ADHS, 2021. Arizona Department of Health Services. Extreme weather and public health. Accessed 16 August 2021. https://azdhs.gov/preparedness/epidemiology-disease-control/extreme-weather/heat-safety/index.php#heat-home.

Ahmadnezhad, E., Naieni, K., Ardalan, A., Mahmoudi, M.,Yunesian, M., Naddafi, K. and Mesdaghinia, A. 2012. Excess Mortality during Heat Waves, Tehran Iran: An Ecological Time-Series Study. *Journal of Research in Health Sciences*, 13. 24-31.

Alemu, Z.A. and Dioha, M.O. 2020. Modelling scenarios for sustainable water supply and demand in Addis Ababa city. Ethiopia. *Environmental Systems Research*, 9, 7-12.

Alexander, L.V. 2015. *Introduction to the ET-SCI indices*. WMO CCI Expert Team on Sector-specific Climate Indices (ET-SCI) Workshop. Nadi, Fiji.

Alexander, L.V. 2016. Global observed long-term changes in temperature and precipitation extremes: A review of progress and limitations in IPCC assessments and beyond. *Weather Climate Extremes*, 11, 4–16.

Alexander, L.V., Fowler, H.J., Bador, M., Behrangi, A., Donat, M.G., Dunn, R., Funk, C., Goldie, J., Lewis, E. and Rogé, M. 2019. On the use of indices to study extreme precipitation on sub-daily and daily timescales. *Environmental Research Letters*, 14, 125008.

Alexander, L.V. and Herold, N. 2016. Climpact2 Indices and Software, The University of South Wales, Sidney, Australia. Accessed 14 November 2020. https://github.com/ARCCSSextremes/climpact2.

Alexander, L.V., Zhang, X., Peterson, T.C., Caesar, J., Gleason, B., Klein Tank, A.M.G., Haylock, M., Collins, D., Trewin, B., Rahimzadeh, F., Tagipour, A., Kumar, K.R., Revadekar, J., Griffiths, G., Vincent, L., Stephenson, D.B., Burn, J., Aguilar, E., Brunet, M., Taylor, M., New, M., Zhai, P., Rusticucci, M. and Vazquez-Aguirre, J.L. 2006. Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical Research,* 111, 208-235.

Alpérovitch, A., Lacombe, J.M., Hanon, O., Dartigues, J.F., Ritchie, K., Ducimetière, P. & Tzourio, C. 2009. Relationship between blood pressure and outdoor temperature in a large sample of elderly individuals: the Three-City study, *Archives of Internal Medicine*, 169 (1), 75-80.

Amou, M., Gyilbag, A., Demelash, T. and Xu,Y. 2021. Heatwaves in Kenya 1987–2016: Facts from CHIRTS High Resolution Satellite Remotely Sensed and Station Blended Temperature Dataset. *Atmosphere,* 12(37), 1-13.

Anguilar, E. 2016. *The ET-CCDI Indices as a starting point for ET-SCI*. WMO Workshop on Enhancing Climate Indices for Sector-Specific Applications in the Caribbean region. Centre for Climate Change, Tarragona, Spain.

Aguilar, E., Barry, A.A., Brunet, M., Ekang, L., Fernandes, A., Massoukina, M., Mbah, J., Mhanda, A., do Nascimento, D.J., Peterson, T.C., Umba, O.T., Tomou, M. and Zhang, X. (2009), Changes in temperature and precipitation extremes in western central Africa, Guinea Conakry, and Zimbabwe, 1955–2006. *Journal of Geophysical Research,* 114, 1-11.

Andrijevic, M., Crespo Cuaresma, J. and Muttarak, R. 2020. Governance in socioeconomic pathways and its role for future adaptive capacity. *Natural Sustainability,* 3, 35–41.

Angula, M.N. and Kaundjua, M.B., 2016. The changing climate and human vulnerability in north-central Namibia, *Journal of Disaster Risk Studies*, 8 (2), 7-15.

Angula, M.N. and Menjono, E. 2014. Gender, culture and climate change in rural Namibia, *Journal for Studies in Humanities and Social Sciences*, 3, 225-238

Apaydin, H., Kemal, F. and Re, E. 2004. Spatial Interpolation Techniques for Climate Data in the Gap Region in Turkey, *Climate Research,* 28, 31-40.

ArcMap, 2016. Raster Interpolation toolset concepts: How IDW works. Accessed 26 November 2019. http://desktop.arcgis.com/en/arcmap/10.3/tools/3d-analyst-toolbox/how-idw-works.htm.

Arendse,A. and T.A. Crane, 2010. *Impacts of Climate Change on Smallholder Farmers in Africa and their Adaptation Strategies: What Are the Roles for Research?* CIAT Working Document No. 221, International Symposium and Consultation, 29-31 March 2010,Arusha,Tanzania, Centro Internacional deAgricultura Tropical (CIAT) and Pan-

Africa Bean Research Alliance (PABRA), CIAT Regional Office. Africa, Kampala, Uganda, 29.

Asfaw, A., Simane, B., Hassen, A. and Bantider, A. 2018. Variability and time series trend analysis of rainfall and temperature in northcentral Ethiopia: a case study in Woleka sub-basin. *Weather Climate Extremes*, 19, 29–41.

Baccini, M., Kosatsky, T. and Biggeri, A. 2013. Impact of Summer Heat on Urban Population Mortality in Europe during the 1990s: An Evaluation of Years of Life Lost Adjusted for Harvesting, *PLoS ONE*, 7 (8), 1-8.

Barkhordarian,A., Bhend, J. and von Storch, H. 2012. Consistency of observed near surface temperature trends with climate change projections over the Mediterranean region. *Climate Dynamics*, 38(10), 1695-1702.

Barnes, J,. MacGregor, J. and Alberts, M. 2012. Expected climate change impacts on land and natural resource use in namibia: exploring economically efficient responses. Pastoralism: *Research, Policy and Practice*, 2(22), 23.

Barnett, A.G., Dobson, A.J., McElduff, P., Salomaa, V., Kuulasmaa, K. & Sans, S. 2005. Cold periods and coronary events: an analysis of populations worldwide, *Journal of epidemiology and community health*, 59 (7), 551-557.

Barnett, A.G., Sans, S., Salomaa, V., Kuulasmaa, K. & Dobson, A.J. 2007. The effect of temperature on systolic blood pressure, *Blood Pressure Monitoring*, 12 (3), 195-203.

Barriopedro, D.E.M., Fischer, J., Luterbacher, J., Trigo, R.M. and Garcia-Herrera, R., 2011. The hot summer of 2010: redrawing the temperature record map of Europe. *Science*, 332(6026), 220-224.

Bellprat, O., Guemas, V., Doblas-Reyes, F. and Donat, M.G. 2019. Towards reliable extreme weather and climate event attribution. *Nature Communications*, 10, 1-16.

Beniston, M., Stephenson, D.B., Christensen, O.B., Ferro, C.A.T., Frei, C., Goyette, S., Halsnaes, K., Holt, T., Jylhä, K., Koffi, B., Palutikof, J., Schöll, R., Semmler, T. and Woth, K. 2007. Future extreme events in European climate: an exploration of regional climate model projections. *Climatic Change*, 81(1), 71-95.

Blain, G.C. 2013. The Mann-Kendall test: the need to consider the interaction between serial correlation and trend. *ActaScientiarum. Agronomy*, 35(4), 393–402.

Błażejczyk, K., Epstein, Y., Jendritzky, G., Staiger, H. and Tinz, B. 2011. Comparison of UTCI to selected thermal indices, *International Journal of Biometeorology,* 56, 515-535

Błażejczyk, K., Jendritzky, G., Bröde, P.K., Fiala, D., Havenith, G., Epstein, Y., Psikuta, A. and Kampmann, B. 2013. An Introduction To The Universal Thermal Climate Index (UTCI), *Geographia Polonica*, 86 (1), 5-10.

Blázquez, J. and Nuñez, M.N. 2013. Analysis of uncertainties in future climate projections for South America:comparison of WCRP-CMIP3 and WCRP-CMIP5 models. *Climate Dynamics*, 41(4), 1039-1056.

Bluestein, M. and Zecher, J. 1999. A New Approach to an Accurate Wind Chill Factor, *Bulletin of the American Meteorological Society*, 80, 1893-1899.

Blunden, J. and Arndt, D. S. 2020. State of the Climate in 2019. *Bulletin of the American Meteorological Society*, 101(8), 429-441.

Bridger, R., 2008. Introduction to Ergonomics. *International Journal of Industrial Ergonomics,* 44, 892-893.

Bröde, P.K., 2009. Physiological Responses to Temperature and Humidity compared with Predictions of PHS and WBGT. Proceedings of ICEE. Bröde, P.K., Błazejczyk, K., Fiala, D., Havenith, G., Holmér, I., Jendritzky, G., Kuklane, K. and Kampmann, B. 2013. The

Universal Thermal Climate Index UTCI compared to ergonomics standards for assessing the thermal environment, *Industrial Health*, 51 (1), 16-24.

Bröde, P., Fiala, D., Błażejczyk, K., Holmér, I., Jendritzky, G., Kampmann, B., Tinz, B. & Havenith, G. 2012. Deriving the operational procedure for the Universal Thermal Climate Index (UTCI), *International Journal of Biometeorology*, 56 (3), 481-494.

Bröde, P.K., Krüger, E.L. and Fiala, D. 2013. UTCI: Validation And Practical Application To The Assessment Of Urban Outdoor Thermal Comfort, *Geographia Polonica*, 86 (1), 11-20.

Brown, P.J., Bradley, R.S. and Keimig, F.T. 2010. Changes in extreme climate indices for the northeastern United States, 1870-2005. *Journal of Climate,* 23(14), 6555-6572.

Brown, S.J., Caeser, J. and Ferro, C.A.T. 2008. Global changes in extreme daily temperature since 1950. *Journal of Geophysical Research*, 113, 1–11.

Bureau of Meteorology, 2021. Annual climate statement 2020. Australian Government. Accessed 09 March 2021. http://www.bom.gov.au/climate/current/annual/aus/#tabs=Temperature.

Burke, M.B., Miguel, E., Satyanath, S., Dykema, J.A. and Lobell, D.B. 2009. Warming increases the risk of civil war in Africa. *Proceedings of the National Academy of Sciences of the United States of America,* 106(49), 20670-20674.

Caesar, J. and Alexander, L. 2006. Large-scale changes in observed daily maximum and minimum temperatures and analysis of a new gridded data set. *Journal of Geophysical Research*, 111. 2014-2026.

Caloiero, T. 2017. Trend of monthly temperature and daily extreme temperature during 1951-2012 in New Zealand. *Theoretical and Applied Climatology*, 129(2), 111–127.

Ceccherini, G., Russo, S., Ameztoy, I., Marchese, A.F. and Moreno, C.C. Heat waves in Africa 1981–2015, observations and reanalysis. *Natural Hazards and Earth System Sciences,* 17, 115-125.

Chai, H., Cheng, W., Zhou, C., Chen, X., Ma, X. and Zhao, S. 2011. Analysis and comparison of spatial interpolation methods for temperature data in Xinjian Ugur Autonomous region, China. *Natural Science*, 3(12), 999–1010.

Chaney, N.W., Sheffield, J., Villarini, G. and Wood, E.F. 2014. Development of a High-Resolution Gridded Daily Meteorological Dataset over Sub-Saharan Africa: Spatial Analysis of Trends in Climate Extremes. *Journal of Climate,* 27, 5815-5835.

Chen, P.Y. and Popovich, P.M. 2002. *Correlation: Parametric and non-parametric measures*. Thousand Oaks, Sage Publications, 1, 9-15.

Cheung, M.W.L. and Chan, W. 2004. Testing dependent correlation coefficients via structural equation modelling, *Organizational Research Methods*, 7(2), 206-223.

Christensen, J.H., Kanikicharla, K.K., Aldrian, E., An, S.I., Cavalcanti, I.F.A., de Castro, M., Dong, W., Goswami, P., Hall, A., Kanyanga, J.K. and Kitoh, A. 2013. Climate phenomena and their relevance for future regional climate change. In Climate change 2013 the physical science basis: Working group I contribution to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press. 1217-1308.

Christidis, N. and Stott, S. 2016. Attribution analysis of temperature extremes using a set of 16 indices. *Weather and Climate Extremes*, 14, 24–35.

Christopherson, R.W. 2014. *Geosystems: An Introduction to Physical Geography.* 8th ed. Pearson, Education Limited. Essex, England. 728

Climate Service Center (CSC). 2013. Climate fact sheet: Namibia. Climate Service Center, Hamburg, Germany.

Coa, W., Hu, J. and Yu, X. 2009. A study on temperature interpolation methods based on GIS. 17th *International Conference on Geoinformation*. IEE.: Fairfax, VA, USA.

Collier, P., Conway, G. and Venables, T. 2008. Climate change and Africa. *Oxford Review of Economic Policy*, 24, 337–353.

Collins, J.M. 2011. Temperature variability over Africa. *Journal of Climate*, 24(14), 3649-3666.

Colombo, A.F., Etkin, D. and Karney, B.W. 1998. Climate Variability and the Frequency of Extreme Temperature Events for Nine Sites across Canada: Implications for Power Usage. *Journal of Climate,* 12(8), 2460-2502.

Coumou, D. and Robinson, A. 2013. Historic and future increase in the global land area affected by monthly heat extremes. *Environmnetal Research Letter,* 8(3), 6-12.

Coumou, D., Robinson, A. and Rahmstorf, S. 2013. Global increase in record breaking monthly mean temperatures. *Climate Change*, 118, 771–782.

Cousineau, L. 2017. Heat Wave Definition. Climate Change Guide: Your Guide to a More Sustainable Future. Accessed 26 November 2019. https://www.climate-change-guide.com/heat-wave-definition.html.

Crawford, A. and Terton, A. 2016. Review of current and planned adaptation action in Namibia. CARIAA Working Paper no. 12. International Development Research Centre, Ottawa, Canada and UK Aid, London, United Kingdom.

Cruz, R.V., Harasawa, H., Lal, M., Wu, S., Anokhin, Y., Punsalmaa, B., Honda, Y., Jafari, M., Li, C. and Huu, N.N. 2007. *Asia. Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E (eds). Cambridge University Press, Cambridge, UK, 469-506.

CSIRO. 2001. Climate projections for Australia. Commonwealth Scientific and Industrial Research Organisation. *Atmospheric Research,* Melbourne, 8, 1-8.

Cubasch, U.D., Wuebbles, D., Chen, M.C., Facchini, D., Frame, N., Mahowald. and Winther, J.G. 2013. Introduction. In: Climate Change 2013: *The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds.). Cambridge University Press, United Kingdom and New York, USA. 119-158.

David, A,. Braby, J,. Zeidler, J,. Kandjinga, L. and Ndokosho, J. 2013. Building adaptive capacity in rural Namibia: Community information toolkits on climate change. *International Journal of Climate Change Strategies and Management,* 5, 215–229.

Davis, C.L., Hoffman, M.T. and Roberts, W. 2016. Recent trends in the climate of Namaqualand, a megadiverse arid region of South Africa. *South African Journal of Science,* 112(4), 1–9.

Deickmann, U., Odendaal W., Tarr, J. and Schreij, A. 2013. Indigenous peoples and climate change in Africa: report on case studies of Namibia's Topnaar and Hai||om Communities Land, Environment and Development Project, Legal Assistance Centre, Windhoek, 112.

Denton, F., Anderson, S. and Ayers, J. 2011. *Getting African Climate Change Research Recognised*. IIED Briefing, Lessons fromAdaptation in Practice Series,November 2011, International Institute for Environment and Development (IIED), London, UK, 4.

Department of Industry and Resources, 1997. Management And Prevention Of Heat Stress. Government of Western Australia. Perth, 1-18.

De Perez, E.C., Van Aalst, M., Bishiniotis, K., Mason, S., Nissan, H., Pappenberger, F., Stephens, E., Zsoster, E. and Van den Hurk, B. 2018. Global predictability of temperature extremes. *Environmental Research Letters*, 13, 1-9.

Diallo, I., Giorgi, F., Sukumaran, S., Stordal, F. and Giuliani, G. 2014. Evaluation of RegCM4 driven by CAM4 over Southern Africa: mean climatology, interannual variability and daily extremes of wet season temperature and precipitation. *Theoretical and Applied Climatology,* 121, 749–766.

Diedhiou, A., Bichet, A., Wartenburger, R., Seneviratne, S., Rowell, D., Sylla, M., Diallo, I., Todzo, S., Touré, N., Camara, M., Ngatcha, B., Kane, N., Tall, L. and Affholder, F. 2018. Changes in climate extremes over West and Central Africa at 1.5°C and 2°C global warming. *Environmental Research Letters*. 13, 1-10.

Diffenbaugh, N.S. and Giorgi, F. 2012: Climate change hotspots in the CMIP5 global climate model ensemble. *Climatic Change,* 114(4), 813-822.

Diffenbaugh, N.S. and Scherer, M. 2011. Observational and model evidence of global emergence of permanent, unprecedented heat in the 20th and 21st centuries. *Climatic Change*, 107(4), 615-624.

Dirkx, E., Hager, C., Tadross, M., Bethune, S. and Curtis B. 2008. Climate change vulnerability and adaptation assessment: Namibia. Desert Research Foundation of Namibia and Climate Systems Analysis Group for the Ministry of Environment and Tourism. Namibia, Windhoek, 149.

Donat, M.G., Alexander, L.V., Yang, H., Durre, I., Vose, R., Dunn, R.J.H., Willett, K.M., Aguilar, E., Brunet, M. and Caesar, J. 2013. Updated analyses of temperature and precipitation extreme indices since the beginning of the twentieth century: the HadEX2 dataset. *Journal for Geophysical Research: Atmospheres*, 118, 2098-2118.

Dosio, A. 2017. Projection of temperature and heat waves for Africa with an ensemble of CORDEX Region Climate Models. *Climate Dynamics,* 49, 493-519.

Dosio, A., Mentaschi, L., Fischer, E.M. and Wyser, K. 2018. Extreme heat waves under 1.5°C and 2°C global warming. *Environmental Research Letters*, 13(5), 1-18.

Driscoll, D.M. 1992. Thermal Comfort Indexes. Current Uses and Abuses, *National Weather Digest*, 17, (4), 33-38.

Easterling, D.R., Meehl, G.A., Parmesan, C., Changnon, S.A., Karl, T.R., Mearns, L.O. 2000. Climate Extremes: Observations, Modeling, and Impacts. *Science*, 289, 2068–2074.

Easterling, D.R., Kunkel, K.E., Wehner, M.F. and Sun, L. 2016. Detection and attribution of climate extremes in the observed record. *Weather and Climate Extremes,* 11, 17–27.

Ebi, K.L., Burton, I. and McGregor, G., 2009. The Status and Prospects for Biometeorology. In Elbi, K.L., McGregor, G. and Burton, I. (eds.). *Biometeorology for adaptation to climate variability and change*. Springer Science & Business Media. Canada, Ontario, 269-275.

EEA, 2012. Climate Change, Impacts and Vulnerability in Europe 2012, an IndicatorBased Report. EEA Report No. 12/2012. *European Environment Agency (EEA),* Copenhagen, Denmark, 304 pp

Projections of rapidly rising surface temperatures over Africa under low mitigation

Engelbrecht, F Adegoke, J., Bopape, M., Naidoo, M., Garland, R., Thatcher, M., McGregor, J., Katzfey, J., Werner, M., Ichoku, C., and Gatebe, C. 2015. Projections of rapidly rising surface temperatures over Africa under low mitigation. *Environmnetal Research Letters,* 10, 1-16.

Fahey, K.A., Wuebbles, D.W., Hibbard, K.A., Dokken, D.J., Stewart, B.C. and Maycock, T.K. 2017. *Climate Science Special Report: A Sustained Assessment Activity of the U.S. Global*

Change Research Program. U.S. Global Change Research Program, Washington, DC, USA. 98-159.

Fanger, P.O. 1970. *Thermal Comfort, Analysis and Application in Environment Engineering*. Danish Technical Press, Copenhagen.

Farajzadeh, H., Saligheh, M., Alijani, B., 2016. Application of Universal Thermal Climate Index in Iran from a tourism perspective, *International Journal of Environment and Climate Change*, 35, 117–138.

Few, S.F., Philip, S.Y., Van Olenborgh, G.J., Otto, F.E.L., Vautard, R. and Van der Schrier, G. 2019. The exceptional summer heatwave in southern Europe. In: Explaining extremes of 2017 from a climate perspective. *Bulletin of the American Meteorological Society*. 100(1), 49–53.

Fiala, D., Havenith, G., Bröde, P., Kampmann, B. and Jendritzky, G. 2012. UTCI-Fiala multi-node model of human heat transfer and temperature regulation, *International Journal of Biometeorology*, 56 (3), 429-441.

Fiala, D., Lomas, K.J. and Stohrer, M. 1999. A computer model of human thermoregulation for a wide range of environmental conditions: The passive system, *Journal of Applied Physiology*, 87, 1957-1972.

Fiala, D., Lomas, K.J. and Stohrer, M. 2001. Computer prediction of human thermoregulatory and temperature responses to a wide range of environmental conditions, *International Journal of Biometeorology*, 45 (3), 143-159.

Fiala, D., Lomas, K.J. and Stohrer, M. 2003. First-Principles Modeling of Thermal Sensation Responses in SteadyState and Transient Conditions. *ASHRAE Transactions*, 109 (1), 179-186.

Fierro, A. O. and Leslie, L. M. 2013. Links between Central West Western Australian Rainfall Variability and Large-Scale Climate Drivers. *Journal of Climate*, 26(7), 2222-2246.

Filahi, S., Tanarhte, M., Mouhir, L., Morhit, M.E.L. and Tramblay, Y. 2016. Trends in indices of daylu temperature and precipitation extremes in Marocco. *Theoretical and Applied Climatology,* 1(24), 959-972.

Fioravanti, G., Pervitali, E. and Desiato, F. 2019. A new homogenised daily data set for temperature variability assessment in Italy. *International Journal of Climatology*, 39, 5635–5654.

Flavelle, C. and Popovich, N. 2019. Heat Deaths Jump in Southwest United States, Puzzling Officials. 26 August 2019. The New York Times, Washington.

Floyd, L.E., J.W. Cook, L.C. Herring, and P.C. Crane, 2003: SUSIM'S 11-year observational record of the solar UV irradiance. *Advances in Space Research*, 31, 2111-2120.

Founda, D., Pierros, F., Katavoutas, G. and Keramitsoglou, I. 2019. Observed Trends in Thermal Stress at European Cities with Different Background Climates, *Atmosphere*, 10 (8), 436.

Frich, P., Alexander, V., Della-Marta, P., Gleason, B., Haylock, M., Klein Tank, A.M.G. and Peterson, T. 2002. Observed coherent change in climatic extremes during the second half of the twentieth century. *Climate Research,* 19, 193–212.

Fröhlich, C. and Lean, L. 2004: Solar radiative output and its variability: Evidence and 7 mechanisms. *The Astronomy and Astrophysics Review*, 12, 273-320.

Funk, C., Dettinger, M.D., Michaelsen, J.C., Verdin, J.P., Brown, M.E., Barlow, M. and Hoell, A. 2008. *Warming of the Indian Ocean threatens eastern and southern African food security but could be mitigated by agricultural development*. Proceedings of the National Academy of Sciences of the United States of America. 105(32), 11081-11086.

Funk, C., Eilerts, G., Verdin, J., Rowland, J. and Marshall, M. 2011. *A Climate Trend Analysis of Sudan*. USGS Fact Sheet 2011-3072, U.S. Department of the Interior, U.S. Geological Survey (USGS), Reston, VA, USA, 6.

Funk, C., Michaelsen, J. and Marshall, M.2012. Mapping recent decadal climate variations in precipitation and temperature across Eastern Africa and the Sahel. In: *Remote Sensing of Drought: Innovative Monitoring Approaches.* Wardlow, B.D., Anderson, M.C. and.Verdin J.P. (Eds). CRC Press, Boca Raton, FL, USA, 331-358.

Gaffen, G. J. and Ross, R. J. 1998. Increased summertime heat stress in the US, *Nature*, 396, 529-530.

Garland, R.M., Matooane, M., Engelbrecht, F.A., Bopape, M.J.M., Landman, W.A., Naidoo, M., Merwe, J.V.D. and Wright, C.Y. Regional Projections of Extreme Apparent Temperature Days in Africa and the Related Potential Risk to Human Health. *International Journal of Environmental Research and Public Health,* 12, 12577-12604.

Ge, Q., Kong, Q., Xi, J. and Zheng, J. 2016. Application of UTCI in China from a tourism perspective, *Theoretical and Applied Climatology*, 128 (4), 551-561.

Gebrechorkos, S.H., Hülsmann, S. and Bernhofer, C. 2018. Changes in temperature and precipitation extremes in Ethiopia, Kenya, and Tanzania. *International Journal of Climatology,* 39, 18.

Geng, Q., Wu, P. and Zhao, X. 2016. Spatial and temporal trends in climatic variables in arid areas of northwest China. *International Journal of Climatology,* 36, 4118–4129.

Geographia. 2005. Exploring Namibia: An introduction to Namibia. Accessed 2 December 2020. http://www.geographia.com/namibia/

Gibbons, J.D. and S. Chakraborti. 2003. *Nonparametric Statistical Inference*. Marcel Dekker, New York.

Givoni, B. 1979. Man, *Climate and Architecture*. Applied Science Publishers. London, 483.

Goodess, C., Jacob, D., Déqué, M., Guttiérrez, J., Huth, R., Kendon, E., Leckebusch, G., Lorenz, P. and Pavan, V. 2009. Downscaling methods, data and tools for input to impacts assessments. In: ENSEMBLES: Climate Change and its Impacts: Summary of Research and Results from the ENSEMBLES Project. Van der Linden, P. and Mitchell J.F.B. (eds). Met Office Hadley Centre, Exeter, UK, pp. 59-78.

Goovaerts, P. 2000. Geostatistical approaches for incorporating elevation into the spatial interpolation of rainfall, *Journal of Hydrology*, 228, 113-129.

Gore, M., Abiodun, B.J. and Kucharski, F. 2020. Understanding the influence of ENSO patterns on drought over southern Africa using SPEEDY. *Climate Dynamics*, 54(1-2), 307-327.

Government of the Republic of Namibia. 2002. Initial national communication to the United Framework Convention on Climate Change. Windhoek: Ministry of Environment and Tourism.

Government of the Republic of Namibia. 2011. National policy on climate change for Namibia - 2011. Windhoek: Ministry of Environment and Tourism.

Government of the Republic of Namibia. 2013. National Climate Change Strategy and Action Plan:2013 - 2020. Windhoek: Ministry of Environment and Tourism.

Government of the Republic of Namibia. 2015 Third National Communication to the United Nations Framework Convention on Climate Change. Ministry of Environment and Tourism, Windhoek, 173.

Graba, S. and Zumthurm, T. 2018. The land and its climate knows no transition, no middle ground, everywhere too much or too little: a documentary-based climate chronology for central Namibia, 1845–1900, *International Journal Of Climatology,* 38 (1), 643-659.

Gray, L.J., Beer, J., Geller, M., Haigh, J.D., Lockwood, M., Matthes, K., Cubasch, U., Fleitmann, D., Harrison, G., Hood, L., Luterbacher, J., Meehl, G.A., Shindell, D., van Geel, B. and White, W. 2010: Solar influences on climate. *Reviews of Geophysics*, 48(4), 1-53.

Gremlowski. L. 2010. *Community-Based Adaptation to floods in North-Central Namibia - A Case Study in the Omusati Region*. University of Applied Sciences. Germany, Hamburg.

GRN – See Government of the Republic of Namibia.

Gunarathna, M.H.J.P., Nirmanee, K. G. and Kumari, N. 2016. Are Geostatistical Interpolation Methods Better than Deterministic Interpolation Methods in Mapping Salinity of Groundwater?. *International Journal of Research and Innovations in Earth Science,* 3. 2394-1375.

Haag, I., Jones, P.D. and Samimi, C. 2019. Central Asia’s Changing Climate: How Temperature and Precipitation Have Changed across Time, Space, and Altitude. *Climate*, 7, 123-146.

Harrington, L.J., Frame, D.J., Hawkins, E. and Joshi, M. 2017. Seasonal cycles enhance disparities between low- and high-income countries in exposure to monthly temperature emergence with future warming. *Environmental Research Letters*, 12-21.

Harrington, L.J. and Otto, F.E.L. 2010. Reconciling theory with the reality of African heatwaves. *Nature Climate Change,* 10, 794-798.

Harvard Medical School. 2019. Heat Stroke (Hyperthermia)-Harvard Health Publishing. Accessed 12 October 2019. https://www.health.harvard.edu/a_to_z/heat-stroke-hyperthermia-a-to-z.

Hatfield, J. L. and Prueger, H. J. 2015. Temperature extremes: Effect on plant growth and development, *Weather and Climate Extremes*, 10, 4-10.

Havenith, G. 2001. An individual model of human thermoregulation for the simulation of heat stress response, *Journal of Applied Physiology*, 90, 1943-1954.

Havenith, G., Fiala, D., Błazejczyk, K., Richards, M., Broede, P., Holmér, I., Rintamaki, H., Benshabat, Y. and Jendritzky, G. 2011. The UTCI Clothing Model, *International Journal of Biometeorology,* 56 (3), 461-470.

Hendrix, C.S. and Salehyan, I. 2012. Climate change, rainfall, and social conflict in Africa. *Journal of Peace Research,* 49(1), 35-50.

Hirsch, R.M., J.R. Slack. and R.A. Smith. 1982. Techniques of trend analysis for monthly water quality data, *Water Resources Research,* 18 (1), 107-121.

Hoag., H. 2014. Russian summer tops 'universal' heatwave index. International weekly journal of Science. Accessed 13 October 2019. https://www.nature.com/news/russian-summer-tops-universal-heatwave-index-.16250#targetText=The%20torrid%20weather%20that%20choked,gauge%20the%20magnitude%20of%20heatwaves.

Holmgren, K., Tyson, P.D., Moberg, A and Svanered, O. 2001. A preliminary 3000-year regional temperature reconstruction for South Africa. *South African Journal of Science,* 97, 49-51.

Hondula, D. M., Davis, R.E. and Georgescu, M. 2018. Clarifying the connections between green space, urban climate, and heat-related mortality. *American Journal of Public Health,* 108(2), 562-563.

Hondula, D. M., Balling, R. C. Vanos, J. K. and Georgescu, M. 2015. Rising temperatures, human health, and the role of adaptation. *Current Climate Change Reports*, 1(3),144-154.

Höppe, P. 1999. The physiological equivalent temperature - a universal index for the biometeorological assessment of the thermal environment, *International Journal of Biometeorology*, 43, 71-75.

Hulme, H., Doherty, R., Ngara, T., New, M., and Lister, D. 2001. African climate change: 1900-2100. *Climate Research*, 17, 145-168.

Hyrkäs, H., Jaakkola, M.S., Ikäheimo, T.M., Hugg, T.T. & Jaakkola, J.J. 2014. Asthma and allergic rhinitis increase respiratory symptoms in cold weather among young adults, *Respiratory Medicine,* 108 (8), 63-70.

ICRC, 2020. International Committee of the Red Cross. *When Rain Turns to Dust*. ICRC, Geneva. 62.

Ikäheimo, T.M. 2014. *The effects of temperature on human health*. Center for Environmental and Respiratory Health Research, WHO Collaborating Center in Global Change, Environment and Public health. Institute of Health Sciences. University of Oulu.

IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J.B.R., Maycock, T.K., Waterfield, T., Yelekçi, O., Yu, R. and Zhou, B. (Eds). Cambridge University Press. In Press

IPCC, 2018. Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Masson-Delmotte, V., Zhai, P., Pörtner, H.O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J.B.R., Chen, Y., Zhou, X., Gomis, M.I., Lonnoy, E., Maycock,T., Tignor, M. and Waterfield T. (Eds). World Meteorological Organization, Geneva, Switzerland, 1-32.

Irannezhad, M., Moradkhani, H. and Kløve, B. 2019. Corrigendum to "Spatio-temporal variability and trends in extreme temperature events in Finland over the recent decades: Influence of Northern Hemisphere teleconnection patterns". *Advances in Meteorology,* 1, 1–17.

Jaakkola, K., Saukkoriipi, A., Jokelainen, J., Juvonen, R., Kauppila, J., Vainio, O., Ziegler, T., Rönkkö, E., Jaakkola, J.J. and Ikäheimo, T.M. 2014. Decline in temperature and humidity increases the occurrence of influenza in cold climate, *Environmental Health*, 13(1), 22.

Jacob, D. and Podzun, R. 2010. Global warming below 2°C relative to pre-industrial level: how might climate look like in Europe. *Nova Acta Leopoldina*, 384, 71-76.

Jendritzky, G., de Dear, R. and Havenith, G. 2012. UTCI—why another thermal index?, *International Journal of Biometeorology*, 45 (3), 421-428.

Jendritzky, G., Havenith, G., Weihs, P., Batchvarova, E., and DeDear, R. 2007. The universal thermal climate index UTCI goal and state of COST action 730. In Mekjavic, I.B., Kounalakis, S.N. and Tayloreds, N.A.S. (eds.). *Proceedings of the 12th International Conference on Environmental Ergonomics*. Ljubljana, 509-512

Jendritzky, G., Maarouf, A., Staiger, H. 2001. Looking for a Universal Thermal Climate Index UTCI for Outdoor Applications. Windsor-Conference on Thermal Standards. Windsor. UK: 1-17

Jendritzky, G., Staiger, H., Bucher, K., Graetz, A. and Laschewski, G. 2000. The Perceived Temperature - The Method of the Deutscher Wetterdienst for the Assessment of Cold Stress and Heat Load for the Human Body. Internet Workshop on Windchill. 3-7 April 2000. Environment Canada.

John, J., Garland, R.M. Landman, W.A. 2015. Understanding extreme temperature events by environmental health stakeholders in South Africa. CSIR, Pretoria, South Africa. 17.

Johnson, N.C., Xie, S., Kosaka, Y. and Li, X. 2018. Increasing occurrence of cold and warm extremes during the recent global warming slowdown. *Nature Communications*, 9, 1–12.

Jones, C. and Carvalho, L.V. 2013. Climate change in SouthAmerican monsoon system: present climate and CMIP5 projections. *Journal of Climate*, 26(17), 6660-6678.

Jones, P. D., Lister, D. H. and Li, Q. 2008. Urbanization effects in large-scale temperature records, with an emphasis on China. *Journal of Geophysical Research,* 113, 1-12.

Jones, P.D., Lister, D.H., Osborn, T.J., Harpham, C., Salmon, M. and Morice, C.P. 2012. Hemispheric and large-scale land-surface air temperature variations: An extensive revision and an update to 2010. *Journal of Geophysical Research,* 117, 118-129.

Jury, M.R. 2017. Climate trend across South Africa since 1980. *Water SA,* 43(4), 297-307.

Kaiser, D.P. and Qian, Y. 2002. Decreasing trends in sunshine duration over China for 1954–1998: indication of increased haze pollution?. *Geophysical Research Letter*, 29(21),381–384

Kampmann, B., Bröde, P., Jendritzky, G., Fiala, D. and Havenith, G. 2011. The Universal Thermal Climate Index UTCI for Assessing the Outdoor Thermal Environment. The Fourth International Conference on Human-Environment System. Japan.

Kandjinga, L,. Zeidler, J,. Nunes, I,. Chunga, R. and Ndokosho, J. 2010. How to reach out to local communities and assist them to adapt to climate change. ICID+18, 2nd International Conference: Climate, Sustainability and Development in Semi-arid Regions. 16 – 20 August 2010, Ceara, 20.

Karl, T.R., Nicholls, N. and Ghazi, A. 1999. CLIVAR/GCOS/WMO workshop on indices and indicators for climate extremes: Workshop summary. *Climatic Change*, 42, 3-7.

Karoly, D.J. and Braganza, K. 2005. Attribution of recent tempera-ture changes in the Australian region. *Journal of Climate*. 18, 457-64.

Karuaihe, S.T. 2019. “Namibia’s urban poor are stuck in limbo, without land or services”. *The Conversation*. 19 September 2019. Accessed 7 December 2020. https://theconversation.com/namibias-urban-poor-are-stuck-in-limbo-without-land-or-services122870#:~:text=In%202004%2C%20informal%20settlers%20constituted,population%20were%20living%20in%20shacks.

Keja-Kaereho, C. and Tjizu, B. 2019. Climate Change and Global Warming in Namibia: Environmental Disasters vs. Human Life and the Economy. *Management and Economics Research Journal*, 5(1), 15-28.

Kenawy, A.M.E.L., Lopez-Moreno, J.I., McCabe, M.F., Robaa, S.M., Domínguez-Castro, F., Peña-Gallardo, M., Trigo, R.M., Hereher, M.E., Al-Awadhi, T. and Vicente-Serrano, S.M. 2019. Daily temperature extremes over Egypt: Spatial patterns, temporal trends, and driving forces. *Atmospheric Research*, 1, 226-238.

Kendall, M.G. 1955. *Rank Correlation Methods*. London: Charles Griffen: 196.

Kendall, M.G. 1975. Non-parametric tests against trend, *Econometrica*, 13: 163-171.

Kew, S.F., Philip, S.J., Hauser, M., Hobbins, M., Wanders, N., Van Oldenborgh, G.J., Van der Wiel, K., Veldkamp, T.I.E., Kimutai, J., Funk, C. and Otto, F.E.L. 2013. Impact of precipitation and increasing temperatures on drought trends in eastern Africa. *Earth System Dinamics,* 12, 17-35.

Kgabi, N.A., Uugwanga, M. and Ithindi, J. 2016. Atmospheric Conditions and Precipitation in Arid Environments: A Case of Namibia. *International Journal of Environmental Protection*, 6(1), 148-159. .

Khandekar, M.L. 2013. Are Extreme Weather Events on the Rise? *Energy and Environment*, 24(4), 537-549

Kidane, Y. O., Steinbauer, M. J. and Beierkuhnlein, C. 2019. Dead end for endemic plant species? A biodiversity hotspot under pressure. *Global Ecology and Conservation,* 1, 19-29.

Kim, Y.-H., Min, S.-K., Zhang, X.B., Zwiers, F., Alexander, L.V., Donat, M.K. and Tung, Y.-S. 2016. Attribution of extreme temperature changes during 1951-2000. *Climate Dynamics,* 46, 1769–1782.

Kjellström, E., Nikulin, G., Hansson, U., Strandberg, G. and Ullerstig, A. 2011. 21st century changes in the European climate: uncertainties derived from an ensemble of regional climate model simulations. *Tellus A, Series A*. 63A(1), 24-40.

Klein Tank, A.M.G., Zwiers, F.W. and Zhang, X. 2009. Guidelines on analysis of Extremes in a Changing Climate in Support of Informed Decisions for Adaptation (WCDMP no. 72, WMO-TD no. 1500). Switzerland: World Meteorological Organization, 54 pp.

Klintenberg. P., Seely. M. and Christiansson. C. 2007. Local and national perceptions of environmental change in central Northern Namibia: do they correspond? *Journal of Arid Environments*, 69: 506-525.

Knox, J., Hess, T., Daccache, A. and Wheeler, T. 2012. Climate change impacts on crop productivity in Africa and South Asia. *Environmental Research Letters,* 7, 8-13.

Kolendowicz, L., Półrolniczak, M., Szyga-Pluta, K. and Bednorz, E. 2018. Human-biometeorological conditions in the southern Baltic coast based on the universal thermal climate index (UTCI), *Theoretical and Applied Climatology,* 143 (2), 363-379.

Koppe, C. and Jendritzky, G. 2005. Inclusion of short-term adaptation to thermal stresses in a heat load warning procedure. *Meteorologische Zeitschrift*, 14(2), 271–278.

Kosaka, Y. and Xie, S. 2013. Recent global-warming hiatus tied to equatorial Pacific surface cooling. *Nature*, 501, 403-407.

Kousari, M.R., Ahani, H. and Hendi-Zadeh, R. 2013. Temporal and spatial trend detection of maximum air temperature in Iran during 1960–2005. *Global and Planetary Change,* 111, 97–110.

Kovats, R.S., Valentini, R., Bouwer, L.M., Georgopoulou, E., Jacob, D., Martin, E., Rounsevell, M. and Soussana, J.F. 2014. Europe. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Barros, V.R., Field, C.B., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R. and White, L.L. (Eds). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1267-1326.

Kreft, S., Eckstein, D., Junghans, L., Kerestan, C. and Hagen, U. 2015. Who Suffers Most From Extreme Weather Events? Weather-related Loss Events in 2013 and 1994 to 2013. Global Climate Risk Index 2015. *Germanwatch*. Berlin.

Kruger, A.C. and Nxumalo, M. 2017. Surface temperature trends from homogenised time series in South Africa: 1931-2015. *International Journal of Climatology*, 37, 2364–2377.

Kruger, A.C., Rautenbach, H., Mbatha, S., Ngwenya, S. and Makgoale, T.E. 2019. Historical and projected trends in near-surface temperature indices for 22 locations in South Africa. *South African Journal for Science,* 115(6), 9-21.

Kruger, A.C. and Sekele, S.S. 2012. Trends in extreme temperature indices in South Africa: 1962-2009. *International Journal of Climatology*, 33(3), 661-676.

Kruger,A.C. and Shongwe, S. 2004. Temperature trends in South Africa: 1960-2003. *International Journal of Climatology*, 24(15), 1929-1945.

Kumar, S., Kinter, S.I., Dirmeyer, P.A., Pan, Z. and Adams, J.M. 2013. Multi-decadal climate variability and the “warming hole” in NorthAmerica – resultsfrom CMIP5 20th and 21st century climate simulations. *Journal of Climate*, 26(11), 3511-3527.

Kunkel, K.E., Bromirski, P., Brooks, H.E., Cavazos, T., Douglas, A.V., Easterling, D.R., Emanuel, K.A., Groisman, P.Y., Holland, G.J., Knutson, T.R., Kossin, J.P., Komar, P.D., Levinson, D. and Smith, R.L. 2008. Observed changes in weather and climate extremes. In: Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands. Karl, T.R., Meehl, G.A., Miller, C.D., Hassol, S.J., Waple, A.M. and Murray, W.L. (Eds). Report by the United States Climate Change Science Program (CCSP) and the Subcommittee on Global Change Research, Department of Commerce, NOAA’s National Climatic Data Center,Washington, DC, USA. 35-80.

Kunkel, K.E., Stevens, L.E., Stevens, S.E., Sun, L., Janssen, E., Wuebbles, D. and Dobson, J. G. 2013. *Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 9. Climate of the Contiguous United States*. NOAA Technical Report NESDIS 142-9. National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service, Washington, D.C., 85 pp.

Kurihara, K., Ishihara, K., Sakai, H., Fukuyama, Y., Satou, H., Takayabu, I., Murazaki, K., Sato, Y., Yukimoto, S. and Noda, A. 2005. Projections of climatic change over Japan due to global warming by high resolution regional climate model in MRI. *Scientific Online Letters on the Atmosphere*, 1, 97-100.

Kusangaya, S., Warburton, M.L., Van Garderen, E.A. and Jewitt G.P.W. 2012. Impacts of Climate Change on Water Resources in Southern Africa: A Review. Applied Center for Climate and Earth Systems Science. University of KwaZulu Natal, South Africa. 17.

Kuvare, U., Maharero, T. and Kamupingene, G. 2008. Research on farming systems change to enable adaptation to climate change. University of Namibia for the Ministry of Environment and Tourism and the United Nations Development Program Namibia, Windhoek: 103.

Landman, W.A., and Manson, S.J. 1999. Change in the association between Indian ocean sea-surface temperatures and summer rainfall over South Africa and Namibia, *International Journal of Climatology. Royal Meteorological Society*, 19: 1477-1492.

Lam, C.K.C., Gallant, A. and Tapper, N. 2016. Perceptions of thermal comfort in heatwave and non-heatwave conditions in Melbourne, Australia, *Urban Climate*, 24: 204-218.

Landsberg, H.E. 1972. The Assessment of Human Bioclimate, a Limited Review of Physical Parameters. World Meteorological Organization, Geneva: 331.

Lavado, C.W.S., Ronchail, J., Labat, D., Espinoza, J.C. and Guyot, J.L. 2012. Basin-scale analysis of rainfall and runoff in Peru (1969-2004): Pacific, Titicaca and Amazonas drainages. *Hydrological Sciences Journal*, 57(4), 625-642.

Lee, C.C. and Sheridan, S.C. 2018. Trends in weather type frequencies across North America, *Climate and Atmospheric Science*, 1, 41-59.

Lenderink, G. and Van Meijgaard, E. 2008. Increase in hourly precipitation extremes beyond expectations from temperature changes. *Nature Geoscience*, 1(8), 511-514.

Lenssen, N.J.L., Schmidt, G.A., Hansen, J.E., Menne, M.J., Persin, A., Ruedy, R. and Zyss, D. 2019. Improvements in the GISTEMP Uncertainty Model. *Journal of Geophysical Research: Atmosphere*, 124(12), 6307-6326.

Li, D., Zhou, T., Zou, L., Zhang, W. and Zhang, L. 2018. Extreme high-temperature events over East Asia in 1.5°C and 2°C warmer futures: Analysis of NCAR CESM low-warming experiments. *Geophysical Research Letters*, 45, 1541–1550.

Li, J. and Heap, A.D. 2014. Spatial interpolation methods applied in the environmental sciences: A review, *Environmental Modelling & Software,* 53, 173-189.

Liao, H., Chang, W.Y. and Yang, Y. 2015. Climatic effects of air pollutants over China: a review. *Advances in Atmospheric Sciences*, 32(1),115–139.

Longley, P. A., Goodchild, M. F., Maguire, D. J. and Rhind, D. W. 2005. *Geographic information systems and sciences*. 2nd Ed. John Wiley & Sons Ltd. West Sussex, UK.

Logan, F.R. 2009. Namib. Encyclopaedia Britannica. Accessed 2 December 2020. https://www.britannica.com/place/Namib.

Logan F.R. and Silberbauer, G.B. 2019. Kalahari Desert. Encyclopaedia Britannica. Accessed 2 December 2020. https://www.britannica.com/place/Kalahari-Desert.

Lott, F., Christidis, N. and Stott, P. 2013. Can the 2011 East African drought be attributed to anthropogenic climatechange? *Geophysical Research Letter,* 40,1177–1181

Lu, G.Y. and Wong, D.W. 2008. An adaptive inverse-distance weighting spatial interpolation technique, *Computers & Geosciences*, 34, 1044-1050.

Luber, G. and McGeehin, M. 2009. Climate change and extreme heat events, *American Journal of Preventative Medicine,* 35(5), 429-435.

Luterbacher, J., Liniger, M. A., Menzel, A., Estrella, N., Della-Marta, P. M., Pfister, C., Rutishauser, T. and Xoplaki, E. 2007. Exceptional European warmth of autumn 2006 and winter 2007: Historical context, the underlying dynamics, and its phenological impacts, *Geophysical Research Letter*, 34, 1-18.

Ly, M., Traore, S.B., Alhassane, A. and Sarr, B. 2013. Evolotion of some observed climate extremes in West African Sahel. *Weather and Climate Extremes,* 1, 19-25.

Machiwal, D. and Jha, M.K. 2008. Comparative evaluation of statistical tests for time series analysis: application to hydrological time series. *Hydrological Sciences Journal*, 53(2), 353–366.

Madzwamuse, M. 2010. *Drowning Voices: The Climate Change Discourse in South Africa*. Policy Brief 05/2010, Heinrich-Böll-Foundation Southern Africa, Cape Town, South Africa, 8.

MacKellar, N., New, M. and Jack, C. 2014. Observed and modelled trends in rainfall and temperature for South Africa: 1960–2010. *South African Journal of Science,* 110(8), 1-13.

Magrin, G.O., Marengo, J.A., Boulanger, J.P., Buckeridge, M.S., Castellanos, E., Poveda, G., Scarano, F.R. and Vicuña, S. 2014. Central and South America. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Barros, V.R., Field, C.B., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R. and White L.L. (Eds). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1499-1566.

Mallet, J., Fortin, G. and Germain, D. 2018. Extreme weather events in northeastern New Brunswick (Canada) for the period 1950-2012: Comparison of newspaper archive and weather station data. The Canadian Geographer. 62(2), 130–143.

Mann, H.B. 1945. Non-parametric tests against trend. *Econometrica*, 13, 245-259.

Marigi, S.N., Njogu, A.K. and Githungo, W.N. 2016. Trends of Extreme Temperature and Rainfall Indices for Arid and Semi-Arid Lands of South Eastern Kenya. *Journal of Geoscience and Environment Protection*, 4, 158-171.

Matzarakis, A., Rutz, F. and Mayer, H. 2000. Estimation and calculation of the mean radiant temperature within urban structures. In de Dear, R., Kalma, J., Oke, T. and Auliciems, A. (eds.). *Biometeorology and Urban Climatology at the Turn of the Millenium*. WMO, Geneva, 273-278.

Mearns, O., Katz, R.W. and Schneider, S.H. 1984. Extreme High-Temperature Events: Changes in their Probabilities with Changes in Mean Temperature. *Journal of Climate and Applied Meteorology,* 23(12), 1601-1613.

Meissner, R. and Jacobs-Mata, I. 2016. South Africa's Drought Preparedness in the Water Sector: Too Little Too Late. South African Institute of International Affairs. Accessed 2 December 2020 https://www.africaportal.org/publications/south-africas-drought-preparedness-in-the-water-sector-too-little-too-late/

Mekash, A., Tesfaye, K. and Duncan, A.J. 2014. Trends in daily observed temperature and precipitation extremes over three Ethiopianeco-environments. *International Juornal of climatology,* 34, 1990-1999.

Mendelsohn, J., Jarvis, A., Roberts, C. and Robertson, T. 2002. *Atlas of Namibia*. David Philip Publishers, Cape Town.

Mequaninta, F., Mitikub, R. and Shimelesc, A. 2016. Observed and Future Climate Variability and Extremes Over East Shoa Zone, Ethiopia. *Journal of Climatology and Weather Forcasting,* 4(3), 1-9.

MET. 2011. Namibia Second National Communication to the United Nations Framework Convention on Climate Change. Windhoek: Ministry of Environment and Tourism.

MET. 2012. Regional Climate Change Information Toolkits. Windhoek: Ministry of Environment and Tourism.

Messori, G., Caballero, R. and Gaetani, M. 2016. On cold spells in North America and storminess in western Europe. *Geophysical Research Letters,* 43, 6620–6628.

Mfune, J. K. and Ndombo, B. 2005. An assessment of the capacity and needs required to implement Article 6 of the UNFCCC in Namibia. Windhoek: Ministry of Environment and Tourism.

Miller, G.T. and Spoolman, S.E. 2012. *Living in the Environment*. 17th ed. Brooks/Cole, Cengage Learning. Canada. pp. 482.

Miller, K.A., Mcunu, N., Anhauser, A., Forrow, A., Santillo, D. and Johnston, P. 2020. Weathering the Storm: Extreme weather events and climate change in Africa. Greenpeace Research Laboratories Technical Report. Africa. 54.

Mistry, M. 2019. A High-Resolution Global Gridded Historical Dataset of Climate Extreme Indices. *Data,* 4, 41-58.

Mora, C., Dousset, B., Caldwell, I., Powell, F., Geronimo, R., Bielecki, C., Counsell, C., Dietrich, B., Johnston, E., Louis, L., Lucas, M., Mckenzie, M., Shea, A., Tseng, H., Giambelluca, T., Leon, L., Hawkins, E.D. and Trauernicht, C. 2017. Global risk of deadly heat. *Nature Climate Change,* 7, 501-506.

Morak, S., Hegerl, G.C. and Christidis, N. 2013. Detectable changes in the frequency of temperature extremes. *Journal of Climate,* 26, 1561–1574.

Morishima, W. and Akasaka M. 2010. Seasonal trends of rainfall and surface temperature over southern Africa. *African Study Monographs*, 40, 67-76.

Moron, V., Oueslati, B., Pohl, B., Rome, S. and Janicot S. 2016. Trends of mean temperatures and warm extremes in northern tropical Africa (1961–2014) from observed and PPCA-reconstructed time series. *Journal of Geophysical Research: Atmospheres*, 121, 5298–531.,

Mudelsee, M. 2019. Trend analysis of climate time series: A review of methods. *Earth-Science Reviews*, 190, 310-322.

Myhre, G., Shindell, D., Bréon, F.M., Collins, W., Fuglestvedt, J., Huang, J., Koch, D., Lamarque, J.F., Dee, D., Mendoza, B., Nakajima, T., Robock, A., Stephens, G., Takemura, T. and Zhang, H. 2013. Anthropogenic and natural radiative forcing. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V. and Midgley, P.M. Eds. Cambridge University Press, United Kingdom and New York, USA. 659–740

Nairn, J. and Fawcett, R. 2013. *Defining heatwaves: heatwave defined as a heatimpact event servicing all community and business sectors in Australia*. CAWCR Technical Report No. 060. Bureau of Metreorology, Australia.

Namibweb. 2002. Namibia country information for travellers: Republic of Namibia – The jewel of Africa. Accessed 2 December 2020. https://www.namibweb.com/info.html#:~:text=Namibia%20has%20four%20distinct%20topographical,areas%20of%20Okavango%20and%20Caprivi.

Namibia Weather Network. 2019. Namibia Weather. Accessed 15 June 2020. https://weather.namsearch.com/wxtrends.php

Nangombe, S. S., Zhou, T., Zhang, W., Zou, L. and Li, D. 2019. High-temperature extreme events over Africa under 1.5 and 2 °C of global warming. *Journal of Geophysical Research: Atmospheres*, 124, 4413– 4428.

Napoli, D.I., Pappenberger, F. and Cloke, H.L. 2018. Assessing heat-related health risk in Europe via the Universal Thermal Climate Index (UTCI), *International Journal of Biometeorology*, 62 (7), 1155-1165.

Nassiri, P., Monazzam, M.R., Golbabaei, F., Dehghan, S.F., Rafieepour, A., Mortezapour, A.R. and Asghari, M. 2017. Application of Universal Thermal Climate Index (UTCI) for assessment of occupational heat stress in open-pit mines, *Industrial Health,* 55 (5), 437-443.

National Research Council,. 2010. *America's climate choices: Advancing the science of climate change*. The National Academies Press, Washington.

Naveendrakumar, G., Vithanage, M., Kwon, H.H., Iqbal, M.C.M., Pathmarajah, S. and Obeysekera, J. 2018. Five decadal trends in averages and extremes of rainfall and temperature in Sri Lanka. *Advances in Meteorology*, 20(18), 13-21.

Näyhä, S., Hassi, J., Jousilahti, P., Laatikainen, T. & Ikäheimo, T.M. 2011. Cold-related symptoms among the healthy and sick of the general population: National FINRISK Study data, 2002, *Public Health*, 125 (6), 380-388.

Näyhä, S., Rintamäki, H., Donaldson, G., Hassi, J., Jousilahti, P., Laatikainen, T., Jaakkola, J.J. & Ikäheimo, T.M. 2014. Heat-related thermal sensation, comfort and symptoms in a northern population: the National FINRISK 2007 study, *European Journal for Public Health*, 24 (4), 620-626.

Neukom, R., Nash, D.J., Endfield, G.H., Grab, S.W., Grove, C.A., Kelso, C., Vogel, C. and Zinke, J. 2014. Multi-proxy summer and winter precipitation reconstruction for southern Africa over the last 200 years. *Climate Dynamics,* 42, 2713-2726.

New, M. and Bosworth, B. 2018. What global warming of 1.5 C and higher means for Botswana and Namibia. *Climate and Knowledge Development Network*.

New, M., Hewitson, B., Stephenson, A., Tsiga, A., Kruger, A., Manhique, R. and Lajoie, R. 2006. Evidence of trends in daily climate extremes over southern and west Africa. *Journal of Geophysical Research: Atmospheres,* 111(14), 1984-2012

Newsham. A.J. and Thomas. D. 2009. Agricultural adaptation, local knowledge and livelihood diversification in North-Central Namibia. Research Technical Report, Tyndall Climate Change Research Centre, Norwich, 48.

Ngwenya, B., Oosthuizen, J., Cross, M. and Frimpong, K. 2018. Heat Stress and Adaptation Strategies of Outdoors Workers in the City of Bulawayo, Zimbabwe. *Journal of Community Medicine and Public Health Care.* 5. 1-6.

Niang, I., Ruppel, O.C., Abdrabo, M.A., Essel, A., Lennard, C., Padgham, J. and Urquhart, P. 2014. Africa. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects.* Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Barros, V.R., Field, C.B., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R. and White L.L. (Eds). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 1199-1265.

Nicholls, N. and Collins, D. 2006. Observed change in Australia over the past century. *Energy and Environment,* 17, 1-12.

Nicholson, S.E., Nash, D.J., Chase, B.M., Grab, S.W., Shanahan, T.M., Verschuren, D., Asrat, A., Lézine, A.M. and Umer, M. 2013. Temperature variability overAfrica during the last 2000 years. *Holocene*. 23(8), 1085-1094.

Nkenmelang, T., New, M. and Zoroug, M. 2018. Temperature and precipitation extremes under current, 1.5°C and 2.0°C global warming above pre-industrial levels over

Botswana, and implications of climate change vulnerability. *Environmental Research Letters,* 13, 1-11.

NOAA, 2020. National Centers for Environmental Information, State of the Climate: Global Climate Report for Annual 2019. Accessed October 20, 2020. published online January 2020. https://www.ncdc.noaa.gov/sotc/global/201913.

Noome, K. & Fitchett, J. 2019. An assessment of the climate suitability of Afriski Mountain Resort for outdoor tourism using the Tourism Climate Index (TCI). *Journal of Mountain Science*, 16(11), 2453-2469.

NPC (National Planning Commission). 2002. *Namibia's Natural Resources Sector*. A Contribution to Vision 2030, October 2002.

NPCC – See GRN 2011.

Ohashi, Y., Katsuta, T., Tani, H., Okabayashi, T., Miyahara, S. and Miyashita, R. 2018. Human cold stress of strong local-wind "Hijikawa-Arashi" in Japan, based on the UTCI index and thermo-physiological responses, *International Journal of Biometeorology*, 62 (7), 1241-1250.

O'Loughlin, J., Linke, A. M. and Witmer, F. D. W. 2014. Temperature, precipitation, and violence in Africa. *Proceedings of the National Academy of Sciences of the United States of America*, 111, 16712–16717.

O'Loughlin, J., Witmer, F.D., Linke, A.M., Laing, A., Gettelman, A. and Dudhia, J. 2012. Climate variability and conflict risk in East Africa, 1990-2009. *Proceedings of the National Academy of Sciences of the United States of America*. 109, 18344–18349.

Omondi, A.P., Awange, J.L., Ogallo, L.A., Barakiza, R., Girmaw, G.B., Fesseha, I., Kululetera, V., Kilembe, C., Mbati, M.M., Kilavi, M., King'uyu, S.M., Omeny, P.A., Njogu, A., Badr, E.M., Musa, T.A., Muchiri, P., Bamanyan, D. and Komutunga. E. 2014. Changes in temperature and precipitation extremes over the Greater Horn of Africa region from 1961 to 2010. *International Journal of Climatology,* 34, 1262-1277.

Onoz, B. and Bayazit, M. 2003. The power of statistical trend detection. *Turkish Journal of Engineering and Environmental Sciences,* 27, 247–251.

Ongoma, V. and Chen, H., Temporal and spatial variability of temperature and precipitation over East Africa from 1951 to 2010. *Meteorology and Atmospheric Physics,* 129, 131-144.

Orimoloye, I.R., Mazinyo, S.P., Kalumba, A.M., Ekundayo, O.Y. and Nel, W. 2019. Implications of climate variability and change on urban and human health: A review. *Cities*, 91, 213-223.

Orlowsky, B. and Senevirante, S.I. 2012. Global changes in extreme events: regional and seasonal dimension. *Climate Change,* 110, 669-696.

Orth, R., Vogel, M.M., Luterbacher, J., Pfister, C. and Seneviratine, S.I., 2016. Did European temperatures in 1540 exceed present-day records? *Environmental Research Letters*, 11 (11), 4-18.

Otto, F.E.L., Boyd, E., Jones, R.G., Cornforth, R.J., James R., Parker, H.R. and Allen, M.R. 2015. Attribution of extreme weather events in Africa: a preliminary exploration of the science and policy implications. *Climate Change,* 132, 531-543.

Otto, F.E.L., Massey, N., Oldenborgh, G.J., Jones, R.G. and Allen, M.R. 2012. Reconciling two approaches to attribution of the 2010 Russian heat wave. *Geophysical Resesrch Letter,* 1, 39-47.

Osczevski, R. J. 2000. Windward Cooling, An Overlooked Factor in the Calculation of Wind Chill, *Bulletin of the American Meteorological Society*, 81 (12), 2975-2978

Otterå, O.H., Bentsen, M., Drange, H. and Suo, L. 2010. External forcing as a metronome for Atlantic multidecadal variability. *Nature Geoscience*, 3, 688-694.

Panda, K., Mishra, A., Kumar, A., Mandal, K.G., Thakur, A.K. and Srivastava, R.C. 2014. Spatiotemporal patterns in the mean and extreme temperature indices of India, 1971-2005. *International Journal of Climatology*, 34,3585–3603.

Pantavou, K., Lykoudis, S., Nikolopoulou, M. and Tsiros I.X. 2018. Thermal sensation and climate: a comparison of UTCI and PET thresholds in different climates, *International Journal of Biometeorology*, 62 (9), 1695-1708.

Pappenberger, F., Jendritzky, G., Staiger, H., Dutra, E., Di Giuseppe, F., Richardson, D.S. and Cloke, H.L. 2015. Global forecasting of thermal health hazards: the skill of probabilistic predictions of the Universal Thermal Climate Index (UTCI), *International Journal of Biometeorology*, 59, 311-323.

Perkins, S.E. 2015. A review on the scientific understanding of heatwaves – Their measurement, driving mechanisms, and changes at the global scale. *Atmospheric Research*, 12,242–267.

Perkins, S.E. and Alexander, L.V. 2013. On the Measurement of Heat Waves. *Journal of Climate*, 26, 4500-4517.

Perkins-Kirkpatrick, S.E. and Lewis, S.C. 2020. Increasing trends in regional heatwaves. *Nature Communications,* 11, 33-57.

Perkins-Kirkpatrick, S.E., White, C.J., Alexander, L.V., Argüeso, D., Boschat, G., Cowan, T., Evans, J.P., Ekström M., Oliver, E.C.J., Phatak, A. and Purich, A. 2016. Natural hazards in Australia: heatwaves. *Climate Change*, 139. 101–114.

Peterson, T.C. and Folland, C. 2001. *Report on the Activities of the Working Group on Climate Change Detection and Related Rapporteurs*. WHO, Geneve, Switzerland. 143.

Peterson, T.C., Hoerling, M.P., Stott, P.A. and Herring, S. 2013. Explaining extreme events of 2012 from a climateperspective. *Bulletin of the American Meteorological Society,* 94(9), 1–74.

Peterson, T.C., Scott, P. and Herring, S. 2012. Explaining extreme events of 2011 from a climate perspective. *Bulletin of the American Meteorological Society*, 93, 1041-1067.

Peterson, T.C., Zhang, X., Brunet-India, M. and Vázquez-Aguirre, J.L. 2008. Changes in North American extremes derived from daily weather data. *Journal of Geophysical Research*, 113, 7113-7129.

Perlwitz, J., Knutson, T., Kossin, J.P. and LeGrande, A.N. 2017. *Large-scale circulation and climate variability*. In Climate Science Special Report: Fourth National Climate Assessment, Volume I. Wuebbles, D.J., Fahey, D.W., Hibbard, K.A., Dokken, D.J., Stewart, B.C. and Maycock, T.K. Eds. U.S. Global Change Research Program. 161-184.

Pinto, I. 2020. State of Climate in 2019 for Southern Africa. Climate Systems Analyses Group, UCT.

Pitt, M. 2008. "The Pitt review: learning lessons from the 2007 floods." Accessed 14 October 2019. https://webarchive.nationalarchives.gov.uk/20100702215619/http://archive.cabinetoffice.gov.uk/pittreview/thepittreview/final_report.html.

Pohlert, T. 2020. Non-Parametric Trend Tests and Change-Point Detection. Rpackage, Cran. Software. Available from: https://cran.stat.upd.edu.ph/.

Ponjoan, A., Blanch, J., Alves-Cabratosa, L., Marti-Lluch, R., Comas-Cufi, M., Parramon, D., Del Mar Garcia-Gil, M., Ramos, R. and Petersen, I. 2017. Effects of extreme temperature on cardiovascular emergency hospitalizations in Mediterranean region: a self-controlled case series study. *Environmental Health*, 16, 32-43.

Poudal, A., Cuo, L., Ding, J. and Gyawali, A.R. 2020. Spatio-temporal variability of the annual and monthly extreme temperature indices in Nepal. *International Journal of Climatology,* 40, 4956-4977.

Provençal, S., Bergeron, O., Leduc, R. and Barrette, N. 2016. Thermal comfort in Quebec City, Canada: sensitivity analysis of the UTCI and other popular thermal comfort indices in a mid-latitude continental city, *International Journal of Biometeorology*, 60 (40), 591-603.

Psikuta, A., Fiala, D., Laschewski, G., Jendritzky, G., Richards, M., Błażejczyk, K., Mekjavič, I., Rintamäki, H., De Dear, R. and Havenith, G. 2012. Evaluation of the Fiala multi-node thermophysiological model for UTCI application, *International Journal of Biometeorology*, 56 (3), 443-460.

Radovic, V. and Iglesias, I. 2019. Extreme weather events: Definition, classification and guidelines towards vulnerability reduction and adaption management. In: Climate Action. *Encyclopaedia of the UN Sustainable Development Goals*. Cham: Springer.

Ragone, F., Wouters, J. and Bouchet, F. 2018. *Computation of extreme heat waves in climate models using a large deviation algorithm*. Proceedings of the National Academy of Sciences of the United States of America. 115, 24–29.

Rathnayake, U. 2019. Comparison of Statistical Methods to Graphical Methods in Rainfall Trend Analysis: Case Studies from Tropical Catchments, *Advances in Meteorology*, 2019, 1-10.

Rauf, A.U., Rafi, M.S., Ali, I. and Muhammad, U.W. 2016. Temperature trend detection in upper Indus basin by using Mann-Kendall test. *Advances in Science, Technology and Engineering Systems Journal*, 1(4), 5–13.

Razavi, R., Switzman, H., Arain, A. and Coulibaly, P. 2016. Regional climate change trends and uncertainty analysis using extreme indices: A case study of Hamilton, Canada. *Climate Risk Management,* 13, 43-63.

Reddy, D.C.L. and Vincent, K. 2017. *Climate Risk and Vulnerability: A Handbook for Southern Africa* (2nd Ed). CSIR, Pretoria, South Africa.

Rehman, S. 2012. Long-term wind speed analysis and detection of its trends using Mann-Kendall test and linear regression method. *Arabian Journal for Science and Engineering,* 38(2), 421–437.

Reid, H., Sahlén, L., Macgregor, J. and Stage, J. 2007. The economic impact of climate change in Namibia: how climate change will affect the contribution of Namibia's natural resources to its economy. Environmental Economics Programme, Discussion Paper 07-02, International Institute for Environment and Development, London, 46.

Reid, H., Sahlén, I., Stage, J. and MacGregor, J. 2008. Climate Change Impacts on Namibia's Natural Resources and Economy. *Climate Policy,* 8(5), 452–66.

Ren, Y.Y., Ren, G.Y., Sun, X.B., Shrestha, A.B., You, Q.L., Zhan, Y.J., Rajbhandari, R., Zhang, P.F. and Wen, K.M. 2017. Observed changes in surface air temperature and precipitation in the Hindu Kush Himalayan region over the last 100-plus years. *Advances in Climate Change Research,* 8, 148–156.

Reid, H., Sahlén, L., Stage, J. and MacGregor, J. 2007. The economic impact of climate change in Namibia: "How climate change will affect the contribution of Namibia's Natural resources to its economy." Environmental Economics Programme. London: 2-7.

Richardson, D. S. 2000. Skill and relative economic value of the ECMWF ensemble prediction system, *Quarterly Journal of the Royal Meteorological Society*, 126(563), 649–667.

Romero-Lankao, P., Smith, J.B., Davidson, D.J., Diffenbaugh, N.S., Kinney, P.L., Kirshen, P., Kovacs, P. and Villers Ruiz, L. 2014. North America. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Barros, V.R., Field, C.B., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R. and White L.L. (Eds). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 1439-1498.

Rother, H.A., Etzel, R.A, Shelton, M., Paulson, J.A., Hayward, R.A. and Theron, L.C. 2020. Impact of Extreme Weather Events on Sub-Saharan African Child and Adolescent Mental Health: A Protocol for a Systematic Review. *Atmosphere,* 11(493), 1-12.

Russso, S., Marchese, A.F., Sillmann, J. and Immè, G. 2016. When will unusual heat waves become normal in a warming Africa? *Environmnetal Research Letters,* 11, 1-10.

Rutherford, M.C., Ladislav, M., Lötter, M.C., Bredenkamp, G.J., Smit, J.H.L., Scott-Shaw, C.R., Hoare, D.B., Goodman, P.S., Bezuidenhout, H., Scott, L., Ellis, F., Powrie, L., Siebert, F., Mostert, T.H., Henning, B.J., Ventner, C.E., Camp, K.G.T., Siebert, S., Matthews, W. and Hurter, P. 2006. Savanna Biome, The vegetation of South Africa, Lesotho and Swaziland. 440-529.

RVAA- Regional Vulnerability Assessment & Analysis Programme. 2019. Namibia-Vulnerability Assessment Committee Results 2019, Southern African Development Community, United Nations Office for the Coordination of Humanitarian Affairs.

Saeid, A.V., Keykhai, M., Jahanbakhshi, F., Sheikholeslami, J., Ahmadi, A., Yang, H. and Abbaspour, K. 2019. The future of extreme climate in Iran. Scientific Reports. *Nature Research,* 9(1), 1-21.

Salameh, A.A.M., Gámiz-Fortis, S.R., Castro-Díez, Y., Hammad, A.A. and Esteban-Parra, M.J. 2018 Spatial-temporal analysis for extreme temperature indices over the Levant region. *International Journal of Climatology*, 39, 5556-5582.

Schär, C. and Jendritzky, G. 2004. Climate change: hot news from summer 2003. *Nature*, 432(7017), 559-560.

Schloeder, C.A., Zimmerman, N.E. and Jacobs, M.J. 2001. Comparison of methods for interpolating soil properties using limited data, *Soil Science Society of America Journal*, 65, 470–479.

Schneider, M., Bell, T., Lubinda, M. and Pallet, J. 2015. Climate change vulnerability and adaptation assessment. Chapter for Namibia's Third National Communication to the UNFCCC. Developed for the Ministry of Environment and Tourism by Desert Research Foundation of Namibia and Kulima Integrated Development Solutions, Windhoek, 88.

Schulz, N., Boisier, J.P. and Aceituno, P. 2012. Climate change along the arid coast of northern Chile. *International Journal of Climatology*, 32(12), 1803-1814.

Schulze, R.E., 2011. Approaches towards practical adaptive management options for selected water related sectors in South Africa in a context of climate change. *Water SA,* 37(5), 11-26.

Sen, P.K. 1968. Estimates the regression coefficient based on Kendall's tau. *Journal of American Statistical Association*. 63,1379-1389.

Şen, Z. 2011. Innovative trend analysis methodology. *Journal of Hydrological Engineering,* 17,1042–1046.

Some'e, B.S., Ezani, A. and Tabari, H. 2013. Spatiotemporal trend of aridity index in arid and semi-arid regions of Iran. *Theory and Applied Climatology,* 111, 149–160.

Shi, P., Ma, X., Chen, X., Qu, S. and Zhang, Z. 2013. Analysis of variation trends in precipitation in an upstream catchment of Huai river. *Mathematical Problems in Engineering*, 2013, 11-16.

Shiu, S.C., Liu, C., Fu, A., Dai, Y. and Sun, Y. 2012. How much do precipitation extremes change in a warming climate? *Geophysical Research Letters*, 39, 17-34.

Shongwe, M.E., Van Oldenborgh, G.J., Van den Hurk, B.J.J.M. and Van Aalst, M.K.2011. Projected changes in mean and extreme precipitation in Africa under global warming. Part II: East Africa. *Journal of Climate*, 24(14), 3718-3733.

Shongwe, M.E., Van Oldenborgh, G.J., Van den Hurk, B.J.J.M., De Boer, B., Choelho, C.A.S. and Van Aalst, M.K. 2009. Projected Changes in Mean and Extreme Precipitation in Africa under Global Warming. Part I: Southern Africa. *Journal of Climate,* 22, 3189-3837.

Stenchikov, G., Delworth, T.L., Ramaswamy, V., Stouffer, R.J., Wittenberg, A. and Zeng, F. 2009. Volcanic signals in oceans. *Journal of Geophysical Research*, 114, 1-13.

Stott, P.A., Christidis, N., Otto, F.E.L., Sun, Y., Vanderlinden, J.P., van Oldenborgh, G.J., Vautard, R., von Storch, R., Walton, P., Yiou, P. and Zwiers, F.W. 2016. Attribution of extreme weather and climate related events. *WIREs Climate Change*, 7(1). 23–41.

Stott, P.A., Gillett, N.P., Hegerl, G.C., Karoly, D.J., Stone, D.A., Zhang, X. and Zwiers, F. 2010. Detection and attribution of climate change: a regional perspective. *WIREs Climate Change*, 1, 192-211.

Stott, P.A., Stone, D.A. and Allen, M.R. 2004. Human contribution to the European heatwave of 2003. *Nature,* 432,610–614.

Sillmann, J., Kharin, V.V., Zhang, X., Zwiers, F.W. and Bronaugh, D. 2013. Climate extremes indices in the CMIP5 multimodel ensemble: Part 1. Model evaluation in the present climate. *Journal of Geophysical Research: Atmospheres,* 118, 1716-1733.

Slocum, T. A., McMaster, R. B., Kessler, F. C. and Howard, H. H. 2005. *Thematic cartography and geographic visualisation*. 2nd Ed. Pearson Prentice Hall. New York, USA.

Sneyers, R. 1990. *On the statistical analysis of series of observations*. World Meteorological Organization, Technical Note no. 143, WMO no 415.

Spear, D., Zaroug, M.A.H., Daron, J.D., Ziervogel, G., Angula, M.N., Haimbili, E.N., Hegga, S.S., Baudoin, M.A., New, M., Kunamwene, I., Togarepi, C. and Davies, J.E. 2018. Vulnerability and responses to climate change in drylands: The case of Namibia. CARIAA-ASSAR Working Paper. University of Cape Town, Cape Town.

Spearman, C. 1904. General intelligence objectively determined and measured. *The American Journal of Psychology*, 15(2), 201–292.

Spriggs, A. 2001. Africa: Namibia. World Wildlife Fund. Accessed 2 December 2020. https://www.worldwildlife.org/ecoregions/at1316.

Steffen W., Hughes, L. and Perkins, S.E. 2014. *Heatwaves: Hotter, longer, more often*. Special Report by the Climate Council of Australia, Sydney, Australia, 62.

Suppiah, R., Hennessy, K., Whetton, P., Mcinnes, K., Macadam, I., Bathols, J., Ricketts, J., Page, C. 2007. Australian climate change projections derived from simulations performed for the IPCC 4th Assessment Report. *Australian Meteorological Magazine*. 56(3), 131-152.

Thinking Hazards. 2017. Global Facility for Disaster Reduction and Recovery. Accessed 20 February 2019. http://thinkhazard.org/en/report/172-namibia/EH.

Thuiller, W., Midgley, G.F., Hughes, G.O., Bomhard, B., Drew. G., Rutherford, M.C. and Woodward, F.I. 2006 Endemic species and ecosystem sensitivity to climate change in Namibia, *Global Change Biology*, 12, 759-776.

Tiengrod, P. and Wongseree, W. 2013. A comparison of spatial interpolation methods for surface temperature in Thailand. *International Computer Science and Engineering Conference (ICSEC)*.

Toth, E., Brath, A. and Montanari, A. 2000. Comparison of short-term rainfall prediction models for real-time flood forecasting. *Journal of Hydrology*. 239(4), 132–147.

Totiyapungprasert. P. 2019. Heat deaths in Phoenix reached a record high in 2018. 7 May 2019. The Republican, Phoenix.

Tshiala, F.M., Olwoch, J.M. and Engelbrecht, F.A. 2011. Analysis of Temperature Trends over Limpopo Province. *South Africa.Journal of Geography and Geology*, 3(1), 13.

Turpie, J., Midgley, G., Brown, C., Barnes, J.I., Pallett, J., Desmet, P., Tarr, J. and Tarr, P. 2010. Climate change vulnerability and adaptation assessment for Namibia's biodiversity and protected area system. Ministry of Environment and Tourism, Directorate of Parks & Wildlife Management, Windhoek, 248.

Tyler, K., White, T. and Anslow, F. 2015. Indicators of climate change for British Columbia 2015 Update. Ministry of Environment, Victoria, Canada. 50.

Urban, A. and Kyselý, J. 2014. Comparison of UTCI with Other Thermal Indices in the Assessment of Heat and Cold Effects on Cardiovascular Mortality in the Czech Republic, *International Journal of Environmental Research and Public Health,* 11 (1), 952-967.

Vanos, J. K., Kalkstein, L.S. and Sanford, T.J. 2015. Detecting synoptic warming trends across the US Midwest and implications to human health and heat-related mortality. International Journal of Climatology 35(1):85-96.

Van der Linden, P. and Mitchell, J.F.B. 2009 ENSEMBLES: Climate Change and its Impacts: Summary of Research and Results from The ENSEMBLES Project. Met Office Hadley Centre, Exeter, UK, 160.

Van der Merwe, A. and McCormick, M. 1999. Development of the National Strategy for Water Demand Management. *Final Report to the Namibian Water Resources Management Review.* Environmental Engineering Services, Windhoek.

Van der Walt, A.J. and Fitchett, J.M. 2021. E Extreme Temperature Events (ETEs) in South Africa: a review. *South African Geographical Journal*, 1, 1-20.

Van Oldenborgh, G.J., Mitchell-Larson, E., Veccchi, G.A., De Vries, H., Vautard, R. and Otto, F. 2019. Cold waves are getting milder in the northern midlatitudes. *Environmental Research Letters*, 14, 1-13.

Vatani, J., Golbabaei, F., Dehghan, S.F. and Yousefi, A. 2015. Applicability of Universal Thermal Climate Index (UTCI) in occupational heat stress assessment: a case study in brick industries, *Industrial Health. National Institute of Occupational Safety and Health*, 54 (1),14-19.

Vincent, L.A., Aguilar, E., Saindou, M., Hassane, A.F., Jumaux, G., Roy, D., Booneeady, P., Virasami, R., Randriamarolaza, L.Y.A., Faniriantsoa, F.R., Amelie, V., Seeward, H. and Montfraix, B. 2011. Observed trends in indices of daily and extreme temperature and precipitation for the countries of the western Indian Ocean, 1961-2008. *Journal of Geophysical Research: Atmospheres,* 116(10), 1530-1551.

Vincent, L.A., Zhang, X., Brown, R.D., Feng, Y., Mekis, E., Milewska, E.J., Wan, H. and Wang, X.L. 2015. Observed Trends in Canada’s Climate and Influence of Low-Frequency Variability Modes. *Journal of Climate*, 28, 4545-4560.

Vizy, E.K. and Cook, K.H. 2012. Mid-twenty-first-century changes in extreme events over northern and tropical Africa. *Journal of Climate*, 25(17), 5748-5767.

Vogel, M.M., Zscheischler, J., Wartenburger, R., Dee, D. and Seneviratne, S.I. 2019. Concurrent 2018 hot extremes across Northern Hemisphere due to human-induced climate change. *Earth's Future*, 7, 692–703.

Vose, R.S., Applequist, S., Bourassa, M.A., Pryor, S.C., Barthelmie, R.J., Blanton, B., Bromirski, P.D., Brooks, H.E., DeGaetano, A.T., Dole, R.M., Easterling, D.R., Jensen, R.E., Karl, T R., Katz, R.W., Klink, K., Kruk, M.C., Kunkel, K.E., MacCracken, M.C., Peterson, T.C., Shein, K., Thomas, B.R., Walsh, J.E., Wang, X.L., Wehner, M.F., Wuebbles, D.J. and Young, R.S., 2015. Monitoring and understanding changes in extremes: extratropical storms, winds, and waves. *Bulletin of the American Meteorological Society*, 95: 377–386.

Vuille, M., Francou, B., Wagnon, P., Juen, I., Kaser, G., Mark, B.G. and Bradley, R.S. 2008. Climate change and tropical Andean glaciers: past, present and future. *Earth Science Reviews*, 89(4), 79-96.

Walikewitz, N., Jänicke, B., Langner, M. and Endlicher, W. 2018. Assessment of indoor heat stress variability in summer and during heat warnings: a case study using the UTCI in Berlin, Germany, *International Journal of Biometeorology,* 62 (1), 29-42.

Walsh, J., Wuebbles, D., Hayhoe, K., Kossin, J., Kunkel, K., Stephens, G., Thorne, P., Vose, R., Wehner, M., Willis, J., Anderson, D., Doney, S., Feely, R., Hennon, P., Kharin, V., Knutson, T., Landerer, F., Lenton, T., Kennedy, J. and Somerville, R. 2014. Our changing climate. In: Climate Change Impacts in the United States: The Third National Climate Assessment. Melillo, J.M., Richmond, T.C. and Yohe, G.W. (Eds). *U.S. Global Change Research Program*. Washington, D.C. 19-67.

Warburton, M.L. and Schulze, R.E., 2005. *Chapter 15: Detection of Climate Change: A Review of Literature on Changes in Temperature, Rainfall and Streamflow, on Detection Methods and Data Problems*. In: Schulze, R.E. (Eds).Climate Change and Water

Resources in southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation. Water Research Commission, Pretoria, RSA. 257 274

Watanabe, S. and Ishii, J. 2016. Effect of outdoor thermal environment on pedestrians' behaviour selecting a shaded area in a humid subtropical region, *Building Environment*, 95: 32-41.

Weihs, P., Staiger, H., Tinz, B., Batchvarova, E., Rieder, H., Vuilleumier, L., Maturilli, G. and Jendritzky, G. 2011. The uncertainty of UTCI due to uncertainties in the determination of radiation fluxes derived from measured and observed meteorological data, *International Journal of Biometeorology*, 56 (3), 537-555.

Wilcox, R. 2001. *Fundamentals of Modern Statistical Methods*. Springer, New York, NY.

WMO. 2011. *Guide to climatological practices*. Geneva: WMO. WMO No, 100.

WMO. 2018. World Meteorological Organization Commission for Climatology. State of the Climate in Africa 2017. World Meteorological Organisation, Geneva.

WMO. 2019. July matched, and maybe broke, the record for the hottest month since analysis began. Acccessed 10 March 2021. https://public.wmo.int/en/media/news/july-matched-and-maybe-broke-record-hottest-month-analysis-began .

WMO. 2020. World Meteorological Organization Commission for Climatology. State of the Climate in Africa 2019. World Meteorological Organisation, Geneva. Report. WMO-No.1253, 37.

World Bank. 2017. “Namibia”. Accessed 5 June 2019. https://climateknowledgeportal.worldbank.org/country/namibia/climate-data-historical#.

World Bank. 2020. “Namibia At-A-Glance”. Accessed 5 December 2020. https://www.worldbank.org/en/country/namibia/overview.

Wu, H. and Hung, M. 2016. Comparison of Spatial Interpolation Techniques Using Visualization and Quantitative Assessment, Applications of Spatial Statistics, *IntechOpen*, 1, 1-10.

Xu, C., Kohler, T. A., Lenton, T. M., Svenning, J.C. and Scheffer, M. 2020. Future of the human climate niche. *Proceedings of the National Academy of Sciences of the United States of America,* 117, 11350–11355.

Yang, Q., Zheng, J. and Liu, Z. 2016. Which one is the best: the interpolation method comparison on average annual temperature in Xinjiang from 1951 to 2013. IEEE International Geoscience and Remote Sensing Symposium (IGRSS). Beijing.

Yapo, A.L.M., Diawara, A., Yoroba, F., Kouassi, B.K., Sylla, M.B., Kouadio, K., Odoulami, R.C. and Tiemoko, D.R. 2019. Twenty-First Century Projected Changes in Extreme Temperature over Côte d'Ivoire (West Africa). *International Journal of Geophysics,* 19, 23-31.

Yin, H. and Sun, Y. 2018. Detection of Anthropogenic influence on fixed threshold indices of extreme temperature. *American Meteorological Society*, 31, 6341—6352.

Yosef, Y., Aguilar, E. and Alpert, P. 2019. Changes in extreme temperature and precipitation indices: Using an innovative daily homogenised database in Israel. *International Journal of Climatology*, 39, 5022-5045.

Yu, Z. and Li, X., 2015. Recent trends in daily temperature extremes over northeastern China (1960-2011), *Quaternary International*, 381, 35-35.

Zahid, M. and Rasul, G. 2011. Frequency Of Extreme Temperature & Precipitation Events In Pakistan 1965-2009. *Science International-Lahore,* 23(4), 313-319.

Zanchettin, D., Timmreck, C., Graf, H.F., Rubino, A., Lorenz, S., Lohmann, K., Krüger, K. and Jungclaus, J.H. 2012. Bi-decadal variability excited in the coupled ocean–atmosphere system by strong tropical volcanic eruptions. *Climate Dynamics,* 39, 419-444.

Zaroug, M.A., Eltahir, E.A. and Giorgi, F. 2014. Droughts and floods over the upper catchment of the Blue Nile and their connections to the timing of El Niño and La Niña events. Hydrological Earth System Science, 18(3), 1239–1249.

Zeidler, J. and Chunga, R. 2007. Drought Hazard and Land Management in the Drylands of Southern Africa. In: Sivakumar, M.V.K. and Ndiang'ui, N. (eds). Climate and Land Degradation. Environmental Science and Engineering (Environmental Science). Springer, Berlin, Heidelberg.

Zeidler, J., Kandjinga, L. and David, A. 2010. Study on the effects of Climate Change in the Cuvelai Etosha Basin and possible adaptation measures. Integrated Environmental Consultants, Namibia, Windhoek, 34.

Zhang, X., Feng, Y. and Chan, R. 2018. Introduction to RClimDex v1.9, Climate Research Division, Environment Canada, Downsview, Ontario, Accessed 14 November 2020. https://github.com/ECCC-CDAS/.

Zhao, Y., Ducharne, A., Sultan, B., Braconnot, P., Vautard, R., 2015. Estimating heat stress from climate-based indicators: present-day biases and future spreads in the CMIP5 global climate model ensemble, *Environmental Research Letters*, 10, 1-12.

Zhou, L., Dickinson, R.E., Dai, A. and Dirmeyer, P. 2010. Detection and attribution of anthropogenic forcing to diurnal temperature range changes from 1950 to 1999:comparing multi-model simulations with observations. *Climate Dynamics,* 35(7), 1289-1307.

Zhou, M.G., Wang, L.J., Lui, T., Zhang, Y.H., Lin, H.L., Luo, Y., Xiao, J.P., Zeng, W.L., Zhang, Y.W., Wang, X.F., Gu, X., Rutherford, S., Chu, C. and Ma, W.J. 2014. Health impact of the 2008 cold spell on mortality in the subtropical China: the climate and health impact national assessment study (CHINAs). *Environmental Health*, 13, 60-73.

Zhou, Y. and Zhang, J. 2014. Application of GIS in downscaling regional climate model results over the province of Ontario, *Environmental Systems Research*, 3(1), 8-19.

Zhou, Y.Q. and Ren. G.Y. 2011. Change in extreme temperature event frequency over mainland China, 1961−2008. *Climate Research*, 50, 125-139.

Zhou, Y.Q. and Ren, G.Y. 2014. Urbanization effect on long-term trends of extreme temperature events in North China. *Plateau Meteorology*, 33,1589-1598.

Appendix 1

Appendix 1.1: Trend analyses for cold ETCCDI for 2008-2018

Station	ETCCDI																				
	TX_n			TN_n			TNMean			TN10p			TX10p			FD			CSDI		
	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS
Hochfeld	0.00	1.00	0.01	0.29	0.39	0.31	0.21	0.54	0.16	-0.14	0.71	-0.64	-0.21	0.54	-2.99	0.07	1.00	0.00	-	-	0.00
Kalahari Farmhouse	0.44	0.19	0.43	-0.06	0.92	-0.02	0.06	0.92	0.05	0.06	0.92	0.20	-0.67	0.02	-1.47	0.15	0.67	0.83	-	-	0.00
Namib Desert Lodge	0.36	0.36	0.27	0.50	0.11	0.34	0.57	0.06	0.32	**-0.71**	**0.02**	**-2.17**	-0.64	0.04	-1.95	-0.54	0.10	-0.55	-	-	0.00
Swakopmund	-0.11	0.72	-0.08	0.38	0.15	0.06	-0.02	1.00	0.00	-0.11	0.72	-0.35	-0.11	0.72	-0.37	-	-	0.00	0.17	0.64	0.00
Windhoek	-0.20	0.47	-0.30	0.16	0.59	0.05	-0.02	1.00	-0.03	-0.42	0.11	-2.26	-0.29	0.28	-1.86	-0.05	1.00	0.00	-	-	0.00

** Values in bold are different from 0 with a significance level alpha = 0.05.*

Appendix 1.2: Trend analyses for cold ET-SCI for 2008-2018

Station	ET-SCI								
	$CSDI_d$			CWN			CWD		
	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS
Hochfeld	0.18	0.65	0.00	-0.45	0.18	-0.27	-0.45	0.18	-1.03
Kalahari Farmhouse	0.26	0.42	0.00	-0.33	0.28	-0.25	-0.31	0.30	-0.67
Namib Desert Lodge	0.03	1.00	0.00	-0.46	0.12	-0.31	-0.47	0.11	-0.83
Swakopmund	0.34	0.20	0.30	0.09	0.80	0.00	0.18	0.52	0.10
Windhoek	0.14	0.60	0.00	-0.37	0.24	-0.29	-0.38	0.20	-0.95

** Values in bold are different from 0 with a significance level alpha = 0.05.*

Appendix 1.3: Trend analyses for warm ETCCDI for 2008-2018

Station	ETCCDI																				
	TN_x			TX_n			TXMean			TN90p			TX90p			SU			WSDI		
	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS
Hochfeld	0.14	0.71	0.05	0.50	0.11	0.57	0.14	0.71	0.14	0.43	0.17	3.03	0.29	0.39	2.25	0.07	1.00	0.00	-	-	0.00
Kalahari Farmhouse	0.22	0.47	0.07	0.28	0.35	0.37	0.44	0.12	0.39	0.44	0.12	1.18	**0.56**	**0.05**	**1.29**	0.44	0.14	11.12	-0.24	0.56	0.00
Namib Desert Lodge	0.21	0.54	0.39	0.57	0.06	0.59	0.43	0.17	0.32	**0.64**	**0.04**	**1.79**	0.43	0.17	0.69	0.36	0.27	2.67	0.50	0.19	0.00
Swakopmund	0.00	1.00	0.00	0.07	0.86	0.06	0.07	0.86	0.04	-0.16	0.59	-0.71	0.22	1.00	0.02	0.06	0.87	0.00	0.22	0.48	0.00
Windhoek	-0.11	0.72	-0.11	0.16	0.59	0.18	-0.20	0.47	-0.21	0.42	0.11	1.50	0.33	0.21	1.25	0.00	1.00	0.00	-	-	0.00

* *Values in bold are different from 0 with a significance level alpha = 0.05.*

Appendix 1.4: Trend analyses for warm ET-SCI for 2008-2018

Station	ET-SCI											
	SU35			$WSDI_d$			HWN			HWD		
	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS
Hochfeld	0.50	0.11	5.50	**0.26**	**0.60**	**0.79**	**0.69**	**0.03**	**0.67**	**0.67**	**0.04**	**0.80**
Kalahari Farmhouse	0.55	0.06	9.23	**0.63**	**0.04**	**0.50**	-0.35	0.24	-0.33	-0.21	0.52	-0.21
Namib Desert Lodge	0.54	0.06	5.38	0.14	0.68	0.28	0.42	0.18	0.21	0.35	0.24	0.62
Swakopmund	0.21	0.43	0.14	0.12	0.68	0.00	0.02	1.00	0.00	-0.08	0.80	0.00
Windhoek	0.56	0.68	7.35	0.34	0.32	0.38	0.85	0.26	0.54	0.45	0.21	0.78

* *Values in bold are different from 0 with a significance level alpha = 0.05.*

Appendix 1.5: Seasonal trends for TNMean

Station	TNMean											
	Summer			Autumn			Winter			Spring		
	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS
Hochfeld	0.29	0.39	0.23	0.07	0.90	0.22	0.36	0.27	0.18	0.36	0.27	1.04
Kalahari Farmhouse	0.22	0.47	0.18	-0.11	0.75	-0.09	0.11	0.75	0.03	0.00	1.00	0.01
Namib Desert Lodge	0.29	0.39	0.05	0.29	0.39	0.23	**0.71**	**0.02**	**0.42**	**0.64**	**0.03**	**0.37**
Swakopmund	-0.07	0.86	-0.07	-0.07	0.86	-0.14	0.11	0.72	0.15	0.20	0.47	0.04
Windhoek	0.05	0.93	0.01	0.20	0.47	0.22	-0.02	1.00	0.00	0.16	0.59	0.24

* *Values in bold are different from 0 with a significance level alpha = 0.05*.

Appendix 1.6: Seasonal trends for TXn

Station	TXn											
	Summer			Autumn			Winter			Spring		
	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS
Hochfeld	0.36	0.27	0.41	0.14	0.71	0.78	0.40	0.21	0.98	0.50	0.11	1.74
Kalahari Farmhouse	0.33	0.25	0.50	0.06	0.92	0.10	**0.61**	**0.03**	**1.15**	-0.06	0.92	-0.16
Namib Desert Lodge	**0.62**	**0.05**	**0.74**	0.29	0.39	0.52	**0.86**	**0.004**	**0.91**	0.07	0.90	0.01
Swakopmund	0.02	0.47	0.27	0.11	0.72	0.05	0.23	0.42	0.05	0.27	0.32	0.10
Windhoek	-0.07	0.86	-0.20	0.29	0.28	0.73	-0.11	0.72	-0.20	0.11	0.72	0.47

* *Values in bold are different from 0 with a significance level alpha = 0.05*.

Appendix 1.7: Seasonal trends for TNn

Station	TNn											
	Summer			Autumn			Winter			Spring		
	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS
Hochfeld	0.14	0.71	0.20	-0.07	0.90	-0.07	0.43	0.17	0.72	0.36	0.27	0.71
Kalahari Farmhouse	0.06	0.92	0.23	-0.11	0.75	-0.14	0.06	0.92	0.27	-0.18	0.60	-0.15
Namib Desert Lodge	0.07	0.90	0.13	0.07	0.90	0.04	**0.86**	**0.004**	**0.64**	0.29	0.39	0.28
Swakopmund	0.23	0.42	0.09	0.38	0.15	0.18	0.29	0.28	0.13	0.14	0.65	0.03
Windhoek	-0.20	0.47	-0.37	0.14	0.65	0.11	0.38	0.15	0.35	0.05	0.93	0.01

* *Values in bold are different from 0 with a significance level alpha = 0.05*.

Appendix 1.8: Seasonal trends for TN10p

Station	TN10p											
	Summer			Autumn			Winter			Spring		
	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS
Hochfeld	-0.43	0.17	-2.70	-0.14	0.71	-0.57	-0.18	0.62	-1.11	0.00	1.00	-0.32
Kalahari Farmhouse	-0.06	0.92	-0.41	0.44	0.12	1.11	0.00	1.00	0.00	-0.17	0.60	-0.61
Namib Desert Lodge	0.07	0.90	0.37	-0.29	0.39	-1.49	-0.57	0.06	-2.24	**-0.64**	**0.04**	**-2.69**
Swakopmund	0.02	1.00	0.12	-0.11	0.72	-0.52	0.07	0.86	0.31	-0.24	0.37	-0.66
Windhoek	**-0.60**	**0.02**	**-4.98**	-0.07	0.86	-0.38	-0.29	0.28	-2.45	-0.33	0.21	-1.23

* *Values in bold are different from 0 with a significance level alpha = 0.05*.

Appendix 1.9: Seasonal trends for TX10p

Station	TX10p											
	Summer			Autumn			Winter			Spring		
	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS
Hochfeld	-0.29	0.39	-4.20	-0.29	0.39	-2.92	-0.43	0.17	-3.27	0.07	0.90	0.67
Kalahari Farmhouse	**-0.61**	**0.03**	**-2.10**	-0.18	0.60	-1.11	-0.33	0.25	-0.90	0.11	0.75	0.06
Namib Desert Lodge	**-0.71**	**0.02**	**-3.27**	-0.36	0.27	-3.15	-0.36	0.27	-1.56	0.00	1.00	0.02
Swakopmund	-0.09	0.79	-1.75	0.00	1.00	0.00	-0.02	1.00	-0.28	-0.11	0.72	-0.25
Windhoek	-0.29	0.28	-3.62	-0.02	1.00	-0.73	-0.42	0.11	-2.89	-0.20	0.47	-1.09

* *Values in bold are different from 0 with a significance level alpha = 0.05*.

Appendix 1.10: Seasonal trends for TXMean

Station	TXMean											
	Summer			Autumn			Winter			Spring		
	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS
Hochfeld	0.36	0.27	0.54	0.21	0.54	0.12	0.43	0.17	0.32	0.57	0.06	1.86
Kalahari Farmhouse	0.50	0.08	0.39	0.06	0.92	0.07	**0.56**	**0.05**	**0.58**	0.28	0.35	0.10
Namib Desert Lodge	0.57	0.06	0.46	0.36	0.27	0.30	0.14	0.71	0.18	0.71	0.90	0.02
Swakopmund	0.07	0.86	0.07	-0.07	0.86	-0.10	-0.02	1.00	-0.07	0.24	0.37	0.05
Windhoek	0.22	1.00	0.00	0.29	0.28	0.22	0.07	0.86	0.11	0.24	0.37	0.20

* *Values in bold are different from 0 with a significance level alpha = 0.05.*

Appendix 1.11: Seasonal trends for TXx

Station	TXx											
	Summer			Autumn			Winter			Spring		
	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS
Hochfeld	0.29	0.39	0.51	0.14	0.71	0.19	0.07	0.90	0.11	0.43	0.17	2.02
Kalahari Farmhouse	0.28	0.35	0.41	0.28	0.35	0.08	0.44	0.12	0.59	0.17	0.60	0.11
Namib Desert Lodge	0.43	0.17	0.46	0.29	0.39	0.29	0.00	1.00	-0.02	0.29	0.39	0.10
Swakopmund	0.11	0.72	0.12	-0.38	0.13	-0.47	0.07	0.86	0.08	0.07	0.86	0.06
Windhoek	0.00	1.00	0.00	0.20	0.47	0.26	0.00	1.00	0.00	0.16	0.59	0.12

* *Values in bold are different from 0 with a significance level alpha = 0.05.*

Appendix 1.12: Seasonal trends for TNx

Station	TNx											
	Summer			Autumn			Winter			Spring		
	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS
Hochfeld	0.07	0.90	0.15	0.14	0.71	0.24	0.26	0.46	0.48	0.57	0.06	1.38
Kalahari Farmhouse	0.06	0.92	0.07	0.28	0.35	0.42	0.11	0.75	0.03	0.00	1.00	0.05
Namib Desert Lodge	0.11	0.80	0.04	0.29	0.39	0.63	-0.14	0.71	-0.15	0.26	0.45	0.20
Swakopmund	-0.02	1.00	-0.02	-0.38	0.15	-0.27	0.14	0.65	0.04	0.38	0.15	0.12
Windhoek	0.07	0.86	0.20	0.20	0.47	0.09	-0.07	0.86	-0.21	-0.02	1.00	-0.05

* *Values in bold are different from 0 with a significance level alpha = 0.05.*

Appendix 1.13: Seasonal trends for TX90p

Station	TX90p											
	Summer			Autumn			Winter			Spring		
	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS
Hochfeld	0.21	0.54	2.59	0.29	0.39	1.42	0.29	0.39	2.39	0.36	0.27	3.78
Kalahari Farmhouse	0.50	0.08	1.24	0.20	0.53	0.89	0.11	0.75	0.55	0.00	1.00	-0.60
Namib Desert Lodge	0.50	0.11	0.97	0.19	0.61	0.91	0.07	0.90	0.39	-0.14	-0.71	-0.20
Swakopmund	-0.11	0.72	-0.34	-0.02	1.00	-0.26	0.02	1.00	0.69	-0.02	1.00	-0.02
Windhoek	0.16	0.59	0.81	0.20	0.47	0.61	0.24	0.37	1.43	0.20	0.47	1.68

* *Values in bold are different from 0 with a significance level alpha = 0.05.*

Appendix 1.14: Seasonal trends for TN90p

Station	TN90p											
	Summer			Autumn			Winter			Spring		
	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS	MK	ρ	SS
Hochfeld	0.14	0.71	0.53	0.29	0.39	3.40	0.21	0.54	2.97	0.36	0.27	3.12
Kalahari Farmhouse	0.33	0.25	1.89	0.17	0.60	1.21	0.11	0.76	0.17	0.22	0.47	0.91
Namib Desert Lodge	0.21	0.54	1.34	0.36	0.27	1.03	**0.64**	**0.04**	**2.59**	0.36	0.27	1.45
Swakopmund	-0.20	0.47	-0.74	-0.29	0.28	-0.90	0.07	0.86	0.38	0.24	0.37	0.52
Windhoek	0.51	0.06	1.44	0.33	0.21	1.46	0.20	0.47	0.96	0.29	0.28	1.47

* *Values in bold are different from 0 with a significance level alpha = 0.05*