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ANALYZING SPATIOTEMPORAL PATTERNS OF DROUGHTS IN DODOMA REGION

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ANALYZING SPATIOTEMPORAL PATTERNS OF DROUGHTS

IN DODOMA REGION

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A Dissertation Submitted to the Department of Geospatial Sciences and Technology in Partially Fulfilment of the Requirements for the Award of degree of Bachelor of Science in Geoinformatics (BSc. GI) at Ardhi University.

CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Ardhi University dissertation titled **“Analyzing spatiotemporal patterns of droughts a case study of Dodoma region”** in partial fulfillment of the requirements for the award of degree of Bachelor of science in Geoinformatics at Ardhi University.

...…………………..

Ms. Beatrice Kaijage

(Supervisor)

Date……………….

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I, MASSAWE, DEODATI Z, hereby declare that, the contents of this dissertation are the results of my own findings through my study and investigation, and to the best of my knowledge, this dissertation has never been presented anywhere for similar or any other academic award in any higher learning institution

…………………………………..

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DEDICATION

I dedicate this dissertation to my parent's late father Mr. Zakaria E. Massawe, late mother Ms. Odilia Z. Massawe for their efforts in my upbringing since my childhood up to this moment. I also dedicate to my supervisor Ms. Beatrice Kaijage, my brother's, Mr. Didas, Mr. William, Mr. Amedeus, Mr. Gaudence, late Mr. Emanuel and last but not least my all friends and relatives for their tireless prayers, encouragements, support and love.

ABSTRACT

This study incorporated two distinct drought indices, namely the Standardized Precipitation Evapotranspiration Index (SPEI), which takes into consideration atmospheric factors such as evaporative demand. This particular factor is not addressed by the standardized precipitation index. Another index used was Vegetation Condition Index (VCI) which is the modification of Normalized Difference Vegetation Index (NDVI) that provide the valuable information on the impacts of drought, to examine the spatiotemporal patterns of drought in Dodoma region from 1990 to 2020. The SPEI was computed using precipitation and temperature data obtained from NASA at each district in Dodoma region from remote sensing observations, specifically focusing on the months of January, February, and March during the rainy season.

The analysis of the SPEI results indicated an increase in drought occurrences in 2000 and 2010 recent years compared to previous ones 1990. According to literature Positive values of SPEI ranging from +0.99 to +2 representing wet periods, while negative values of SPEI ranging from -0.99 to -2 representing dry periods which indicate drought condition at each station in Dodoma region. SPEI results from this study in the year 2000, stations such as Kondoa, Mpwapwa, Kongwa, Dodoma, Bahi, Chemba and Chamwino had -1 SPEI value which indicate moderate drought due to low precipitation and higher temperature received at that year. Normal conditions ranging between -0.99 to +0.99 were observed in 2010 at each district in Dodoma region, while in 2020 the SPEI value were +1 that indicate moderate wet in Kondoa, +1.5 and +1.75 that indicate severe wet in Chamwino and Mpwapwa, greater than +2 SPEI value that indicate extremely wet conditions in Kongwa, Dodoma urban, Bahi and Chemba, attributed to higher precipitation and lower temperatures compared to the years 1990, 2000, and 2010.

Furthermore, the VCI computed based on NDVI from satellite images obtained from USGS Earth Explorer, The VCI results demonstrated that in 1990, Southern parts of Chamwino, sourth-western parts of Mpwapwa, eastern parts of Bahi and Kondoa exhibited low vegetation coverage and consequently indicate drought conditions. In contrast, Chemba, Dodoma urban, Bahi, and Kongwa had dense vegetation cover which indicate no drought condition. Chamwino encountered severe drought conditions in southern parts. In 2000 and 2010, most areas of the Dodoma region were affected by drought, with severe drought conditions observed in parts of Bahi, Chamwino, and Mpwapwa. This aligns with the lower precipitation recorded during those years. In 2020, a majority of the Dodoma region displayed abundant vegetation compared to 1990, 2000, and 2010, except for eastern part of Bahi and southern part of Chamwino and

Mpwapwa. The findings of this study can contribute valuable insights into drought patterns, thus aiding in the development of effective drought management plans.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

RS-Remote Sensing

GIS-Geographical Information System

GST-Geospatial Sciences and Technology

NDVI-Normalized Different Vegetation Index

VCI-Vegetation Condition Index

LST-Land Surface Temperature

TCI-Temperature Condition Index

SPI-Standardized Precipitation Index

SPEI- Standardized Precipitation Evapotranspiration Index

USGS-United States Geological Survey

NASA-National Aeronautics and Space Administration

NGO’S-Non-Governmental Organizations

TMA-Tanzania Meteorological Agency

WGS-World Geospatial System

TRMM-Tropical Rainfall Measurement Mission

WMO-World Meteorological Organization

OLI/TIRS-Operational Land Imager/Thermal Infrared Sensor

ETM+ -Enhanced Thematic Mapper Plus

TM-Thematic Mapper

TIR-Thermal Infrared Radiation

CHAPTER ONE

INTRODUCTION

1.0 Background

Drought is a natural climatic event, that arises from the lack of precipitation over an extended period of time (e.g. a season or several years). It occurs in all the geographical zones, but its characteristics vary significantly from one region to another. Drought is a temporary anomaly and as such it differs from aridity, which is a permanent feature of climate, associated with low rainfall regions (Mutua, 2008). The development of droughts is caused by combination of many climatic factors such as high temperature, precipitation deficiency, low relative humidity, high wind and greater sunshine (WMO, 2006). In Tanzania, an average of 4.8 million people per year are estimated to be directly affected by drought under the current climate conditions for the period 1979-2018 (UNDRR & CIMA, 2019). The number of people who will be affected by drought is approximated to be 7.8 million under projected climate conditions for the period 2051-2100 and this is due to the increase in global temperature (UNDRR & CIMA, 2019).

Dodoma region is current facing a severe drought due to below-average rainfall in the past two years, and the water levels in the region's dams are dangerously low. This has resulted in a water shortage that is affecting both humans and livestock (Mwakaje et al., 2017). The drought has caused widespread crop failure in the region, leading to the loss of livelihoods for many farmers and an increased risk of food insecurity (Mwaikambo et al., 2018). The government of Tanzania has declared a state of emergency in Dodoma region due to the drought. The government is taking steps to mitigate the impact of the drought, including providing food aid and drilling new boreholes. The drought in Dodoma region is a wake-up call about the dangers of climate change. The region is already experiencing the effects of climate change, and it is only going to get worse. This drought is a reminder that we need to take action to mitigate climate change and adapt to its impacts (Mtenda et al., 2019).

Drought analysis is addressed by various indices, with the Standardized Precipitation Index (SPI) being common, introduced by McKee et al. in 1993. However, SPI solely utilizes precipitation data and disregards atmospheric demand, which affects accuracy. Researchers like Seme Donald employed SPI alongside Temperature Condition Index (TCI), utilizing satellite and MODIS data from 2001-2016. Findings favored SPI's long-term drought assessment capability in Tanzania. Kain Lyton combined Landsat images (2000, 2013, 2017) and meteorological data (1987-2006) to assess and monitor drought risks. This study employed Standardized Precipitation Evapotranspiration Index (SPEI) introduced by Vicente et al. in 2010, incorporating both precipitation and evaporative demand. Additionally, Vegetation Condition Index (VCI) was employed using Normalized Difference Vegetation Index (NDVI), effectively indicating vegetation health during drought by gauging greenness changes, offering valuable insights compared to NDVI alone, as established by Kogan in 1995.

Remote sensing enables the analysis of drought patterns over large, remote areas by providing continuous data inaccessible through traditional methods, while GIS facilitates integrating and analyzing diverse data for drought monitoring. Therefore, on this research satellite observed meteorological data that is precipitation data, temperature data for 7 stations at each district in Dodoma region from 1990 to 2020 and satellite images at each interval of 10 years was used to analyze spatiotemporal pattern of drought that is meteorological drought at different location, hence the study show clear how drought pattern vary at different locations and duration over time in Dodoma region.

1.1 Problem statement

Despite the significant impacts of drought on natural and human systems, there is limited understanding of the spatiotemporal patterns of drought and how these patterns may change over location and time. This lack of understanding on spatiotemporal patterns of drought can limit the ability to effectively monitor and respond to drought condition, particular in regions that are already water stressed or vulnerable to environmental change. Drought index Standardized Precipitation Evapotranspiration index SPEI is an index that combines both precipitation and potential evapotranspiration (PET) data to provide a more comprehensive measure of drought that takes into account not only precipitation deficits but also the evaporative demand of the atmosphere (Vicente et al., 2010). SPEI is an improvement over the more commonly used Standardized Precipitation Index (SPI), which only considers precipitation. Since semi-arid regions like Dodoma often have high evaporation rates due to their arid to semi-arid climate, using SPEI can offer a more accurate representation of the combined effects of precipitation deficits and increased evaporation demands. This research focus on analyzing spatiotemporal drought patterns by using SPEI in Dodoma region which finally help to understand clear how these drought patterns varies from one location to another to support climate change adaptation and mitigation plans.

1.2 Objectives

1.2.1 Main objective

- The main objective of this research is to analyze spatiotemporal pattern of drought by using satellite observed meteorological data for the time series 1990 to 2020 and satellite images of Dodoma region from 1990 to 2020 at each interval of 10 years.

1.2.2 Specific objectives

- To analyze the effects of climate change on drought patterns in Dodoma region.
- To determine Standardized Precipitation Evapotranspiration Index (SPEI) and Vegetation Condition Index (VCI) for analyzing spatiotemporal pattern of drought in Dodoma region.
- To examine the changes in drought magnitude, location and duration over time in Dodoma region.

1.3 Research questions

- How does precipitation, temperature and vegetation vary spatially and temporally in relation to drought occurrences in Dodoma region?
- What is the spatiotemporal pattern of drought in Dodoma region over the past decade?
- Which areas in Dodoma region are more affected by drought?

1.4 Software used

- Different software were used in execution of this research which includes ERDAS IMAGINE 2014 for image processing and calculation of Normalized Different Vegetation Index (NDVI). ArcMap 10.8 for extraction of the area of interest, calculating and mapping Vegetation Condition Index (VCI) to show drought pattern in Dodoma region. Microsoft Excel and RStudio 4.1.1 ,4.2.2 for calculating and plotting Standardized Precipitation Evapotranspiration Index (SPEI) to show drought pattern in Dodoma region.

1.5 Significance of the study

- Agricultural production and food security: Dodoma region heavily relies on agriculture, which is vulnerable to drought. Understanding the spatiotemporal patterns of drought and their impacts on agricultural production and food security will help policymakers and stakeholders to develop strategies to mitigate the negative impacts of drought on agriculture and ensure food security.
- Water resources management: Drought affects the availability and quality of water resources, which are essential for human and animal consumption, agriculture, and other

economic activities. By analyzing the spatiotemporal pattern of drought, the study can help to identify areas where water scarcity is more severe, and develop strategies to manage water resources sustainably.

- Climate change adaptation: The study can provide insights into the potential impacts of climate change on drought patterns in the region and help policymakers and stakeholders to develop strategies to adapt to these changes.
- Disaster risk reduction: Drought is a natural disaster that can have severe impacts on people and the environment. Understanding the spatiotemporal pattern of drought can help to develop effective early warning systems, contingency plans, and disaster risk reduction strategies.

1.6 Beneficiaries

The outputs from this research will benefits the following

- Researchers and academia: The study can contribute to the knowledge base on the spatiotemporal pattern of drought in Dodoma region and provide valuable information for future research and academic studies.
- Policymakers and government agencies: The study can provide important information for policymakers and government agencies to develop effective policies, plans, and strategies to mitigate the negative impacts of drought on agriculture, water resources, and vulnerable populations in Dodoma region.
- Agricultural stakeholders: Farmers, agricultural cooperatives, and other stakeholders in the agriculture sector can benefit from the study by understanding the spatiotemporal pattern of drought and developing strategies to mitigate the impacts on their crops and livestock.
- Water management authorities: Water management authorities can benefit from the study by understanding the spatiotemporal pattern of drought and developing strategies to manage water resources sustainably and ensure adequate water supply for human consumption, agriculture, and other economic activities.

1.7 Scope and limitation of the research

- This study focuses on analyzing spatiotemporal pattern of drought by using Remote Sensing (RS) and Geographical Information System (GIS) techniques and finally developing a drought pattern map which help to analyze drought that had occurs on different part of Dodoma region.

1.8 The study area

Dodoma region lies in the central Tanzania mainland between latitudes 4° to 7° South and longitude 35° to 37° East (United Republic of Tanzania URT, 2011). The region occupies about 41,310 km² of which 85% is a potential agricultural land. The Dodoma region is largely a plateau rising gradually from some 830 metres above the sea level in Bahi swamps to 2000 metres above the sea level (m.a.s.l) in the highlands, north of Kondoa (United Republic of Tanzania URT, 2011). The region has seven (7) districts namely: Bahi, Chamwino, Chemba, Dodoma City, Kondoa, Kongwa and Mpwapwa.

The climate in the Dodoma region is characterized as a savanna type, which exhibits a prolonged dry season lasting from late April to early December. The remaining months experience a short wet season. During the long dry season, strong drying winds and low humidity prevail, leading to increased evapo-transpiration and soil erosion. The average annual rainfall in Dodoma region is 570 millimeters, with approximately 85 percent of it occurring between December and April. The areas of Mpwapwa and Kondoa Districts receive higher rainfall, especially in the agriculturally productive parts. However, the rainfall is relatively low and unpredictable in terms of frequency and amount. This unpredictability has resulted in a risk-averse approach to traditional agriculture and poses a significant constraint to ongoing efforts aimed at improving crop yields. As for temperatures, they vary based on altitude, but generally, the region experiences an average maximum temperature of 31°C and an average minimum temperature of 18°C. From June to August, temperatures can reach very high levels, with hot afternoons reaching up to 35°C and chilly nights in hilly areas dropping to around 10°C. Figure 1.1 show location of the study area.

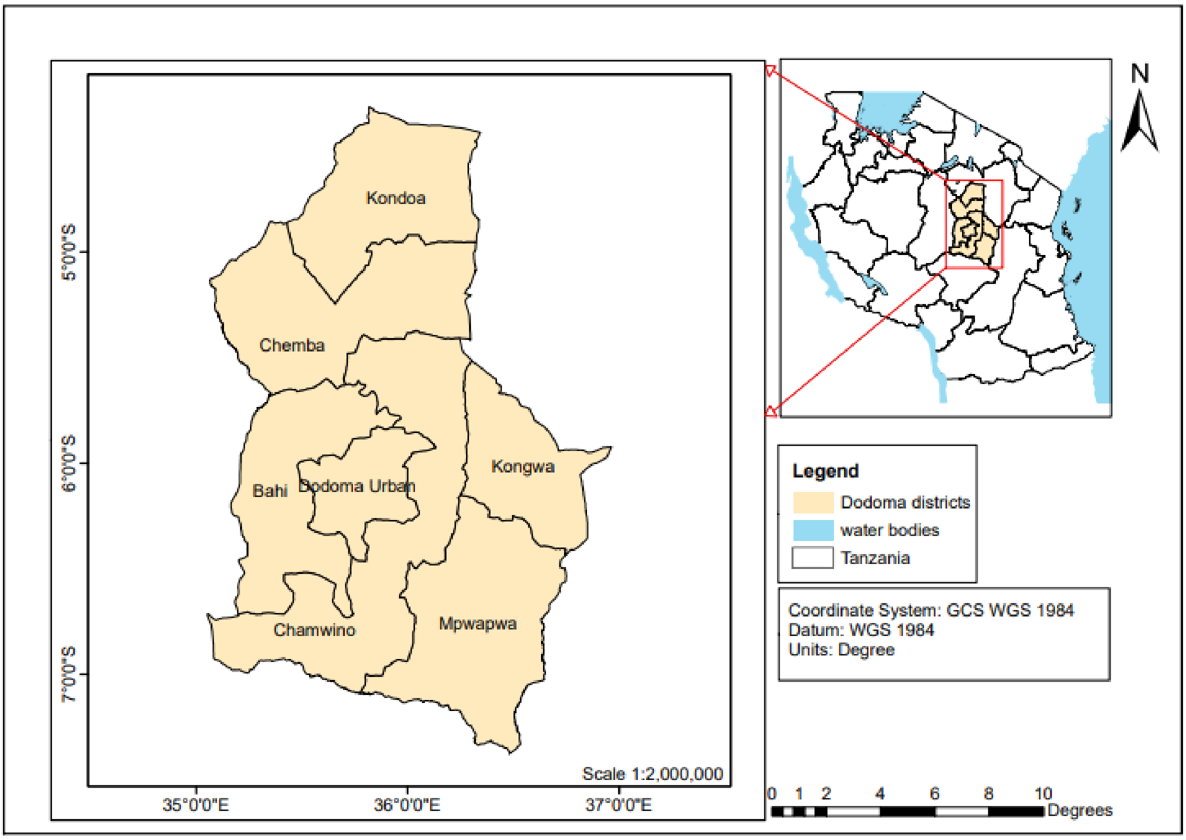

Figure 1.1: Location map of Dodoma region

CHAPTER TWO
LITERATURE REVIEW

2.0 Drought: The concepts

Drought differs from other natural hazards (e.g., floods, tropical cyclones, and earthquakes) in several ways. First, the effects of drought often accumulate slowly over a considerable period of time and may remain for years after the termination of the event, the onset and end of drought is difficult to determine. Because of this, drought is often referred to as a creeping phenomenon (Tannehill, 1947). Second, drought impacts also differ spatially and temporally, depending on the societal context of drought. A universal definition of drought is an unrealistic expectation this conclude that definitions of drought should reflect a regional bias since water supply is largely a function of climatic regime (Wilhite & Glantaz, 1985). Definitions of drought can be categorized broadly as either conceptual or operational (Wilhite & Glantaz, 1985). Conceptual definitions of drought were: -

i. "an extended period a season, year, or several years of deficient rainfall relative to the statistical multi-year mean for a region (Wilhite & Glantaz, 1985).
ii. Deficiency of precipitation from expected or normal that, when extended over a season or longer period of time, is insufficient to meet the demands of human activities, resulting in economic, social, and environmental impacts (Tannehill, 1947).
iii. The drought appears when rainfall in a region is less than statistical multi-year average for that region over extended time period (Mala, 2014).

Operational definitions attempt to identify the precise characteristics and thresholds that define the onset, continuation, and termination of drought episodes as well as their severity. These definitions are the foundation of an effective early warning system. They can also be used to analyze drought frequency, severity, and duration for a given historical period. For more details about operational definition of drought consider below each type of drought as defined: -

2.1 Types of droughts

Drought can be categorized into four types such as: -

i. Meteorological drought refers to the type of drought characterized by precipitation deficiency over a predetermined period of time, it is a natural event and results from multiple causes, which differ from region to region (WMO, 2006). Dodoma region is known to experience meteorological drought which result water shortages, reduced crop yields, and other negative impacts on the environment, agriculture, and local communities (WMO, 2006). Other types of droughts include: -

ii. Agricultural drought refers to the type of drought that results from soil moisture deficiency to support crop growth due to lack of precipitation and increase of evapotranspiration over specified period of time (WMO, 2006).
iii. Hydrological drought refers to the type of drought that is characterized by the deficiency of surface and/or subsurface water supplies from some average condition at various points in time. Example in lakes, reservoirs, aquifers, and streams (WMO, 2006).
iv. Socio-economic drought is type of drought that occurs when there is disproportion between the supply and demand such as water or hydroelectric power which depend on precipitation and this disproportion can result from increasing population, development or other factors (WMO, 2006).

2.2 Characteristics of drought

Drought is associated with different characteristics that affects different regions differently and some of these characteristics are: -

i. Duration:

Drought is characterized by an extended period of time with below-average precipitation. The duration of a drought can vary from a few weeks to several years. For instance, the United States experienced a severe drought in the 1930s, which lasted for almost a decade, and it is commonly referred to as the Dust Bowl (Wilhite, 2000).

ii. Intensity:

The intensity of a drought refers to the severity of the dry spell. This can be determined by the amount of precipitation received, the severity of the water shortage, and the duration of the drought. The intensity of a drought can range from mild to extreme. The higher the intensity, the more severe the impact on the affected regions (Wilhite, 2000).

iii. Spatial extent:

Droughts can affect different regions differently. Some regions may experience severe droughts, while others may not be affected at all. The spatial extent of a drought refers to the area affected by the drought. This can vary from a small region to an entire continent. For instance, the 2011 East African drought affected over 13 million people across several countries, including Kenya, Somalia, and Ethiopia (Wilhite, 2000).

2.3 Effects of drought

Drought has a range of effects on ecosystems, water resources, agriculture, and human well-being, the following below are the some of the effects related to drought: -

i. Effects of drought on water resources in Dodoma region:

Drought can have a significant impact on water resources in Dodoma region, leading to decreased water availability, increased competition for water resources, and the reduction of groundwater reserves. For example, the 2015-2017 drought in Dodoma region led to a significant decrease in water levels in rivers and lakes, making it difficult for people to get water for drinking, cooking, and bathing. The drought also led to the drying up of some boreholes, which further exacerbated the water shortage (Wilhite, 2000). "The drought is having a devastating impact on the region's water resources. Rivers and lakes have dried up, and groundwater levels have declined. This is making it difficult for people to get water for drinking, cooking, and bathing." (Mwakaje et al., 2017).

ii. Effects of drought on agriculture in Dodoma region:

Droughts can have a severe impact on agriculture in Dodoma region, leading to crop failure, livestock losses, and reduced food production. The intensity and duration of the dry spell, as well as the availability of irrigation systems and other adaptive measures, determine the impact of drought on agriculture. For example, the 2015-2017 drought in Dodoma region resulted in a significant reduction in crop yields, a rise in food prices, and the death of livestock (Wilhite, 2000). "The drought is having a devastating impact on the region's agriculture. Crops have failed, and many farmers have lost their livelihoods. The drought is also increasing the risk of food insecurity in the region." (Mwakaje et al., 2017).

iii. Effects of drought on human well-being in Dodoma region:

Drought can have a significant impact on human well-being in Dodoma region, particularly in the semi-arid areas. Reduced water availability can lead to decreased access to drinking water, sanitation, and hygiene facilities, which can increase the risk of waterborne diseases, such as cholera and diarrhea. In addition, drought can lead to social and economic stresses, such as migration, conflict, and poverty (UN-Water, 2019). "The drought is a major threat to the health of people in Dodoma region. The lack of water is making it difficult for people to stay clean, and this is leading to the spread of diseases such as cholera and malaria." (Mwaikambo et al., 2018)

iv. Effects of drought on ecosystems in Dodoma region:

Droughts can have a severe impact on ecosystems in Dodoma region, leading to reduced biodiversity, increased wildfire risks, and altered ecosystem functioning. The impact of drought on ecosystems depends on the intensity and duration of the dry spell, as well as the resilience of the affected ecosystems (Wilhite, 2000). "The drought is having a devastating impact on the environment of Dodoma region. The lack of rain is causing vegetation to die, and this is leading to soil erosion. The drought is also making it difficult for wildlife to find food and water." (Mwakaje et al., 2017).

2.4 Drought indices

This study involves two drought indices, the first one is Standardized Precipitation Evapotranspiration Index (SPEI) which is the meteorological drought indices for monitoring drought based on precipitation data, maximum and minimum temperature data (Vicente et al., 2010) and the second drought indices is Vegetation Condition Index (VCI) which is the remotely Sensed drought indices, this indices use remote sensing technique to provide global coverage of surface characteristics which are logistically and economically impossible to obtain through ground-based observations (Kogan, 1990). The VCI was derived by using Normalized Difference Vegetation Index (NDVI) data which allows detection of drought and measurement of the time of its onset and its intensity, duration, and impact on vegetation.

2.4.1 Standardized Precipitation Evapotranspiration Index (SPEI)

Standardized Precipitation Evapotranspiration Index (SPEI) is a meteorological drought index that replace Standardized Precipitation Index (SPI) and is calculated as the difference between monthly precipitation and monthly potential evapotranspiration. The Standardized Precipitation Evapotranspiration Index (SPEI) is designed to detect and monitor drought conditions in various climatic regions, including semi-arid regions like Dodoma. SPEI is an index that combines both precipitation and potential evapotranspiration (PET) data to provide a more comprehensive measure of drought that takes into account not only precipitation deficits but also the evaporative demand of the atmosphere (Vicente et al., 2010).

SPEI is an improvement over the more commonly used Standardized Precipitation Index (SPI), which only considers precipitation. Since semi-arid regions like Dodoma often have high evaporation rates due to their arid to semi-arid climate, using SPEI can offer a more accurate representation of the combined effects of precipitation deficits and increased evaporation demands (Vicente et al., 2010).

SPEI calculates a standardized value that represents the number of standard deviations by which the observed climate data (precipitation and potential evapotranspiration) deviates from the historical climate data. Positive values indicate wetter conditions, while negative values indicate drier conditions. This index can help identify the severity and duration of drought events, making it a valuable tool for drought monitoring, assessment, and management in regions with water scarcity issues like Dodoma (Vicente et al., 2010).

The Standardized Precipitation Evapotranspiration Index (SPEI) values estimated by fitting historical observations into a log-logistic distribution. The calculation of potential evapotranspiration (PET) requires numerous meteorological parameters such as temperature, humidity and solar radiation as inputs but due to limited datasets the present research used the modified Hargreaves technique which only requires maximum and minimum temperature datasets as well as latitude of the site, then the difference between the precipitation P and PET for the month i can be calculated as follows:

$$CWBLi = Pi - PETi \text{ ……………………(i) (Vicente et al., 2010)}$$

Where Potential Evapotranspiration (PET) was calculated from Hargreaves method/equation as

$$PET = K * (Tmax - Tmin) * \left(\sqrt{(Tmax - Tmin)}\right) * Ra \text{.....................(ii)}$$

Where: PET: Potential evapotranspiration K: Empirical coefficient (typically set as 0.0023) Tmax: Maximum temperature (in ˚C) Tmin: Minimum temperature (in ˚C) Ra: Extraterrestrial radiation.

Extraterrestrial radiation (Ra) represents the amount of solar radiation that reaches the Earth's atmosphere, and it is calculated based on the location's latitude, day of the year, and solar geometry. Hargreaves technique is a simplified method that provides an estimation of reference evapotranspiration but may not capture all local climatic complexities. It is often used in situations where detailed climatic data required for more complex methods (such as the Penman-Monteith method) are not available.

Then, the calculated $CWBLi$ values are aggregated at different time scales. The difference in a given month j and year i depends on the chosen time scale k. For example, the accumulated difference for one month in a particular year i with a 12-month time scale can be calculated as follows :-

$$X^n i, j = \sum_{l=13-k+j}^{12} \mathrm{Di} - 1, \mathrm{l} + \sum_{l=1}^{j} \mathrm{Di}, \mathrm{l}, \text{ if } \mathrm{j} < \mathrm{k}, \text{ and ..………………(iii) (Vicente et al., 2010)}$$

$$X^n i, j = \sum_{l=J-K+1}^{j} \mathrm{Di}, \mathrm{l}, \text{ if } \mathrm{j} \geq \mathrm{k} \text{ ………………..(iv)}$$

where Di,l is the difference between P − PET in the first month of the year i

Based on the behaviour at the most extreme values, the log-logistic distribution adapts very well to standardize the $CWBL$ series to obtain the Standardized Precipitation Evapotranspiration Index (SPEI) by using probability density function of a three-parameter log-logistic distributed variable such as scale, shape and origin parameters, therefore Standardized Precipitation Evapotranspiration Index (SPEI) can be easily obtained as the standardized values of the probability distribution function of the $CWBL$ series, according to the log-logistic distribution as follows:-

$$F(x) = \left[\left(1 + \frac{\alpha}{x - \gamma}\right)^{\beta} \right]^{-1}$$ ……………………(v) (Vicente et al., 2010)

$$SPEI = W - \frac{Co + C1W + C2W^2}{1 + d1W + d2W^2 + d3W^3}$$ …………………(vi) (Vicente et al., 2010)

Where,

$$W = \sqrt{-2\ln(P)}, \ P \leq 0.5$$ ……………………(vii) (Vicente et al., 2010)

P is the probability of exceeding a determined $CWBL$ value, P = 1 – probability distribution function (F(x)). If P > 0.5, then P is replaced by 1 − P and the sign of the resultant Standardized Precipitation Evapotranspiration Index (SPEI) is reversed. The constants are: C0 = 2.515517, C1 = 0.802853, C2 = 0.010328, d1 = 1.432788, d2 = 0.189269, and d3 = 0.001308. In addition to the consecutive time scale 3 months selected to analyze the drought. The SPEI class or categories shown on Table 2.1

Table 2. 1: Categories of dryness/wetness degree according to the Standardized Precipitation Evapotranspiration Index (SPEI) values.

Categories	SPEI Values
Extremely wet	≥ 2.0
Severely wet	1.5 to 1.99
Moderately wet	1.0 to 1.49
Normal	-0.99 to 0.99
Moderate drought	-1.0 to -1.49
Severely drought	-1.5 to -1.99
Extremely drought	≤ -2.0

2.4.2 Vegetation Condition Index (VCI)

Vegetation Condition Index (VCI) is a remote sensed drought indices used to characterize the drought impact on vegetation. The VCI is calculated based on the Normalized Difference Vegetation Index (NDVI), which is a widely used index for monitoring the vegetation growth condition (Kogan, 1990). The VCI is a relative value which indicates the greenness of each pixel relative to the average condition over the historical record at a given time. The VCI allows detection of drought and measurement of the time of its onset and its intensity, duration, and impact on vegetation, hence VCI is calculated by using the formula (vii) were by the results used in monitoring the agricultural drought as shown on table 2.2 (Kogan, 1990).

$$VCI = \frac{NDVI-NDVImin}{NDVImax-NDVImin} \times 100$$ …………………(viii) (Kogan, 1990)

Table 2. 2 Categories of Vegetation Condition Index (VCI).

Categories	VCI Values
50% to 100%	indicates above normal condition of vegetation
35% to 50%	indicate drought condition
< 35%	indicate severe drought condition

2.4.3 Normalized Difference Vegetation Index (NDVI)

NDVI is a standardized index allowing generating an image displaying greenness. NDVI it was first suggested by Tucker in 1979 as an index of vegetation health and density. NDVI includes two bands from a multispectral raster dataset the chlorophyll pigment absorptions in the red band and high reflectivity of plant materials in the near-infrared (NIR) band, NDVI is often used worldwide to monitor drought, monitor and predict agriculture production and assist in prediction hazardous fire zones.

The NDVI is preferred for global vegetation monitoring because it helps compensate for changing illumination conditions, surface slope, and aspect, The differential reflection in red and infrared band enables to monitor density and intensity of green vegetation growth using the spectral reflectivity of solar radiation. Green leaves commonly show better reflection in the near-infrared wavelength range than in visible wavelength range, when leaves are water stressed, diseased or dead they become more yellow and reflect significantly in the near-infrared range, while the difference is most zero for rock and bare soil and the negative values represent clouds, water and snow and values near zero represent rock and bare soil while positive values represent health vegetation. NDVI defined as

$$NDVI = \frac{(NIR-RED)}{(NIR+RED)}$$ …………………………………………..(ix) (Gamage, 2004)

Where, NIR and RED are the reflectance in the near-infrared and red bands. NDVI is a good indicator of green biomass, leaf are index and patterns of production (Gamage, 2004).NDVI is a commonly used vegetation index, it varies from +1 to -1 since climate is one of the most important factors affecting vegetation condition.

2.5 Non-parametric Mann-Kendall (MK) test method

The non-parametric Mann-Kendall test is the statistical method used to detect the drying or wetting trend of the area based on precipitation, maximum and minimum temperature data. This method does not require an assumption of normality in variance and is less sensitive to outliers compared with linear regression analysis, hence it is used to evaluate the significance of the trends in time series. The standardized Z values obtained from MK test provide a convenient means for quantifying the trend were by Positive values of Z indicate increasing trends while negative values of Z show decreasing trends (Mann, 1945). The test can be calculated based on the equations (x) to (xii)

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(Xi - Xj) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(x) (Mann, 1945)}$$

where S is the rating score (called Mann–Kendall sum); X is the data value; I and j counters; n represents the number of data values in the series; sgn (Xi-Xj) is a function. Positive and negative values of S indicate increasing and decreasing trends, respectively. The variance is

$$Var(S) = \frac{n(n-1)(2n+5)}{18} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(xi)}$$

S is standardized (as shown in Equation (xi)) by subtracting its expectation (zero) divided by its standard deviation (σS).

$$Zs = \{\frac{S-1}{\sqrt{Var(S)}}, if\ S > 0{,}0, if\ S = 0, \frac{S+1}{\sqrt{Var(S)}}, if\ S < 0 \ldots\ldots\ldots\ldots\ldots\ldots \text{(xii)}$$

2.6 Spatiotemporal patterns of droughts in Dodoma region.

Spatiotemporal patterns in the case of Dodoma region, Tanzania refer to the spatial and temporal distribution of droughts in the region. Studies have shown that droughts in Dodoma region have become more frequent and severe in recent decades, and that the spatiotemporal patterns of drought have become more complex (Mwakaje et al., 2017). The spatial patterns of drought in Dodoma region show that droughts are more likely to occur in the interior of the region, away from the coast. This is because the interior of the region is more arid and receives less rainfall. The temporal patterns of drought in Dodoma region show that droughts are more likely to occur during the dry season, which is from June to September. The spatiotemporal patterns of drought in Dodoma region have implications for drought mitigation and adaptation strategies. For example, it is important to focus drought mitigation efforts on the areas that are most vulnerable to drought, such as the interior of the region. It is also important to develop drought adaptation strategies that can be implemented during both the wet and dry seasons.

Mwaikambo et al. (2018) used remote sensing data to analyze the spatiotemporal patterns of drought in Dodoma region. The study used data from the Moderate Resolution Imaging Spectroradiometer (MODIS) to create a drought index called the Standardized Drought Index (SDI). The SDI is a drought index that uses vegetation greenness data to assess the severity of drought. The study found that droughts in Dodoma region have become more frequent and severe in recent decades. The study also found that the spatiotemporal patterns of drought have become more complex. The study found that the areas most vulnerable to drought in Dodoma region are those that are located in the interior of the region and those that have a high population density.

CHAPTER THREE

METHODOLOGY

3.0 Introduction

This chapter involves data acquisition, preparation, exploration and processing for the purpose of obtaining outputs that will be used to analyzing spatiotemporal patterns of drought in Dodoma region. Figure 3.1 is a methodology flow chart which shows how this research will be conducted.

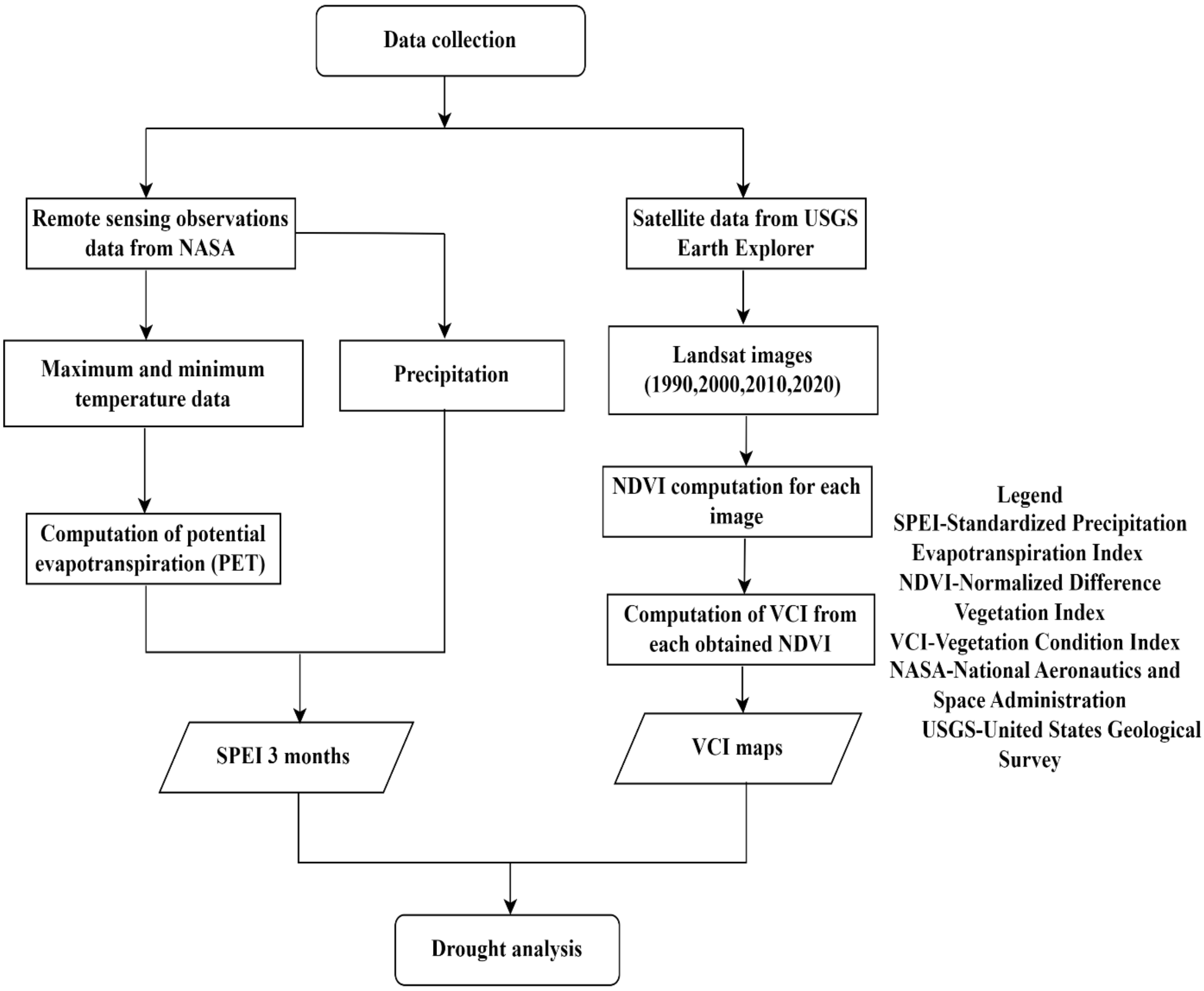

Figure 3. 1: Methodology flow chart

3.1 Data acquisition

3.1.1 Climate data

The data used includes precipitation, minimum and maximum temperature remote sensing observations data from NASA with a temporal resolution of mm/ monthly and °c/ monthly as well as spatial resolution of 0.5° latitude, 0.625° longitude and grid reference system WGS84 from each district in Dodoma region as shown on Table 3.1 for the time series 1990 to 2020 to enable calculation of Standardized Precipitation Evapotranspiration Index (SPEI). The data obtained from the web page https://power.larc.nasa.gov/data-access-viewer (NASA, 2023). Figure 3.2, 3.3 and 3.4 show the sample of the precipitation data, maximum and minimum temperature data for Kondoa station while the other stations data are shown on the appendices.

Table 3. 1: Location of stations were climate data acquired.

S/no	Station name	Latitude (°S)	Longitude (°E)
1	Kondoa	-4.7405	35.8346
2	Chemba	-5.3645	35.3888
3	Dodoma	-6.1702	35.7524
4	Kongwa	-6.0475	36.4798
5	Mpwapwa	-6.6789	36.2745
6	Bahi	-6.1533	35.3566
7	Chamwino	-6.3994	35.911

Table 3. 2: Sample of monthly precipitation (mm) data for Kondoa station.

Parameter	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Preci	1990	73.83	200.4	316.4	226.8	21.09	0	0	0	0	10.55	147.7	47.46
Preci	1991	116	121.3	163.5	73.83	42.19	0	5.27	0	0	0	0	84.38
Preci	1992	0	237.3	31.64	137.1	42.19	0	0	0	0	0	68.55	142.4
Preci	1993	295.3	110.7	79.1	73.83	31.64	10.55	0	0	0	0	21.09	26.37
Preci	1994	58.01	152.9	84.38	73.83	52.73	0	0	0	21.09	0	142.4	110.7
Preci	1995	105.5	68.55	174	226.8	52.73	0	0	0	0	5.27	10.55	10.55
Preci	1996	68.55	158.2	121.3	174	58.01	10.55	0	0	0	0	26.37	15.82
Preci	1997	21.09	84.38	247.9	305.9	168.8	0	5.27	0	0	26.37	116	142.4
Preci	1998	147.7	184.6	15.82	137.1	52.73	0	0	0	0	0	5.27	0
Preci	1999	36.91	0	174	290	47.46	5.27	0	0	0	0	63.28	10.55
Preci	2000	26.37	31.64	47.46	58.01	0	10.55	0	5.27	0	10.55	79.1	84.38

Table 3. 3: Sample of monthly maximum temperature (°c) data for Kondoa station.

Parameter	Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmax	1990	29.4	31.51	25.28	24.3	24.4	24.94	24.48	26.41	29.32	30.19	30.02	28.75
Tmax	1991	30.65	30.94	31.33	27.64	26.69	27.77	25.63	28.43	29.48	30.79	30.94	31.36
Tmax	1992	32.56	32.55	32.48	28.26	26.23	26.21	26.62	27.37	30.13	31.13	29.74	28.93
Tmax	1993	27.65	26.37	27.48	27.28	25.86	25.3	24.98	27.26	29.62	30.45	31.9	31.37

Tmax	1994	33	33.24	29.35	29.23	27.39	27.75	27.09	28.94	29.83	30.55	30.08	29.55
Tmax	1995	30.85	31.72	27.62	28.24	24.9	25.4	25.32	27.45	29.23	30.51	31.48	30.72
Tmax	1996	31.16	31.23	30.64	26.12	26.31	26.5	25.97	28.29	31.08	30.45	31.32	31.43
Tmax	1997	32.86	32.92	31.6	26.73	23.56	23.48	24.58	26.83	29.96	29.37	29.44	27.5
Tmax	1998	27.99	29.92	30.29	29.12	27.5	28.76	26.62	28.58	30.45	31.32	31.58	32.82
Tmax	1999	32.87	34.02	31.98	27.46	24.54	26.37	25.73	27.26	29.34	31.31	30.94	30.38
Tmax	2000	32.65	33.44	29.99	29.23	29.23	27.24	27.66	28.21	29.85	31.84	31.08	29.14

Table 3. 4: Sample of monthly minimum temperature (°c) data for Kondoa station.

Parameter	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmin	1990	11.96	13.57	13.8	14.19	10.91	8.29	5.9	8.68	11.06	10.98	13.9	14.39
Tmin	1991	14.65	12.27	12.65	12.2	11.81	8.96	6.78	8.01	10.76	12.86	11.4	13.83
Tmin	1992	13.76	13.19	12.33	14.65	10.43	8.44	6.4	6.27	10.87	11.72	13.78	13.51
Tmin	1993	13.74	10.82	12.22	14.12	11.55	8.08	5.68	5.87	9.12	11.65	11.79	12.66
Tmin	1994	14.22	14.01	13.27	10.76	11.33	7.14	6.67	8.61	10.4	11.49	13.58	13.27
Tmin	1995	12.7	12.48	13.1	14.01	8.73	9.01	6.8	9.42	8.36	12.78	12.34	13.33
Tmin	1996	13.8	13.99	12.66	13.26	12.1	8.23	6.27	7.1	9.3	10.96	13.26	13.21
Tmin	1997	13.53	13.32	12.95	12.15	8.91	10.94	6.84	7.51	9.43	12.31	14.79	15.18
Tmin	1998	15.09	13.15	13.53	13.19	9.67	7.65	7.2	10.78	12	11.86	11.87	14.63
Tmin	1999	12.81	13.38	14.76	13.32	10.9	8.41	8.44	11.62	11.01	9.9	13.32	12.95
Tmin	2000	13.17	13.13	15.16	12.8	12.26	8.15	7.55	10.44	11.22	11.61	14.12	15.08

3.1.2 Satellite images

In this study, the images acquired was Landsat 4 TM, Landsat 5 TM, Landsat 7 ETM+ and Landsat 8 OLIS/TIRS imagery that were used to analyze spatiotemporal patterns of drought in Dodoma region. In this study the Landsat images used were downloaded from (https://earthexplorer.usgs.gov/) and from both images red bands and near infrared bands was extracted so as to calculate Normalized Difference Vegetation Index (NDVI) that was used to compute Vegetation Condition Index (VCI) so as to achieve objectives of the study .Table 3.2 show the type of Landsat images data used and their characteristics.

Table 3. 5: Satellite image properties.

Landsat		Spectral resolution (m)	Acquisition date	Number of bands
Satellite ID	Sensor			
Landsat 4	TM	30	9/2/1990	7
Landsat 5	TM	30	6/4/1990 8/2/2010 13/4/2010	7
Landsat 7	ETM+	30	12/1/2000	8
Landsat 8	OLI/TIRS	30	11/2/2020 7/3/2020	11

3.2 Data preparation and exploration

In this part the meteorological data that is precipitation, minimum and maximum temperature data for all seven stations was prepared and arranged in a required format for exploration by using Microsoft excel and further processing on R-programming software for calculation of Standardized precipitation Evapotranspiration Index (SPEI) at a time scale 3 months such as January(J), February(F) and March(M) as well as the Landsat images for calculation of Vegetation Condition Index (VCI).

3.3 Data processing

3.3.1 Computation of Standardized Precipitation Evapotranspiration Index (SPEI)

Standardized Precipitation Evapotranspiration Index (SPEI) was calculated by using long term record precipitation data, minimum and maximum temperature data for the time series 1990 - 2020 at each station for the selected rain month that is January(J), February(F) and March(M) in Dodoma region at each district. The following steps involved in calculation of Standardized Precipitation Evapotranspiration Index (SPEI) for all stations at each district in Dodoma region

Step 1: SPEI package, Lmomco package, trend package and ggplot2 package were installed on R-software.

Step 2: Monthly precipitation data, minimum temperature data and maximum temperature data in csv format was imported in R-software.

Step 3: Computation of Potential Evapotranspiration (PET); here potential Evapotranspiration (PET) was calculated by using hargreaves technique that require monthly minimum temperature data, maximum temperature data and latitude of the station for the time series 1990-2020 at each station in Dodoma region.

Step 4: Computation of aggregate value (CWBL); here aggregate value was calculated as the difference between accumulated Precipitation (P) and accumulated Potential Evapotranspiration (PET) for the month i at a time series 1990-2020 for each station in Dodoma region. Refers the formula (i) on literature review.

Step 5: Computation of Standardized Precipitation Evapotranspiration Index (SPEI); Standardized Precipitation Evapotranspiration Index (SPEI) was obtained as the standardized values of the probability distribution function of the aggregate value (CWBL) at a time scale of three months for the time series 1990-2020 at each station in Dodoma region according to the log-logistic distribution, Refers the formula (v) and (vi) on literature review.

Step 6: Plotting of spei-3 months for Kondoa station.

3.3.2 Computation of Vegetation Condition Index (VCI)

Vegetation Condition Index (VCI) was calculated based on Normalized Difference vegetation Index (NDVI) values for the years 1990, 2000, 2010 and 2020 by using red and near-infrared bands of Landsat images for the purpose of analyzing spatiotemporal patterns of drought in Dodoma region. Dodoma region covered by six footprints for each year, therefore calculation of VCI involved the following steps: -

Step 1: Mosaicking, after importing the bands into the Erdas Imagine, red band for all six footprints on each year were mosaicked into a single view with an indistinguishable seamline also the same thing was done for near-infrared band for all six footprints on each year that is 1990, 2000, 2010 and 2020.

Step 2: Layer stacking, the mosaicked red band and near-infrared band was combined so as to produce a new multiband image and this was done for each year 1990, 2000, 2010 and 2020 to enable calculation of NDVI values.

Step 3: Computation of NDVI, Normalized Difference Vegetation Index was calculated as the difference between near-infrared band and red band divide by summation of near-infrared band and red band, hence the results obtained here was used to compute Vegetation Condition Index (VCI).

Step 4: Computation of VCI, Vegetation Condition Index was computed by using the obtained NDVI values referring the formula number (vii) on literature review, hence the output obtained here were used to analyze spatiotemporal patterns of drought in Dodoma region.

3.3.3 Analysis

The non-parametric Mann-Kendall (MK) test statistical method was performed to detect the drying or wetting trend of the area based on precipitation, minimum and maximum temperature data. This method does not require an assumption of normality in variance and is less sensitive to outliers compared with linear regression analysis, hence it was used to evaluate the significance of the trends in time series. The standardized Z values obtained from MK test provide a convenient means for quantifying the trend were by Positive values of Z indicate increasing trends while negative values of Z indicate decreasing trends, the test was calculated by equations (x) to (xii) referring on the literature review.

CHAPTER FOUR

RESULTS, ANALYSIS AND DISCUSSION

4.0 Introduction

This chapter present and discusses the results obtained from various methods that were used to address the objectives of this study.

4.1 Results for time series analysis

Drought patterns in Dodoma region can be understanding clear by analyzing first the variation characteristics of the two elements in Standardized Precipitation Evapotranspiration Index (SPEI) that is precipitation and temperature. The non-parametric Mann Kendall test method was applied to analyze the trends of precipitation and temperature for seven stations at each districts in Dodoma region for the time series 1990 to 2020, and then, the Z-values obtained which shows positive and negative trends to represent trends towards wetter and drier conditions respectively, Z-values for precipitation, minimum and maximum temperature for the selected rain months January, February and March (JFM) at each station in Dodoma region are shown on table 4.

Table 4. 1: Z-values for precipitation, maximum temperature and minimum temperature for selected rain season (JFM) at each station in Dodoma region.

Stations	Precipitation	Maximum temperature	Minimum temperature
Kondoa	-1.3265	-0.40791	1.7849
Chemba	0.78236	-2.1755	1.2237
Dodoma	0.96908	-2.4815	1.5637
Chamwino	0.64614	-2.1755	1.9716
Bahi	0.96908	-2.4815	1.5637
Kongwa	1.2923	-1.9889	0.98608
Mpwapwa	1.4789	-1.9716	1.3433

Figure 4.1 shows the precipitation trend for Kondoa from 1990 to 2020, It can be noted from the figure that precipitation trend decreasing during rainy season January, February and March. In 1990 there was a peak in the precipitation pattern, but it decreased in 2000 and 2010 since then up to another peak in 2020. This situation is attributed to drought in 2000 and 2010 compared to 1990 and 2020.

Figure 4.2 and 4.3 shows the decreasing trend of maximum and increasing trend of minimum temperature for Kondoa station this could be one of the factors that contribute to the drought in Kondoa station for the year 2000 and 2010.

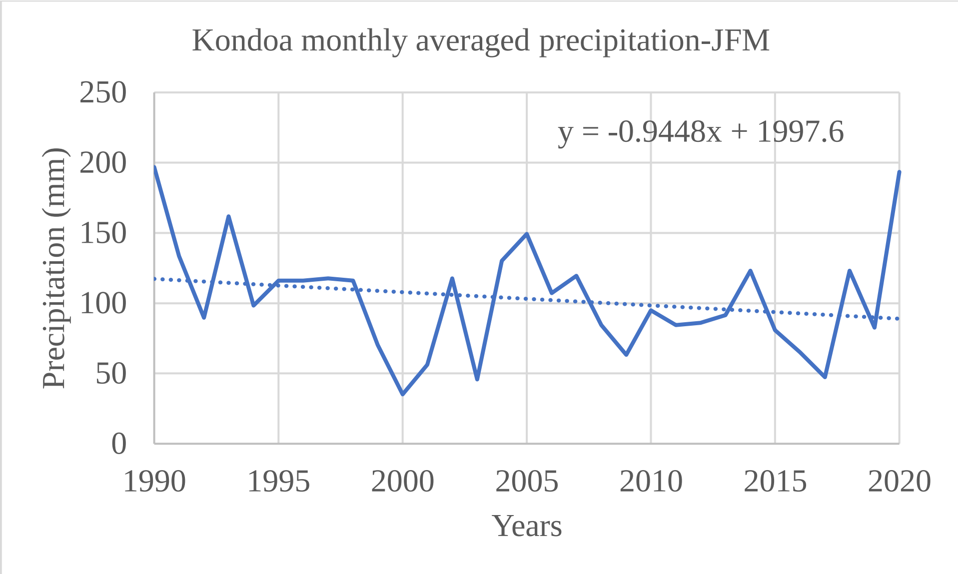

Figure 4. 1: Trend of precipitation over Kondoa from 1990 - 2020.

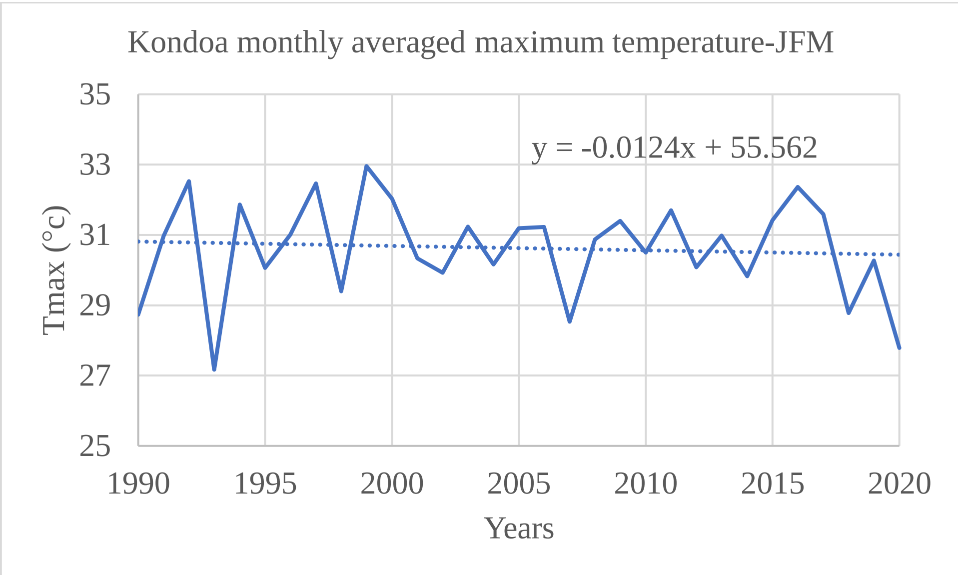

Figure 4. 2: Trend of maximum temperature over Kondoa from 1990 - 2020.

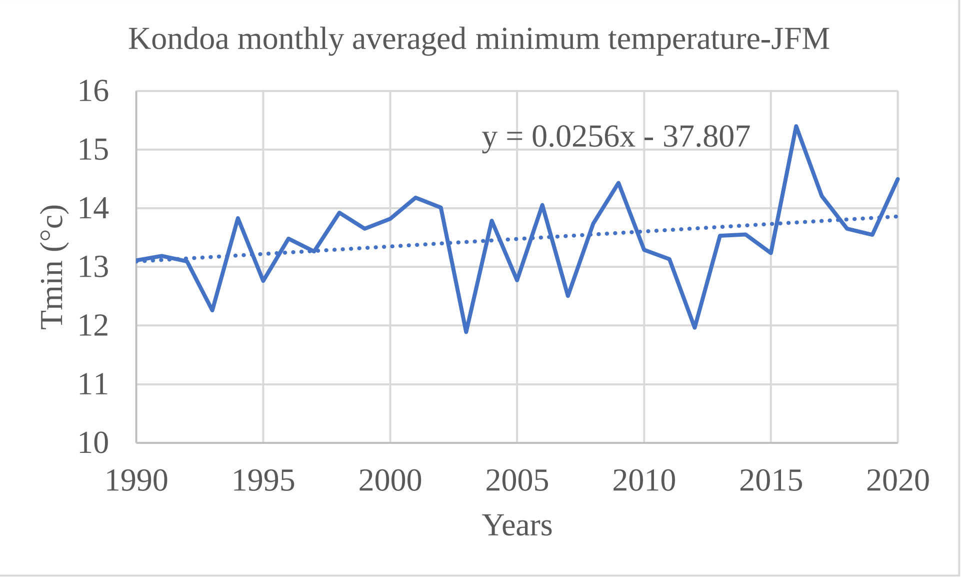

Figure 4. 3: Trend of minimum temperature over Kondoa from 1990 - 2020.

Figure 4.4 shows the precipitation trend for Dodoma from 1990 to 2020, It can be noted from the figure that precipitation trend increasing during rainy season January, February and March. In 1990 there was a peak in the precipitation pattern, but it decreased in 2000 and 2010 since then up to another peak in 2020. This situation is attributed to drought in 2000 and 2010 compared to 1990 and 2020.

Figure 4.5 and 4.6 shows the decreasing trends of maximum and increasing trend of minimum temperatures for Dodoma station this could be one of the factors that contribute to the drought in Dodoma station for the year 2000 and 2010.

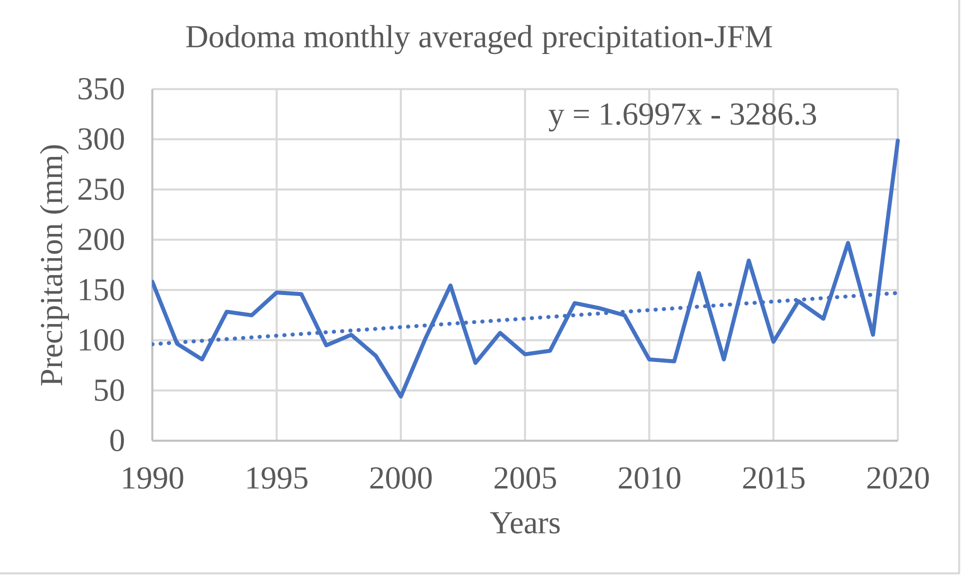

Figure 4. 4: Trend of precipitation over Dodoma from 1990 - 2020.

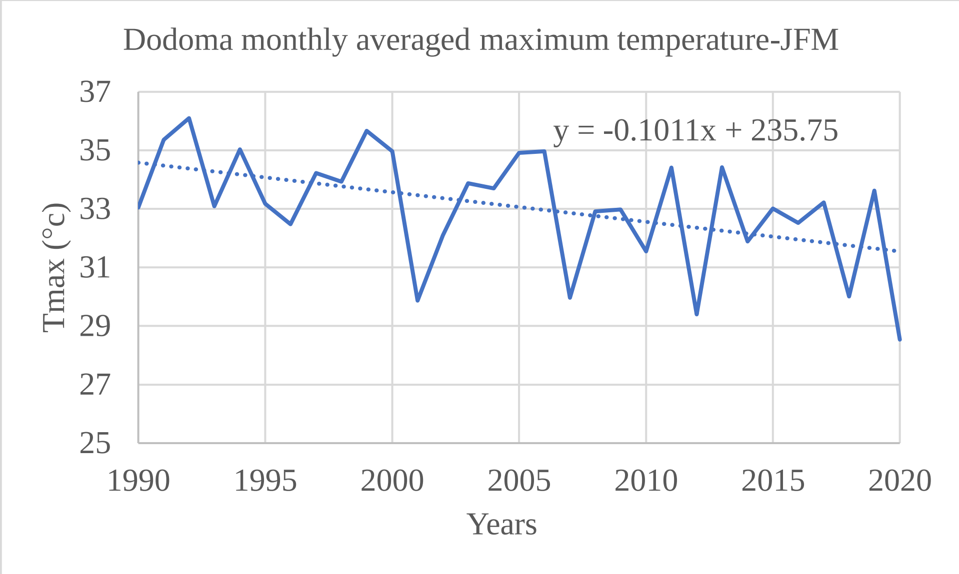

Figure 4. 5: Trend of maximum temperature over Dodoma from 1990 - 2020.

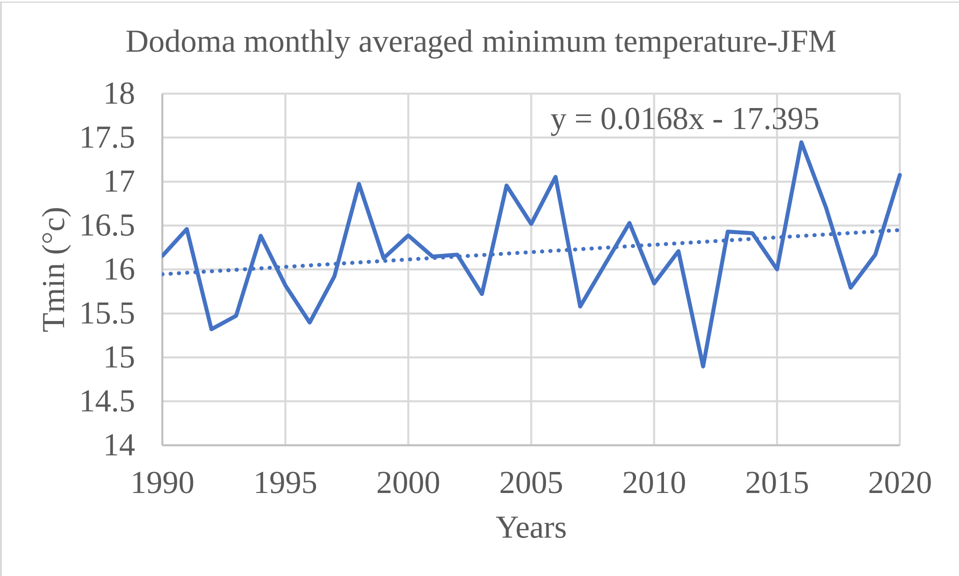

Figure 4. 6: Trend of minimum temperature over Dodoma from 1990 - 2020.

Figure 4.7 shows the precipitation trend for Mpwapwa from 1990 to 2020, It can be noted from the figure that precipitation trend increasing during rainy season January, February and March. In 1990 there was a peak in the precipitation pattern, but it decreased in 2000 and 2010 since then up to another peak in 2020. This situation is attributed to drought in 2000 and 2010 compared to 1990 and 2020.

Figure 4.8 and 4.9 shows the decreasing trend of maximum and increasing trend of minimum temperature for Mpwapwa station this could be one of the factors that contribute to the drought in Mpwapwa station for the year 2000 and 2010.

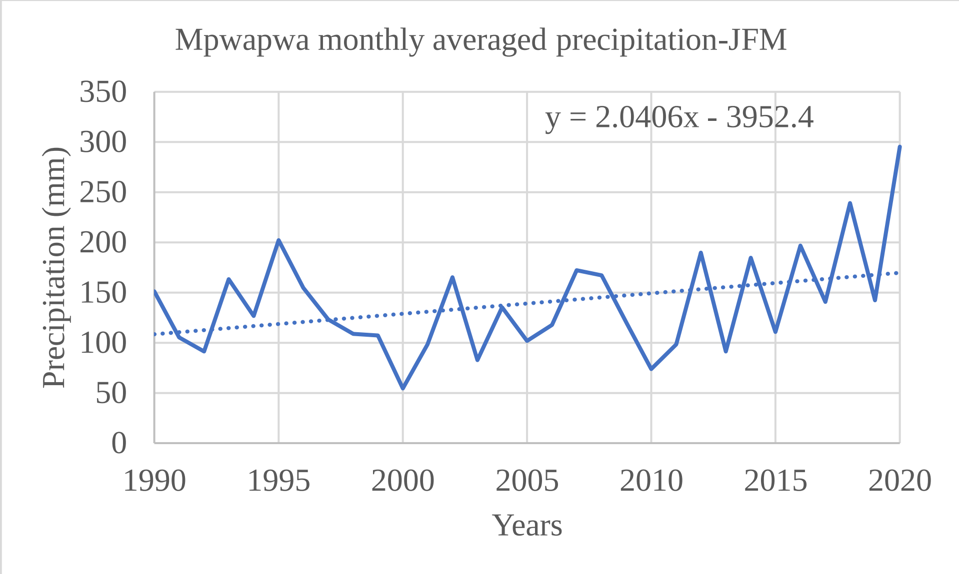

Figure 4. 7: Trend of precipitation over Mpwapwa from 1990 - 2020.

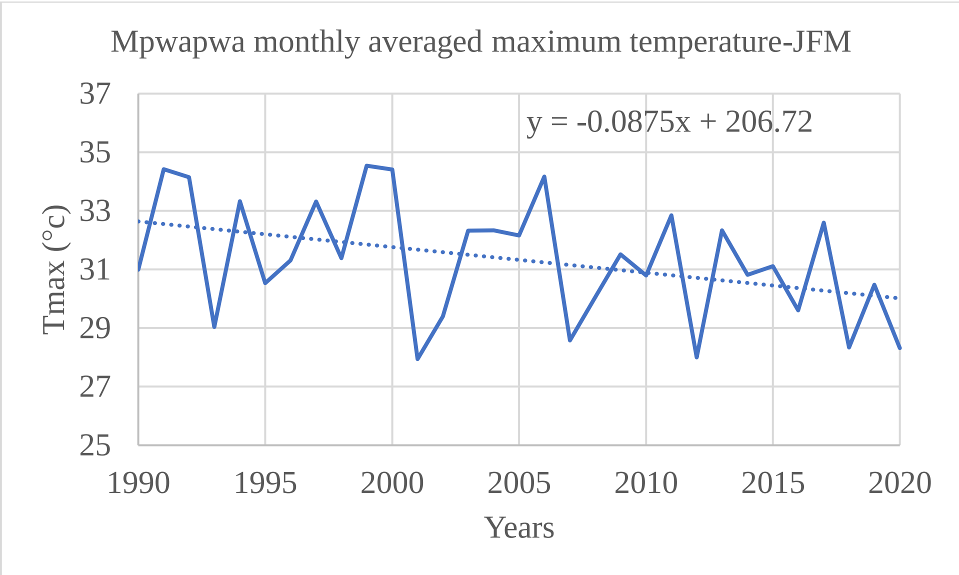

Figure 4. 8: Trend of maximum temperature over Mpwapwa from 1990 - 2020.

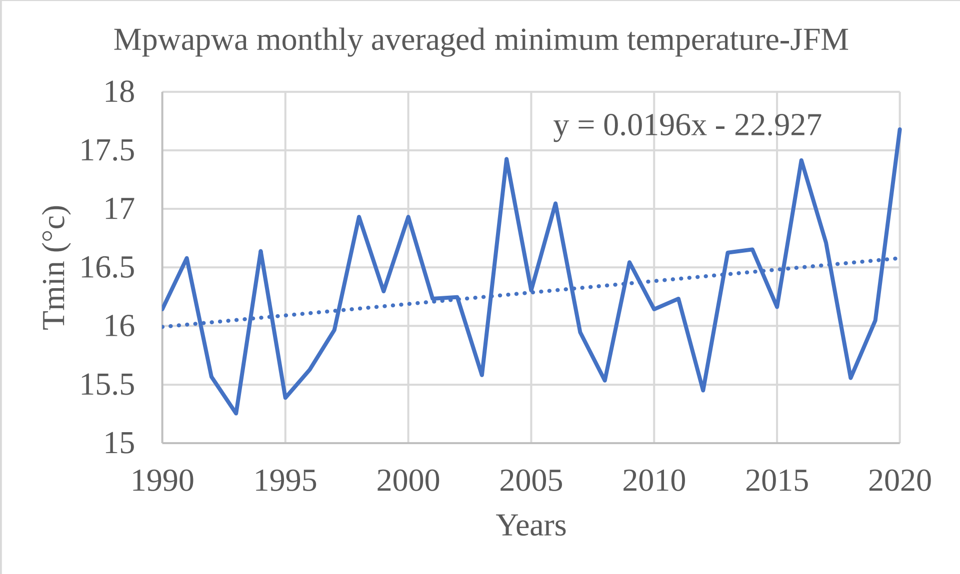

Figure 4. 9: Trend of minimum temperature over Mpwapwa from 1990 - 2020.

4.2 Standardized Precipitation Evapotranspiration Index (SPEI) results

Dodoma region is categorized into two main season that is rain season starting from November to April where by rainfall is at the peak between December to April and drying season starting from May to October. Therefore, this study focuses on analyzing spatiotemporal patterns of drought that is meteorological drought during rainy season from January to March. This analysis gives us information about SPEI at different stations during rainy season from January to March. The SPEI graphs shows drought tendency in recent years compared to some years back, the wettest periods are shown by positive numbers on the graphs ranging from +0.99 to +2 while the dry periods are shown by negative numbers on the graphs ranging from -0.99 to -2 at each station in Dodoma region.

Figure 4.10 depict SPEI-3 analysis of drought patterns for Kondoa station during rain season from January to March (JFM) on which Kondoa SPEI-3 value was -0.75 that indicate moderate drought in 2000 due to high temperature and low precipitation, -1 SPEI-3 value that indicate normal condition in 2010 and +1 SPEI-3 value that indicate moderate wet in 2020 due to high precipitation and low temperature. Referring table 2.1 SPEI-3 values categories of drying/wetting condition that results drought condition due to variation of precipitation and temperature.

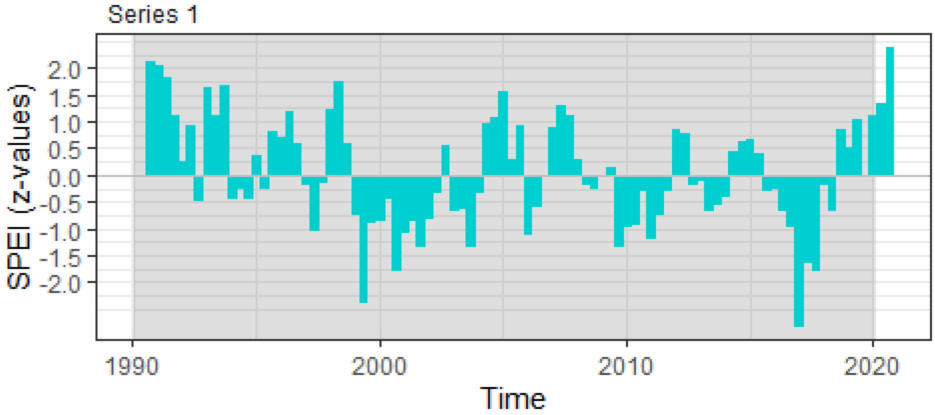

Figure 4. 10: SPEI-3 analysis of drought for Kondoa.

Figures 4.11 depict SPEI-3 analysis of drought patterns for Dodoma urban station during rain season from January to March (JFM) on which Dodoma experience moderate drought that is -1 SPEI-3 value in 2000 due to high temperature and low precipitation, -0.1 SPEI-3 value which indicate normal condition in 2010 and greater than +2 SPEI-3 value that indicate moderate wet in 2020 due to high precipitation and low temperature. Referring table 2.1 SPEI values categories of drying/wetting condition that results drought condition due to variation of precipitation and temperature.

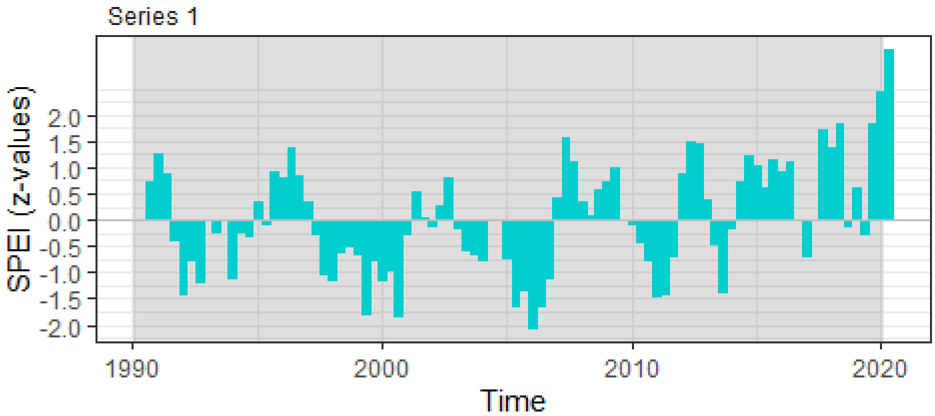

Figure 4. 11: SPEI-3 analysis of drought for Dodoma urban.

Figures 4.12 depict SPEI-3 analysis of drought pattern for Mpwapwa station during rain season from January to March (JFM) on which Mpwapwa SPEI-3 value was -1 that indicate moderate drought in 2000 due to high temperature and low precipitation, +0.1 SPEI-3 value that indicate normal condition in 2010 and +1.75 SPEI-3 value that indicate moderate wet in 2020 due to high precipitation and low temperature. Referring table 2.1 SPEI values categories of drying/wetting condition that results drought condition due to variation of precipitation and temperature.

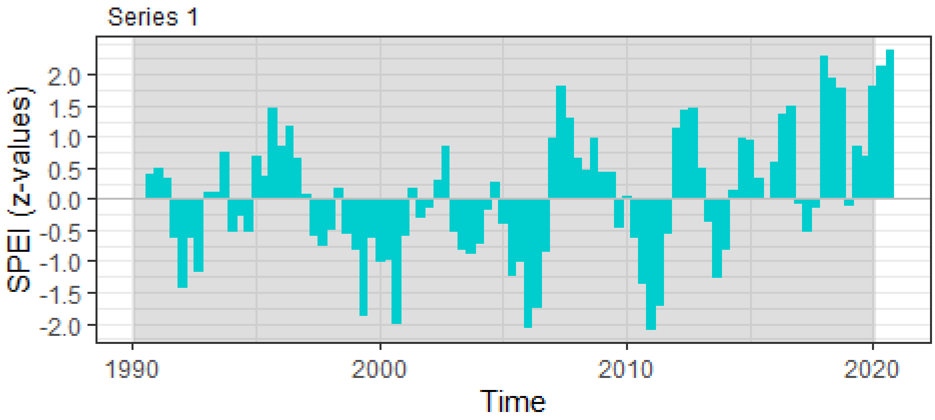

Figure 4. 12: SPEI-3 analysis of drought for Mpwapwa.

Figures 4.13 depict SPEI-3 analysis of drought pattern for Kongwa station during rain season from January to March (JFM) on which Kongwa SPEI-3 value was -1 that indicate moderate drought in 2000 due to high temperature and low precipitation, -0.25 SPEI value that indicate normal condition in 2010 and +2 SPEI-3 value that indicate moderate wet in 2020 due to high precipitation and low temperature. Referring table 2.1 SPEI-3 values categories of drying/wetting condition that results drought condition due to variation of precipitation and temperature.

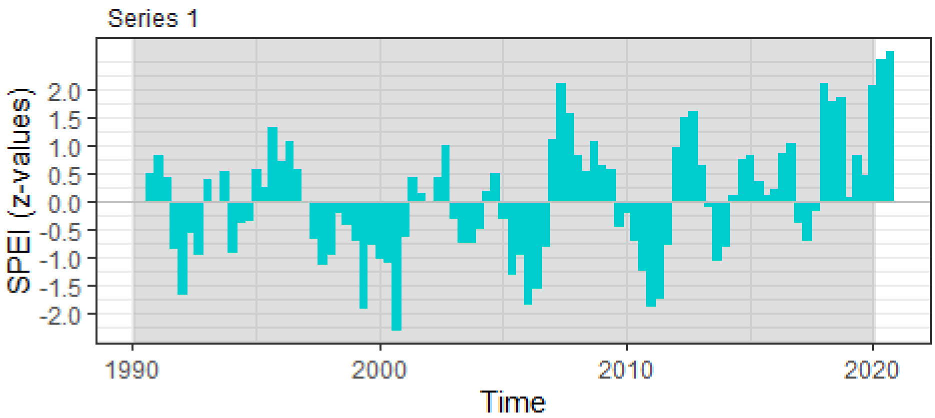

Figure 4. 13: SPEI-3 analysis of drought for Kongwa.

Figures 4.14 depict SPEI-3 analysis of drought patterns for Bahi station during rain season from January to March (JFM) on which Bahi SPEI-3 value was -1 that indicate moderate drought in 2000 due to high temperature and low precipitation, normal condition in 2010 and +2 SPEI-3 value that indicate moderate wet in 2020 due to high precipitation and low temperature. Referring table 2.1 SPEI-3 values categories of drying/wetting condition that results drought condition due to variation of precipitation and temperature.

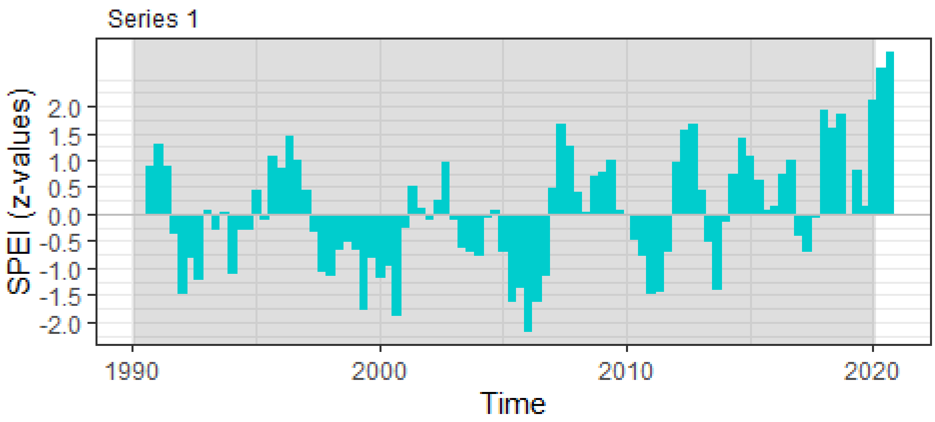

Figure 4. 14: SPEI-3 analysis of drought for Bahi.

Figures 4.15 depict SPEI-3 analysis of drought patterns for Chamwino station during rain season from January to March (JFM) on which Chamwino SPEI value was -1 that indicate moderate drought in 2000 due to high temperature and low precipitation, +0.25 SPEI-3 value that indicate normal condition in 2010 and +1.5 SPEI-3 value that indicate moderate wet in 2020 due to high precipitation and low temperature. Referring table 2.1 SPEI-3 values categories of drying/wetting condition that results drought condition due to variation of precipitation and temperature.

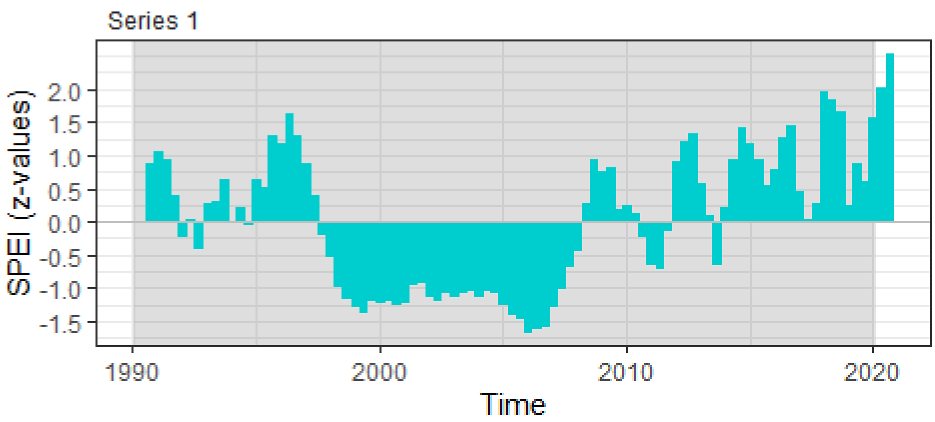

Figure 4. 15: SPEI-3 analysis of drought for Chamwino.

Figures 4.16 depict SPEI-3 analysis of drought patterns for Chemba station during rain season from January to March (JFM) on which Chemba SPEI-3 value was -1 that indicate moderate drought in 2000 due to high temperature and low precipitation, normal condition in 2010 and +2 SPEI-3 value that indicate moderate wet in 2020 due to high precipitation and low temperature.

Referring table 2.1 SPEI values categories of drying/wetting condition that results drought condition is due to variation of precipitation and temperature.

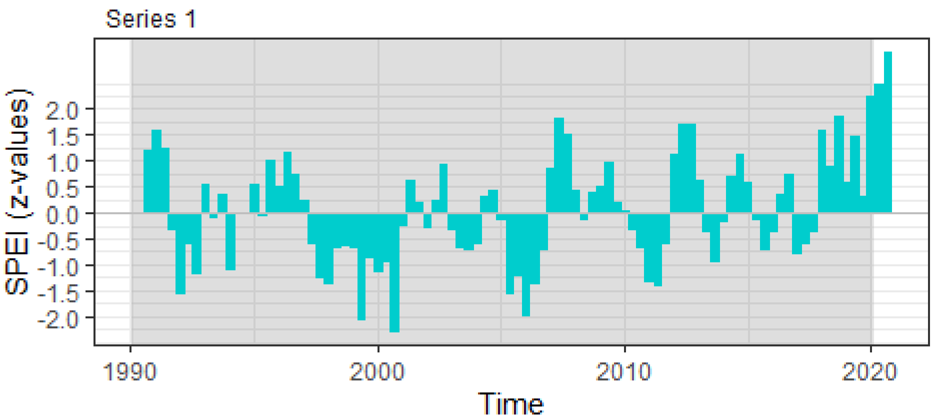

Figure 4. 16: SPEI-3 analysis of drought for Chemba.

4.3 Vegetation Condition Index (VCI) results

Vegetation Condition Index results for the year 1990, 2000, 2010 and 2020 provide information about vegetation condition which finally used to analyze spatiotemporal patterns of drought in Dodoma region. The results show that in 1990 some parts of Kondoa and Mpwapwa have low vegetation covered hence experience drought condition compared to Chemba, Dodoma urban, Bahi and Kongwa which covered with heavy vegetation where by Chamwino experience severe drought condition to some parts. In 2000 and 2010 most of the areas in Dodoma region experience drought condition and some parts of Bahi, Chamwino and Mpwapwa experience severe drought condition this condition verified by low amount of precipitation received at these years while in 2020 most of the areas in Dodoma region covered with heavy vegetation compared to years 1990, 2000 and 2010 except some part of Bahi, Chamwino and Mpwapwa, hence See figure 4.17 where by this information obtained from it as well as table 2.3.

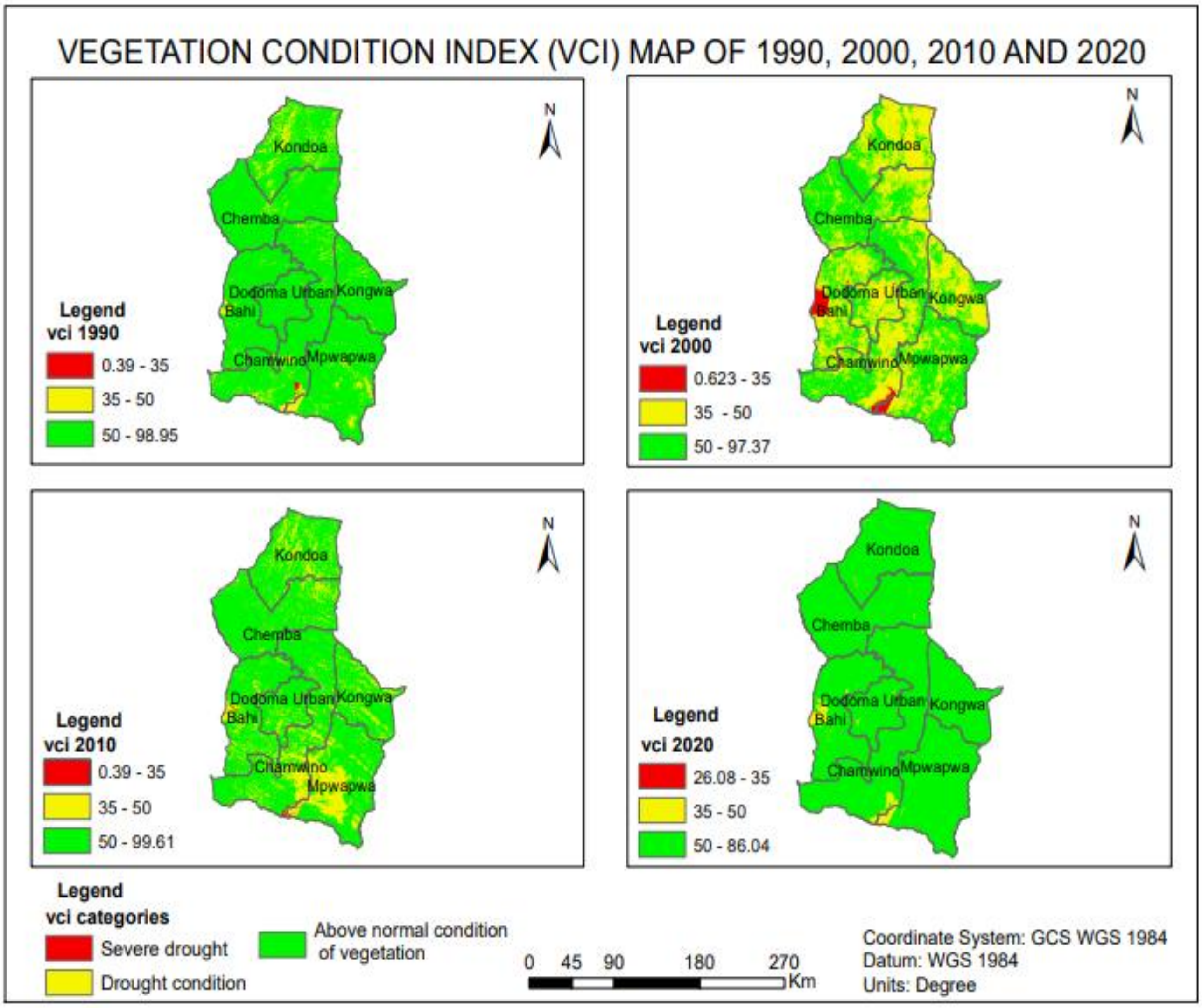

Figure 4. 17: Vegetation condition index map of Dodoma for 1990, 2000, 2010 and 2020.

4.4 Discussion

4.4.1 Time series

The Mann-Kendall test was used to analyze the trends of precipitation and temperature for seven stations in Dodoma region for the time series 1990 to 2020. The results showed that there is an increasing trend in precipitation during the rain season (January, February, and March) for all stations except Kondoa. However, there are also periods of drought, such as in 2000 and 2010. The decreasing trends of maximum temperature and increasing trend of minimum temperature in all stations could be one of the factors that contribute to the drought.

4.4.2 Standardized Precipitation Evapotranspiration Index (SPEI)

The SPEI-3 analysis of drought patterns in Dodoma region during the rain season from January to March shows that there were moderate droughts in 2000 at all stations. This was due to high temperature and low precipitation received. In 2010, the conditions were normal at all stations.

In 2020, there was moderate wetness at all stations due to high precipitation and low temperature received.

4.4.3 Vegetation Condition Index (VCI)

The results of the VCI analysis were consistent with the findings of the SPEI-3 analysis, which showed that there were moderate droughts in 2000 and 2010 at all stations. The decreasing trends of maximum temperature and increasing trend of minimum temperature in all stations could be one of the factors that contribute to the drought. In 2020, most of the areas in Dodoma region had heavy vegetation cover, except for some parts of Bahi, Chamwino, and Mpwapwa. This is likely due to the higher amount of precipitation received during this year.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.0 Introduction

In this chapter conclusion and recommendation are drawn based on the results obtained from this study as follows :-

5.1 Conclusion

The purpose of this research was to analyze spatiotemporal patterns of drought in Dodoma region, Standardized Precipitation Evapotranspiration Index (SPEI) as one of the drought index that used to analyze spatiotemporal patterns of drought in Dodoma region the outputs show drought patterns at different location and duration for the time series 1990 to 2020. It was found that during rainy season (January, February and March) SPEI-3 months analysis indicated that different locations across Dodoma region such as Mpwapwa, Kongwa, Bahi, Dodoma, Chamwino and Chemba experienced moderate drought with SPEI value of -1 in 2000, normal drought in 2010 with SPEI value of -1, -0.1, 0.1, -0.25, 0, 0.25, 0 for Kondoa, Dodoma, Mpwapwa, Kongwa, Bahi, Chamwino and Chemba due to deficiency of precipitation and high temperature received at these years, followed by moderate wet with SPEI value of +1 for Kondoa, severe wet with SPEI value of +1.75 for Mpwapwa and +1.5 for Chamwino and extreme wet for Dodoma, Kongwa, Bahi and Chemba with SPEI value of +2 during 2020 due to high amount of precipitation and low temperature received at these year.

Also, another drought indices used were Vegetation Condition Index (VCI) from which Vegetation Condition Index (VCI) maps succeed to show drought patterns in Dodoma region and how this patterns varies from one location to another for the time period selected 1990, 2000, 2010 and 2020, the results show that in the year 2000 and 2010 there was high drought condition compared to 1990 and 2020. The SPEI and VCI both show similar patterns of drought, but the VCI provides additional information on the impact of drought on vegetation. The study concludes that the combination of SPEI and VCI can provide valuable information for analyzing and managing drought in Dodoma region.

5.2 Recommendations

The Standardized Precipitation Evapotranspiration Index (SPEI) based drought patterns can be integrated with agricultural and hydrological parameters for quantifying drought risk. Further research may include the SPEI and relating spatiotemporal drought patterns with cropping patterns and crop production so as to enable quantification of the impacts of drought.

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APPENDICES

Appendix I: Monthly average precipitation (mm) for Kondoa

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	73.83	200.4	316.4	226.8	21.09	0	0	0	0	10.55	147.7	47.46
1991	116	121.3	163.5	73.83	42.19	0	5.27	0	0	0	0	84.38
1992	0	237.3	31.64	137.1	42.19	0	0	0	0	0	68.55	142.4
1993	295.3	110.7	79.1	73.83	31.64	10.55	0	0	0	0	21.09	26.37
1994	58.01	152.9	84.38	73.83	52.73	0	0	0	21.09	0	142.4	110.7
1995	105.5	68.55	174	226.8	52.73	0	0	0	0	5.27	10.55	10.55
1996	68.55	158.2	121.3	174	58.01	10.55	0	0	0	0	26.37	15.82
1997	21.09	84.38	247.9	305.9	168.8	0	5.27	0	0	26.37	116	142.4
1998	147.7	184.6	15.82	137.1	52.73	0	0	0	0	0	5.27	0
1999	36.91	0	174	290	47.46	5.27	0	0	0	0	63.28	10.55
2000	26.37	31.64	47.46	58.01	0	10.55	0	5.27	0	10.55	79.1	84.38
2001	110.7	21.09	36.91	31.64	10.55	5.27	0	5.27	0	5.27	36.91	26.37
2002	179.3	52.73	121.3	84.38	21.09	0	0	5.27	5.27	116.02	84.38	168.8
2003	47.46	36.91	52.73	36.91	116	5.27	0	0	0	15.82	0	47.46
2004	131.8	195.1	63.28	100.2	0	0	0	0	0	10.55	58.01	110.7
2005	269	21.09	158.2	237.3	31.64	0	0	5.27	0	5.27	5.27	10.55
2006	63.28	36.91	221.5	105.5	15.82	0	0	0	5.27	26.37	147.7	168.8
2007	121.3	94.92	142.4	63.28	26.37	10.55	0	0	0	0	26.37	84.38
2008	21.09	52.73	179.3	158.2	0	0	0	0	0	5.27	73.83	36.91
2009	68.55	73.83	47.46	89.65	10.55	0	0	0	0	10.55	73.83	184.6
2010	100.2	58.01	126.6	52.73	84.38	0	0	0	0	0	58.01	89.65
2011	15.82	79.1	158.2	47.46	26.37	0	0	0	0	26.37	68.55	200.4
2012	110.7	79.1	68.55	163.5	36.91	0	0	5.27	0	5.27	68.55	110.7
2013	142.4	26.37	105.5	131.8	36.91	0	0	0	36.91	0	21.09	147.7
2014	158.2	94.92	116	100.2	42.19	0	0	0	0	5.27	89.65	89.65
2015	142.4	73.83	26.37	94.92	36.91	0	0	0	0	5.27	36.91	89.65
2016	126.6	36.91	31.64	189.8	0	0	0	0	0	5.27	0	15.82
2017	42.19	79.1	21.09	47.46	42.19	0	0	0	0	5.27	63.28	10.55
2018	179.3	5.27	184.6	210.9	52.73	0	0	0	0	84.38	36.91	110.7
2019	121.3	79.1	47.46	36.91	52.73	0	0	0	0	100.2	63.28	94.92
2020	237.3	131.8	210.9	184.6	10.55	0	0	0	5.27	0	237.3	21.09

Appendix II: Monthly average precipitation (mm) for Chemba

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	47.46	205.7	264	168.8	10.6	0	0	0	0	5.27	36.91	21.1
1991	116	116	73.8	10.55	15.8	0	0	0	0	0	0	132
1992	0	210.9	47.5	52.73	0	0	0	0	0	0	31.64	84.4
1993	210.9	116	68.6	52.73	0	0	0	0	0	0	5.27	15.8
1994	100.2	237.3	63.3	10.55	5.27	0	10.55	0	5.27	0	42.19	68.6
1995	152.9	142.4	137	42.19	15.8	0	0	0	0	0	10.55	63.3
1996	84.38	216.2	105	68.55	26.4	0	0	0	0	0	0	63.3
1997	84.38	137.1	52.7	152.9	63.3	0	0	0	0	26.37	110.74	137
1998	68.55	184.6	58	68.55	21.1	0	0	0	0	0	0	5.27
1999	79.1	10.55	174	63.28	5.27	0	0	0	0	0	15.82	0
2000	47.46	15.82	63.3	36.91	0	0	0	0	0	0	100.2	206
2001	242.6	73.83	5.27	47.46	0	0	0	0	0	0	0	26.4
2002	237.3	137.1	79.1	21.09	0	0	0	0	0	21.09	31.64	248
2003	105.5	79.1	58	5.27	31.6	0	0	0	0	47.46	0	84.4
2004	126.6	158.2	79.1	73.83	0	0	0	0	0	0	52.73	248
2005	110.7	26.37	153	36.91	5.27	0	0	0	0	10.55	0	0
2006	58.01	42.19	211	100.2	5.27	0	0	0	0	5.27	89.65	190
2007	195.1	152.9	94.9	31.64	0	0	0	0	0	0	21.09	105
2008	73.83	105.5	185	105.5	0	0	0	0	0	0	52.73	79.1
2009	147.7	152.9	84.4	142.4	5.27	0	0	0	0	0	63.28	369
2010	110.7	105.5	42.2	21.09	36.9	0	0	0	0	0	15.82	153
2011	68.55	73.83	116	36.91	0	0	0	0	0	0	52.73	374
2012	247.9	152.9	105	105.5	10.6	0	0	0	0	5.27	42.19	195
2013	142.4	58.01	84.4	105.5	0	0	0	0	0	0	0	79.1
2014	237.3	126.6	127	84.38	10.6	0	0	0	0	0	68.55	169
2015	152.9	52.73	36.9	47.46	26.4	0	0	0	0	0	100.2	200
2016	195.1	110.7	89.7	195.1	0	0	0	0	0	0	0	89.7
2017	89.65	152.9	89.7	63.28	15.8	0	0	0	0	5.27	31.64	31.6
2018	327	5.27	253	110.7	10.6	0	0	0	0	21.09	15.82	195
2019	137.1	121.3	84.4	89.65	26.4	0	0	0	0	58.01	73.83	274
2020	495.7	121.3	343	121.3	5.27	0	10.55	0	0	0	195.12	100

Appendix III: Monthly average precipitation (mm) for Kongwa

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	52.73	152.93	226.76	147.66	10.55	0	0	0	0	0	42.19	21.09
1991	94.92	84.38	79.1	15.82	63.28	0	0	0	0	0	0	137.11
1992	10.55	210.94	52.73	42.19	5.27	0	0	0	0	0	47.46	126.56
1993	200.39	137.11	89.65	79.1	21.09	0	0	0	0	0	10.55	26.37
1994	73.83	221.48	84.38	21.09	10.55	0	36.91	0	5.27	0	63.28	126.56
1995	174.02	147.66	189.84	100.2	15.82	0	0	0	0	5.27	21.09	36.91
1996	68.55	189.84	158.2	84.38	47.46	0	0	0	0	0	10.55	79.1
1997	58.01	131.84	116.02	174.02	79.1	5.27	0	0	0	47.46	121.29	163.48
1998	68.55	189.84	63.28	100.2	26.37	0	0	0	0	0	0	10.55
1999	68.55	21.09	184.57	52.73	5.27	5.27	15.82	0	0	0	26.37	0
2000	47.46	5.27	58.01	58.01	0	10.55	5.27	0	0	0	100.2	232.03
2001	242.58	68.55	0	73.83	0	0	0	0	0	0	0	52.73
2002	268.95	137.11	73.83	21.09	0	0	0	0	0	26.37	26.37	232.03
2003	94.92	79.1	63.28	10.55	26.37	0	0	0	0	42.19	0	63.28
2004	147.66	142.38	100.2	100.2	0	0	0	0	0	0	68.55	274.22
2005	84.38	52.73	163.48	15.82	15.82	0	0	0	0	15.82	0	0
2006	21.09	58.01	237.3	94.92	15.82	21.09	0	0	0	5.27	58.01	237.3
2007	221.48	184.57	100.2	26.37	10.55	0	0	0	0	0	21.09	126.56
2008	105.47	152.93	205.66	110.74	0	0	0	0	0	0	47.46	63.28
2009	105.47	142.38	89.65	131.84	10.55	0	0	0	0	0	52.73	311.13
2010	116.02	73.83	15.82	36.91	47.46	0	0	0	0	0	21.09	168.75
2011	58.01	73.83	110.74	63.28	5.27	0	0	0	0	0	31.64	311.13
2012	263.67	131.84	142.38	94.92	5.27	0	0	0	0	0	15.82	158.2
2013	147.66	63.28	68.55	100.2	0	0	0	0	0	0	15.82	58.01
2014	205.66	137.11	121.29	94.92	52.73	0	0	0	0	5.27	58.01	168.75
2015	184.57	63.28	63.28	42.19	36.91	0	0	0	0	0	131.84	174.02
2016	210.94	137.11	89.65	184.57	0	15.82	0	0	0	0	0	68.55
2017	100.2	137.11	142.38	73.83	47.46	0	0	0	0	5.27	47.46	21.09
2018	442.97	5.27	210.94	84.38	10.55	0	0	0	0	10.55	15.82	221.48
2019	131.84	94.92	142.38	116.02	31.64	0	0	0	0	52.73	100.2	395.51
2020	406.05	158.2	321.68	105.47	10.55	0	21.09	0	0	0	179.3	100.2

Appendix IV: Monthly average precipitation (mm) for Dodoma

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	105.47	121.3	63.28	5.27	15.82	0	0	0	0	0	0	105.5
1992	5.27	184.6	52.73	26.37	0	0	0	0	0	0	31.64	79.1
1993	184.57	137.1	63.28	42.19	0	0	0	0	0	0	0	10.55
1994	94.92	221.5	58.01	10.55	5.27	0	10.55	0	5.27	0	26.37	47.46
1995	152.93	142.4	147.66	42.19	5.27	0	0	0	0	5.27	10.55	94.92
1996	105.47	216.2	116.02	47.46	15.82	0	0	0	0	0	5.27	79.1
1997	89.65	147.7	47.46	121.3	36.91	0	0	0	0	10.55	105.5	147.7
1998	84.38	179.3	52.73	68.55	10.55	0	0	0	0	0	0	5.27
1999	84.38	21.09	147.66	26.37	0	0	0	0	0	0	15.82	0
2000	47.46	26.37	58.01	36.91	0	0	0	0	0	0	94.92	205.7
2001	232.03	73.83	0	52.73	0	0	0	0	0	0	0	31.64
2002	253.12	131.8	79.1	21.09	0	0	0	0	0	15.82	26.37	226.8
2003	121.29	58.01	52.73	10.55	21.09	0	0	0	0	36.91	0	94.92
2004	126.56	126.6	68.55	63.28	0	0	0	0	0	0	42.19	242.6
2005	89.65	31.64	137.11	15.82	0	0	0	0	0	10.55	0	0
2006	42.19	36.91	189.84	79.1	0	0	0	0	0	5.27	58.01	184.6
2007	174.02	158.2	79.1	21.09	0	0	0	0	0	0	15.82	94.92
2008	73.83	131.8	189.84	63.28	0	0	0	0	0	0	47.46	73.83
2009	147.66	152.9	73.83	137.1	5.27	0	0	0	0	0	47.46	342.8
2010	116.02	94.92	31.64	21.09	21.09	0	0	0	0	0	15.82	142.4
2011	68.55	73.83	94.92	52.73	0	0	0	0	0	0	36.91	353.3
2012	237.3	142.4	121.29	79.1	0	0	0	0	0	0	26.37	121.3
2013	116.02	63.28	63.28	89.65	0	0	0	0	0	0	5.27	58.01
2014	274.22	126.6	137.11	47.46	5.27	0	0	0	0	0	47.46	174
2015	189.84	68.55	36.91	31.64	26.37	0	0	0	0	0	105.5	179.3
2016	210.94	126.6	79.1	168.8	0	5.27	0	0	0	0	0	63.28
2017	100.2	131.8	131.84	63.28	21.09	0	0	0	0	5.27	52.73	21.09
2018	384.96	5.27	200.39	73.83	5.27	0	0	0	0	5.27	5.27	226.8
2019	116.02	94.92	105.47	89.65	26.37	0	0	0	0	42.19	105.5	400.8
2020	442.97	147.7	305.86	110.7	10.55	0	10.55	0	0	0	179.3	89.65

Appendix V: Monthly average precipitation (mm) for Chamwino

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	73.83	205.7	189.8	79.1	5.27	0	0	0	0	0	36.91	10.55
1991	105.47	147.7	94.92	21.09	15.82	0	0	0	0	0	0	94.92
1992	10.55	179.3	47.46	31.64	0	0	0	0	0	0	42.19	79.1
1993	174.02	158.2	84.38	36.91	0	0	0	0	0	0	5.27	10.55
1994	84.38	195.1	52.73	10.55	5.27	0	5.27	0	5.27	0	26.37	79.1
1995	189.84	142.4	179.3	47.46	5.27	0	0	0	0	5.27	5.27	116.02
1996	137.11	221.5	152.9	52.73	5.27	0	0	0	0	0	10.55	89.65
1997	89.65	137.1	73.83	131.8	21.09	0	0	0	0	15.82	105.47	152.93
1998	100.2	200.4	47.46	58.01	5.27	0	0	0	0	0	0	5.27
1999	100.2	21.09	142.4	15.82	0	0	0	0	0	0	15.82	0
2000	52.73	36.91	58.01	31.64	0	0	0	0	0	0	84.38	210.94
2001	195.12	58.01	5.27	58.01	0	0	0	0	0	0	0	42.19
2002	258.4	105.5	63.28	21.09	0	0	0	0	0	10.55	21.09	195.12
2003	126.56	58.01	52.73	5.27	21.09	0	0	0	0	31.64	0	94.92
2004	121.29	94.92	68.55	68.55	0	0	0	0	0	0	52.73	237.3
2005	79.1	36.91	126.6	21.09	0	0	0	0	0	5.27	0	0
2006	26.37	31.64	189.8	73.83	5.27	5.27	0	0	0	5.27	36.91	189.84
2007	189.84	158.2	79.1	15.82	0	0	0	0	0	0	26.37	94.92
2008	89.65	142.4	189.8	63.28	0	0	0	0	0	0	42.19	68.55
2009	105.47	137.1	89.65	142.4	5.27	0	0	0	0	0	31.64	290.04
2010	94.92	105.5	31.64	15.82	15.82	0	0	0	0	0	15.82	116.02
2011	47.46	89.65	89.65	63.28	0	0	0	0	0	0	31.64	348.05
2012	226.76	110.7	137.1	68.55	0	0	0	0	0	0	21.09	100.2
2013	116.02	47.46	52.73	79.1	0	0	0	0	0	0	5.27	68.55
2014	290.04	137.1	152.9	63.28	10.55	0	0	0	0	5.27	36.91	158.2
2015	179.3	73.83	52.73	31.64	21.09	0	0	0	0	0	100.2	158.2
2016	242.58	152.9	137.1	142.4	0	10.55	0	0	0	0	0	31.64
2017	68.55	116	184.6	58.01	15.82	0	0	0	0	5.27	47.46	31.64
2018	453.52	10.55	163.5	52.73	10.55	0	0	0	0	5.27	10.55	221.48
2019	116.02	126.6	100.2	68.55	31.64	0	0	0	0	31.64	126.56	485.16
2020	321.68	221.5	374.4	94.92	5.27	0	5.27	0	0	5.27	131.84	142.38

Appendix VI: Monthly average precipitation (mm) for Mpwapwa

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	73.83	147.66	232	158.2	10.55	0	0	0	5.27	0	58.01	21.09
1991	94.92	110.74	110.7	31.64	84.38	0	0	0	0	0	5.27	147.7
1992	15.82	195.12	63.28	47.46	10.55	0	0	0	0	0	73.83	189.8
1993	200.4	168.75	121.3	105.5	21.09	0	0	0	0	0	31.64	42.19
1994	73.83	216.21	89.65	26.37	15.82	0	31.64	0	5.27	0	84.38	142.4
1995	216.2	142.38	247.9	126.6	21.09	0	0	0	0	5.27	36.91	52.73
1996	73.83	200.39	189.8	79.1	63.28	0	0	0	0	0	15.82	100.2
1997	52.73	137.11	179.3	205.7	73.83	5.27	0	0	0	68.6	152.9	174
1998	73.83	184.57	68.55	110.7	26.37	0	0	0	0	5.27	0	10.55
1999	84.38	31.64	205.7	73.83	5.27	0	15.82	0	0	0	42.19	0
2000	52.73	26.37	84.38	63.28	0	10.55	5.27	0	0	5.27	105.5	253.1
2001	232	58.01	5.27	89.65	0	0	0	0	0	0	10.55	58.01
2002	290	121.29	84.38	21.09	0	0	0	0	0	26.4	31.64	221.5
2003	105.5	79.1	63.28	15.82	26.37	0	0	0	0	47.5	0	68.55
2004	158.2	131.84	116	110.7	0	0	0	0	0	5.27	89.65	284.8
2005	100.2	47.46	158.2	36.91	15.82	0	0	0	0	15.8	0	5.27
2006	21.09	63.28	269	105.5	15.82	26.37	0	0	0	15.8	47.46	226.8
2007	221.5	189.84	105.5	42.19	10.55	0	0	0	0	0	36.91	131.8
2008	116	174.02	210.9	126.6	0	0	0	0	0	5.27	52.73	79.1
2009	79.1	174.02	105.5	137.1	10.55	0	0	0	0	5.27	47.46	284.8
2010	121.3	84.38	15.82	36.91	63.28	0	0	5.27	0	0	36.91	163.5
2011	58.01	110.74	126.6	84.38	5.27	0	0	0	5.27	0	36.91	290
2012	279.5	142.38	147.7	89.65	5.27	0	0	0	0	0	47.46	152.9
2013	142.4	63.28	68.55	94.92	0	0	0	0	0	5.27	15.82	73.83
2014	242.6	142.38	168.8	110.7	47.46	0	0	0	0	15.8	47.46	158.2
2015	179.3	52.73	100.2	58.01	52.73	0	0	0	0	0	195.1	158.2
2016	274.2	168.75	147.7	232	0	36.91	0	0	0	0	0	42.19
2017	73.83	152.93	195.1	126.6	94.92	0	0	0	0	5.27	63.28	36.91
2018	506.3	15.82	195.1	84.38	31.64	0	0	0	0	15.8	21.09	247.9
2019	142.4	142.38	142.4	110.7	42.19	0	0	0	0	58	121.3	406.1
2020	337.5	226.76	321.7	142.4	10.55	5.27	42.19	0	0	15.8	158.2	163.5

Appendix VII: Monthly average precipitation (mm) for Bahi

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	47.46	210.9	216.2	126.56	5.27	0	0	0	0	0	31.64	15.82
1991	105.47	121.3	63.28	5.27	15.82	0	0	0	0	0	0	105.5
1992	5.27	184.6	52.73	26.37	0	0	0	0	0	0	31.64	79.1
1993	184.57	137.1	63.28	42.19	0	0	0	0	0	0	0	10.55
1994	94.92	221.5	58.01	10.55	5.27	0	10.55	0	5.27	0	26.37	47.46
1995	152.93	142.4	147.7	42.19	5.27	0	0	0	0	5.27	10.55	94.92
1996	105.47	216.2	116	47.46	15.82	0	0	0	0	0	5.27	79.1
1997	89.65	147.7	47.46	121.29	36.91	0	0	0	0	10.55	105.47	147.7
1998	84.38	179.3	52.73	68.55	10.55	0	0	0	0	0	0	5.27
1999	84.38	21.09	147.7	26.37	0	0	0	0	0	0	15.82	0
2000	47.46	26.37	58.01	36.91	0	0	0	0	0	0	94.92	205.7
2001	232.03	73.83	0	52.73	0	0	0	0	0	0	0	31.64
2002	253.12	131.8	79.1	21.09	0	0	0	0	0	15.82	26.37	226.8
2003	121.29	58.01	52.73	10.55	21.09	0	0	0	0	36.91	0	94.92
2004	126.56	126.6	68.55	63.28	0	0	0	0	0	0	42.19	242.6
2005	89.65	31.64	137.1	15.82	0	0	0	0	0	10.55	0	0
2006	42.19	36.91	189.8	79.1	0	0	0	0	0	5.27	58.01	184.6
2007	174.02	158.2	79.1	21.09	0	0	0	0	0	0	15.82	94.92
2008	73.83	131.8	189.8	63.28	0	0	0	0	0	0	47.46	73.83
2009	147.66	152.9	73.83	137.11	5.27	0	0	0	0	0	47.46	342.8
2010	116.02	94.92	31.64	21.09	21.09	0	0	0	0	0	15.82	142.4
2011	68.55	73.83	94.92	52.73	0	0	0	0	0	0	36.91	353.3
2012	237.3	142.4	121.3	79.1	0	0	0	0	0	0	26.37	121.3
2013	116.02	63.28	63.28	89.65	0	0	0	0	0	0	5.27	58.01
2014	274.22	126.6	137.1	47.46	5.27	0	0	0	0	0	47.46	174
2015	189.84	68.55	36.91	31.64	26.37	0	0	0	0	0	105.47	179.3
2016	210.94	126.6	79.1	168.75	0	5.27	0	0	0	0	0	63.28
2017	100.2	131.8	131.8	63.28	21.09	0	0	0	0	5.27	52.73	21.09
2018	384.96	5.27	200.4	73.83	5.27	0	0	0	0	5.27	5.27	226.8
2019	116.02	94.92	105.5	89.65	26.37	0	0	0	0	42.19	105.47	400.8
2020	442.97	147.7	305.9	110.74	10.55	0	10.55	0	0	0	179.3	89.65

Appendix VIII: Monthly average maximum temperature (°c) for Kondoa

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	29.4	31.51	25.28	24.3	24.4	24.94	24.48	26.41	29.32	30.19	30.02	28.75
1991	30.65	30.94	31.33	27.64	26.69	27.77	25.63	28.43	29.48	30.79	30.94	31.36
1992	32.56	32.55	32.48	28.26	26.23	26.21	26.62	27.37	30.13	31.13	29.74	28.93
1993	27.65	26.37	27.48	27.28	25.86	25.3	24.98	27.26	29.62	30.45	31.9	31.37
1994	33	33.24	29.35	29.23	27.39	27.75	27.09	28.94	29.83	30.55	30.08	29.55
1995	30.85	31.72	27.62	28.24	24.9	25.4	25.32	27.45	29.23	30.51	31.48	30.72
1996	31.16	31.23	30.64	26.12	26.31	26.5	25.97	28.29	31.08	30.45	31.32	31.43
1997	32.86	32.92	31.6	26.73	23.56	23.48	24.58	26.83	29.96	29.37	29.44	27.5
1998	27.99	29.92	30.29	29.12	27.5	28.76	26.62	28.58	30.45	31.32	31.58	32.82
1999	32.87	34.02	31.98	27.46	24.54	26.37	25.73	27.26	29.34	31.31	30.94	30.38
2000	32.65	33.44	29.99	29.23	29.23	27.24	27.66	28.21	29.85	31.84	31.08	29.14
2001	28.2	31.37	31.44	30.53	29.62	27.62	27.98	29.53	30.82	32.33	30.43	31.94
2002	29.67	31.19	28.91	28.24	28.25	28.51	27.8	28.03	31.04	30.88	29.42	29.93
2003	30.53	31.19	31.99	31	26.49	27.76	27.19	29.55	30.26	31.2	31.17	32
2004	31.08	30.08	29.33	27.43	28.12	26.75	27.67	28.42	31.49	31.84	31.43	30.91
2005	31.22	32.18	30.16	26.12	26.42	25.81	26.55	27.96	29.84	30.62	32	32.75
2006	32.5	32.93	28.24	25.55	28.2	26.9	26.65	29.3	30.52	31.79	29.9	27.65
2007	27.75	29.63	28.21	27.62	27.65	26.23	28.48	28.3	31.44	30.86	31.97	30.94
2008	31.69	31	29.92	25.77	27.05	26.12	26.99	27.92	30.55	32.42	31.82	31.1
2009	32.53	30.23	31.44	27.74	28.2	28.66	27.62	29.06	30.98	31.19	31.02	29.6
2010	29.9	31.35	30.24	28.37	27.33	26.84	26.67	27.92	30.34	31.4	31.41	30.47
2011	31.52	32.7	30.89	28.23	27.71	28.38	27.89	29.09	30.1	31.14	32.4	29.28
2012	29.11	30.53	30.61	28.54	26.9	27.65	27.62	28.99	31.19	31.75	31.27	30.96
2013	30.64	31.23	31.07	27.51	28.05	27.11	27.25	29.25	30.83	32.05	31.88	29.7
2014	31.06	28.91	29.51	27.33	26.49	27.17	28.23	29.69	30.18	31.81	31.51	29.06
2015	30.96	31.33	31.95	29.27	27.31	27.58	28.47	29.15	31.83	31.6	31.64	33.1
2016	32	32.48	32.62	26.4	27.73	26.8	27.65	29.35	29.51	31.87	31.58	31.91
2017	32.8	32.3	29.66	30.79	28.37	28.36	28.11	29.54	32.02	33.19	30.15	31.05
2018	28.58	31.48	26.26	27.3	25.64	25.62	26.23	26.94	29.41	31.11	30.35	30.77
2019	29.44	29.54	31.84	30.71	27.4	28.44	28.19	29.23	31.1	29.68	30.22	29.57
2020	28.66	28.76	25.94	25.02	25.17	24.49	25.24	28.23	30.07	30.98	31.01	28.82

Appendix IX: Monthly average maximum temperature (°c) for Chemba

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	34.89	36.06	28.7	28.58	28.8	29.19	28.38	30.9	33.03	35.33	34.8	34.6
1991	34.73	35.45	36.4	33.08	32.3	31.08	30.26	31.76	33.44	35.31	35.76	34.9
1992	36.15	35.8	36	32.61	32.8	30.82	29.76	31.94	32.87	35.06	34.69	34.1
1993	32.43	31.95	32.8	32.62	32.3	29.95	29.26	31.53	33.74	34.8	36	35.4
1994	36.14	36.05	33.1	33.87	31.5	31.28	29.71	31.58	33.77	35.23	35.58	34.2
1995	34.35	34.94	31.4	32.39	31	29.96	29.01	31.35	33.82	35.34	35.99	35.2
1996	33.68	32.48	33.6	30.91	31.3	29.33	29.55	32.03	34.57	34.4	35.94	35.6
1997	34.94	34.12	34.2	33.3	29.8	29.37	29.18	31.89	35.19	34.55	34.94	31
1998	33.83	34.51	34.1	33.69	31.3	31.9	29.84	32.07	33.98	34.74	35.19	36.6
1999	35.66	37.27	34.8	32.48	31.4	30.64	29.26	31.96	34.06	35.59	35.8	35.7
2000	35.76	36.89	33.6	33.19	32.4	30.2	30.64	32.18	33.32	35.98	34.94	33.2
2001	27.98	30.87	32.1	31.33	32.5	30.4	30.23	32.61	34.26	35.7	35.12	35.6
2002	31.4	33.98	32.3	31.53	32.3	31.51	31.06	31.65	35.21	35.12	34.59	35.4
2003	32.83	34.07	35.5	34.25	31.8	31.62	30.26	32.46	33.94	35.37	35.78	36.1
2004	34.64	32.61	32.9	30.35	31.8	30.13	30.69	31.88	34.58	36.18	35.42	32.8
2005	33.49	36.92	34.7	32.53	32.1	31.26	30.07	31.53	34.78	34.59	36.4	36.1
2006	36.34	36.38	31	29.12	33.2	29.81	29.19	32.52	34.62	36.02	34.85	31.2
2007	29.86	30.01	30.2	32.14	32.3	30.26	31.77	31.32	35.13	35.28	36.42	35.3
2008	34.75	33.7	32.4	28.72	31.5	30.26	30.64	32.39	34.62	36.1	36.07	34.6
2009	35.7	30.72	33	29.46	31.2	31	30.49	31.62	34.57	34.9	35.63	35.1
2010	30.77	31.96	32.2	33.33	31	30.58	30.15	31.05	33.83	35.69	35.48	35.6
2011	34.77	34.41	34.1	32.27	31.9	31.52	31.76	31.65	33.82	36.53	36.08	34.6
2012	29.11	30.37	29.6	27.71	29	29.45	29.65	31.82	34.4	35.8	35.5	35.6
2013	34.06	32.94	34.1	31.7	31.5	30.39	30.18	32.69	34.93	36.28	36.41	34.5
2014	34.01	31.37	32.7	31.65	31.2	31.65	31.32	33.9	33.9	34.93	35.58	32.7
2015	32.38	34.76	35.3	32.9	31.2	31.3	31.45	32.55	36.25	35.69	34.81	35.3
2016	34.1	32.57	33.7	28.93	29.3	28.87	29.88	31.82	32.7	35.98	35.53	35.7
2017	35.39	35.32	29.5	33.18	30.8	30.67	30.52	32.63	34.1	36.6	35.12	35.4
2018	29.01	34.62	28.4	28.81	29.3	28.86	29.26	31.19	33.86	35.2	35.73	36
2019	33.11	33.87	34.9	33.66	30.4	30.44	31.36	32.69	35.18	34.93	34.65	32.7
2020	29.77	29.13	27.9	27.35	27	26.19	26.25	29.98	33.23	33.92	34.55	31.7

Appendix X: Monthly average maximum temperature (°c) for Kongwa

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	32.06	34.67	27.33	27.35	27.58	27.94	26.98	29.56	31.79	34.15	33.62	34.05
1991	33.27	35.23	35.51	31.96	30.26	29.03	28.05	30.13	31.76	33.45	34.15	32.76
1992	34.6	34.36	34.55	31.22	31.5	29.41	28.31	30.12	31.17	33.8	33.82	32.66
1993	30.79	29.49	30.3	29.83	30	27.98	26.92	29.59	31.18	33.18	35.26	34.07
1994	35.17	35.57	31.23	31.39	30.23	29.53	28.15	30.14	32.79	33.65	34.21	33.36
1995	32.35	33.59	28.35	28.01	28.03	27.57	27.12	28.49	31.51	33.18	34.37	33.92
1996	32.6	31.94	31.83	28.11	28.6	27.48	27.95	30.72	33.55	32.76	34.26	34.58
1997	34.62	34.36	32.87	30.83	27.37	27.05	27	29.45	33.42	31.9	32.66	29.27
1998	31.07	33.37	31.93	31.46	29.88	30.67	27.87	31.01	31.62	32.7	33.91	35.98
1999	34.78	36.44	33.44	29.8	29.17	28.97	27.91	30.48	31.85	34.45	34.17	34.62
2000	35.18	36.53	32.45	31.94	30.42	28.11	28.8	29.84	31.37	33.98	34.01	32.33
2001	27.85	27.51	28.62	28.75	29.98	28.88	29.44	30.92	32.48	34.25	34.45	35.1
2002	30.3	30.69	29.44	29.1	30.61	29.96	30.37	29.41	33.85	33.1	34.11	34.97
2003	30.87	32.3	34.26	33.28	31.12	30.45	28.7	31.4	32.48	34.19	34.9	34.73
2004	33.96	30.79	31.73	28.08	30.01	28.47	29.08	30.12	33.52	34.3	34.15	31.51
2005	30.73	35.28	33.02	30.21	30.78	29.38	29.26	30.71	32.59	32.83	35.41	35.35
2006	35.8	35.85	29.71	27.21	30.63	28.33	27.55	30.38	32.56	33.94	33.79	31.34
2007	28.55	28.33	28.43	29.06	29.4	28.8	30.93	29.94	33.44	33.55	35.31	34.44
2008	33.15	29.8	29.4	26.04	28.18	28.09	29.07	30.98	32.75	34.45	35.46	33.8
2009	35.51	29.23	31.85	28.11	29.19	29.72	29.08	30.36	32.97	33.12	34.19	34.16
2010	29.38	30.28	32.09	32.47	29.65	28.77	28.76	29.65	32.36	34.48	34.48	35.36
2011	33.53	33.35	33.01	29.69	29.83	30.04	30.49	30.69	32.07	36	35.24	34.24
2012	28.73	28.58	27.94	27.4	27.34	28.53	28.4	30.58	33.55	35.37	34.36	33.82
2013	33.01	31.87	33.01	30.01	29.94	29.13	29.23	31.65	33.74	35.15	35.68	34.24
2014	33.76	30.06	29.63	28.76	28.6	29.3	29.62	32.44	32.84	33.77	33.94	32.47
2015	29.68	31.62	33.4	30.98	28.7	30.09	29.95	30.65	34.72	34.05	33.57	34.41
2016	31.19	29.8	30.51	27.73	27.26	26.68	28.55	30.16	30.79	34.37	34.37	34.94
2017	35.03	34.43	28.47	28.68	28.31	27.34	28.18	30.4	32	35.18	33.65	34.26
2018	28.19	30.67	27.57	27.05	27.36	27.06	28.15	29.3	31.9	33.56	34.18	34.98
2019	31.12	32.44	32.03	29.74	27.73	28.21	29.99	30.87	33.12	33.25	32.72	30.89
2020	28.81	28.52	27.39	26.9	26.23	25.04	25.23	28.36	31.68	32.99	33.22	30.9

Appendix XI: Monthly average maximum temperature (°c) for Dodoma

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	34.14	36.25	28.76	29.46	29.76	28.87	28.01	30.63	32.68	34.97	34.75	35.23
1991	34.67	35.31	36.12	33.03	31.85	30.54	29.65	31.29	33.3	34.78	35.51	34.4
1992	36.5	35.64	36.16	32.65	33.12	30.23	29.19	31.39	32.65	34.78	34.96	34.61
1993	33.58	32.89	32.79	32.64	31.73	29.58	28.71	31.03	32.96	34.44	36.09	35.77
1994	36.67	34.79	33.65	33.32	30.95	30.47	29.4	31	33.68	34.89	35.85	34.33
1995	34.12	34.55	30.87	31.02	30.48	29.23	28.4	30.65	33.05	34.83	35.46	35.25
1996	32.38	31.89	33.15	30.66	30.44	28.87	28.81	31.14	34.08	33.82	35.49	35.83
1997	35.05	33.47	34.17	32.75	29.81	28.96	28.76	31	34.48	33.88	34.49	30.98
1998	33.9	33.86	34.04	33.46	31.61	31.84	29.23	31.63	33.03	34.07	35.38	36.98
1999	35.32	36.94	34.76	32.16	31.34	30.37	28.93	31.63	33.45	35.11	35.39	36.01
2000	35.85	36.01	33.06	32.97	31.73	29.67	30.07	31.4	32.74	34.84	35.37	33.32
2001	28.62	29.69	31.3	30.5	31.61	30.04	29.83	31.7	33.51	35.15	35.08	36.07
2002	30.9	33.4	32	30.84	31.76	31.07	30.69	31.01	35.05	34.48	34.73	35.87
2003	32.19	33.83	35.62	34.33	31.76	31.06	29.66	31.93	33.44	35.19	35.69	35.81
2004	34.76	32.83	33.53	30.24	31.76	29.67	30.12	31.26	34.04	35.51	35.3	32.86
2005	33.37	36.69	34.68	32.52	31.83	30.79	29.99	31.42	34.24	34.19	36.46	36.43
2006	36.76	36.88	31.27	29.44	32.59	29.48	29.12	32.08	34.03	35.24	35.08	32.15
2007	29.75	30.01	30.15	32.03	31.94	30.15	31.62	30.96	34.63	34.73	35.97	35.38
2008	34.27	32.81	31.67	28.27	30.79	29.48	29.97	31.7	34.07	35.61	36.02	34.51
2009	35.87	30.3	32.77	29.44	30.44	30.47	29.98	31.3	33.81	34.69	35.44	35.37
2010	30.65	31.21	32.78	33.44	31.04	29.82	29.69	30.64	33.29	35.23	35.26	36.09
2011	34.81	34.24	34.19	31.87	31.49	31.27	31.37	31.37	33.32	36.53	35.88	34.51
2012	28.85	29.99	29.36	28.15	28.73	29.48	29.01	31.44	33.99	35.66	35.23	35.02
2013	34.83	33.67	34.77	32.37	31.47	30.4	29.87	32.21	34.94	35.73	36.48	34.63
2014	33.83	30.49	31.36	30.78	30.3	30.73	30.49	33.27	33.47	34.63	35.24	33.61
2015	31.16	33.68	34.19	32.19	30.94	31.19	31.06	31.85	35.83	35.12	34.95	35.65
2016	33.58	31.49	32.51	28.96	28.91	28.6	29.44	31.04	32.3	35.11	35.76	36.01
2017	35.42	35.29	28.95	31.3	30.06	29.8	29.76	32.02	33.48	36.15	34.89	35.4
2018	28.45	33.12	28.46	28.8	29.22	29.46	28.98	30.66	33.44	34.79	35.73	36.27
2019	32.86	33.78	34.24	32.65	29.96	30.03	30.75	32.08	34.57	34.86	34.05	32.19
2020	29.16	28.87	27.58	27.35	26.96	25.99	26.08	29.2	32.83	33.5	34.01	31.23

Appendix XII: Monthly average maximum temperature (°c) for Chamwino

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	33.28	36.09	28.28	29.46	29.55	29.34	28.5	30.69	33.19	35.22	35.06	35.98
1991	34.84	36.03	35.6	32.42	32.05	30.62	29.76	31.6	33.24	35.15	35.7	34.65
1992	36.84	35.58	35.6	32.73	32.65	30.42	29.49	31.69	33.23	35.13	35.23	34.37
1993	33.36	31.42	30.52	30.94	31.23	29.69	28.93	31.26	33.24	34.62	36.08	36.02
1994	37	34.36	33.4	33.19	31.39	30.59	29.92	31.39	34.38	34.89	35.69	35.14
1995	34.18	34.31	29.26	29.79	30	28.82	28.55	30.82	33.26	35.09	35.57	35.65
1996	32.42	30.63	31.28	28.8	29.8	29.03	28.59	31.13	34.19	34.01	35.49	35.96
1997	35.42	33.14	33.39	31.66	29.65	28.83	29.11	30.98	34.87	33.98	34.27	30.75
1998	32.41	32.25	32.3	32.08	32.01	32.39	29.48	31.91	33.33	34.34	35.26	37.75
1999	35.57	36.83	34.54	31.97	31.22	30.69	29.58	31.9	33.76	35.64	35.64	36.1
2000	36.76	36.2	32.83	33.19	31.7	29.95	30.37	31.47	33.1	34.67	35.67	34.05
2001	28.94	29.14	30.72	30.82	31.9	30.43	30.08	31.97	33.73	35.61	35.23	36.65
2002	30.62	31.83	30.8	31.08	31.88	31.49	30.98	31.24	34.93	34.77	34.91	36.08
2003	32.31	33.73	35.71	33.97	32.18	31.31	30.21	32.51	33.88	35.36	35.8	35.76
2004	35.26	32.9	33.51	30.45	32.08	30.01	30.39	31.54	34.32	35.77	35.45	33.53
2005	32.55	35.72	34.24	32.56	32.26	31.1	30.38	32.23	34.65	34.78	36.49	36.58
2006	37.61	37.38	32.76	29.39	32.14	29.74	29.31	32.18	34.34	35.48	35.23	32.87
2007	30.33	30.37	30.52	31.7	31.31	30.39	32.19	31.4	35.26	34.96	35.95	35.32
2008	33.87	31.15	30.2	28.18	30.01	29.56	30.25	31.95	34.42	36.08	36.48	35.04
2009	36.01	29.9	32.32	29.87	30.79	30.8	30.24	31.83	34.12	34.7	35.58	35.8
2010	31.08	31.29	33.51	33.84	31.62	30.41	30.07	30.86	33.57	35.62	35.33	36.49
2011	35.33	34.76	33.65	31.51	31.51	31.62	31.2	31.76	33.81	36.84	36.51	35.05
2012	29.39	29.51	29.11	28.16	28.8	29.34	29.19	31.77	34.71	35.96	35.17	34.88
2013	34.69	33.8	34.87	32.73	31.75	30.94	30.2	32.43	35.39	36.03	36.66	34.91
2014	33.99	29.77	30.13	29.75	29.74	30.4	30.37	33.38	33.9	34.7	35.76	34.84
2015	30.69	32.33	32.62	32.1	31.08	31.65	31.18	32.09	36.08	35.28	35.03	35.44
2016	32.57	30.73	30.87	28.55	28.44	28.24	29.75	31.15	32.39	35.03	35.88	36.18
2017	35.9	36.01	29.4	30.3	30.06	29.78	30.1	32.05	33.83	36.13	35.4	36
2018	28.73	31.15	28.69	29.01	29.36	29.91	29.51	30.85	33.69	35.26	36.65	36.62
2019	32.62	33.15	32.9	31.93	30.38	30.23	31.17	32.4	35.23	35.4	35.13	32.92
2020	29.46	29.44	28.18	27.57	27.37	26.85	27.22	30.09	33.19	34.35	34.55	32.05

Appendix XIII: Monthly average maximum temperature (°c) for Mpwapwa

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	31.2	34.64	27.13	27.19	27.36	28.28	27.72	29.8	32.3	34	33.9	34.24
1991	34.01	34.8	34.46	31.12	30.23	28.77	27.93	30.44	31.69	33.7	33.99	33.12
1992	34.65	33.94	33.87	31.23	31.17	29.52	28.29	30.14	31.7	33.9	34.01	32.43
1993	30.13	28.48	28.49	28.61	28.95	27.7	27.03	29.72	31.43	32.9	35.19	34.12
1994	35.11	34.16	30.72	30.98	30.4	29.48	28.63	30.36	33.13	33.8	34.04	33.45
1995	31.65	32.08	27.88	27.22	27.44	27	27.06	28.58	31.4	33.1	34.27	33.89
1996	32.6	31.14	30.2	26.98	27.88	27.26	27.69	30.45	33.75	32.9	34.01	34.9
1997	34.69	33.42	31.83	29.73	27.34	27.01	27.23	29.4	33.23	31.8	32.39	29.35
1998	30.3	32.26	31.58	31.33	30.31	31.31	28.31	31.24	31.8	33.1	33.94	36.64
1999	34.74	35.58	33.3	29.29	28.65	29.2	28.09	30.68	31.95	34.4	34.05	34.62
2000	35.33	36.2	31.7	31.58	29.97	28.26	28.99	29.64	31.73	33	34.21	32.88
2001	28.12	27.17	28.53	28.98	30.12	29.04	29.98	31.19	32.48	34.8	34.55	35.68
2002	29.49	29.33	29.36	29.41	30.95	30.19	30.86	29.6	33.46	33.1	33.9	34.94
2003	30.51	32.15	34.31	33.09	31.52	30.37	29.12	31.83	32.76	34	35.01	35.07
2004	34.33	30.8	31.86	28.05	30.08	28.59	29.3	30.16	33.91	34.1	34.19	31.83
2005	30.21	33.94	32.34	30.48	31.31	29.94	29.58	31.23	32.69	33.4	35.44	35.28
2006	35.65	36.3	30.56	26.87	30.19	28.63	27.92	30.52	32.83	34.5	33.51	32.45
2007	28.54	28.54	28.66	29.75	29.84	29.53	31.62	30.57	33.8	33.5	35.39	33.88
2008	32.67	29.25	28.25	25.98	27.79	28.28	29.3	31.12	32.98	34.7	35.39	33.96
2009	34.87	28.78	30.91	27.78	29.19	30.01	29.12	31.03	33.06	33.4	34.48	34.8
2010	29.35	29.94	33.09	33.03	30.1	29.14	28.73	29.98	32.51	34.5	34.23	35.47
2011	33.51	32.9	32.15	29.15	29.58	30.23	30.21	31.14	32.65	36.1	35.5	34.41
2012	28.51	27.96	27.53	27.15	27.58	29.06	28.72	31.15	33.75	35.2	34.26	34.05
2013	32.51	31.72	32.77	30.33	30.21	29.29	29.58	31.6	34.19	35.2	35.83	34.48
2014	34.29	29.35	28.8	28.08	28.18	29.02	29.43	32.55	33.28	34.2	34.43	33.28
2015	29.01	31.62	32.72	30.38	28.56	30.53	30.17	30.96	34.51	33.9	33.79	33.43
2016	30.38	29.2	29.23	27.69	26.88	26.04	28.58	29.94	31.09	34.1	34.9	34.97
2017	34.78	34.32	28.69	27.69	27.51	26.51	27.98	30.03	32.23	35.5	33.7	34.44
2018	27.9	29.44	27.66	27.01	27.22	27.19	28.32	29.92	32.03	34	34.49	34.77
2019	30.28	30.89	30.28	29.22	27.94	28.52	30.41	31.51	33.37	33.1	33.52	31.18
2020	28.55	28.83	27.56	27.02	26.35	25.44	26.1	29.26	32.05	33.7	33.15	31.76

Appendix XIV: Monthly average maximum temperature (°c) for Bahi

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	34.14	36.25	28.76	29.46	29.76	28.87	28.01	30.63	32.68	34.97	34.75	35.23
1991	34.67	35.31	36.12	33.03	31.85	30.54	29.65	31.29	33.3	34.78	35.51	34.4
1992	36.5	35.64	36.16	32.65	33.12	30.23	29.19	31.39	32.65	34.78	34.96	34.61
1993	33.58	32.89	32.79	32.64	31.73	29.58	28.71	31.03	32.96	34.44	36.09	35.77
1994	36.67	34.79	33.65	33.32	30.95	30.47	29.4	31	33.68	34.89	35.85	34.33
1995	34.12	34.55	30.87	31.02	30.48	29.23	28.4	30.65	33.05	34.83	35.46	35.25
1996	32.38	31.89	33.15	30.66	30.44	28.87	28.81	31.14	34.08	33.82	35.49	35.83
1997	35.05	33.47	34.17	32.75	29.81	28.96	28.76	31	34.48	33.88	34.49	30.98
1998	33.9	33.86	34.04	33.46	31.61	31.84	29.23	31.63	33.03	34.07	35.38	36.98
1999	35.32	36.94	34.76	32.16	31.34	30.37	28.93	31.63	33.45	35.11	35.39	36.01
2000	35.85	36.01	33.06	32.97	31.73	29.67	30.07	31.4	32.74	34.84	35.37	33.32
2001	28.62	29.69	31.3	30.5	31.61	30.04	29.83	31.7	33.51	35.15	35.08	36.07
2002	30.9	33.4	32	30.84	31.76	31.07	30.69	31.01	35.05	34.48	34.73	35.87
2003	32.19	33.83	35.62	34.33	31.76	31.06	29.66	31.93	33.44	35.19	35.69	35.81
2004	34.76	32.83	33.53	30.24	31.76	29.67	30.12	31.26	34.04	35.51	35.3	32.86
2005	33.37	36.69	34.68	32.52	31.83	30.79	29.99	31.42	34.24	34.19	36.46	36.43
2006	36.76	36.88	31.27	29.44	32.59	29.48	29.12	32.08	34.03	35.24	35.08	32.15
2007	29.75	30.01	30.15	32.03	31.94	30.15	31.62	30.96	34.63	34.73	35.97	35.38
2008	34.27	32.81	31.67	28.27	30.79	29.48	29.97	31.7	34.07	35.61	36.02	34.51
2009	35.87	30.3	32.77	29.44	30.44	30.47	29.98	31.3	33.81	34.69	35.44	35.37
2010	30.65	31.21	32.78	33.44	31.04	29.82	29.69	30.64	33.29	35.23	35.26	36.09
2011	34.81	34.24	34.19	31.87	31.49	31.27	31.37	31.37	33.32	36.53	35.88	34.51
2012	28.85	29.99	29.36	28.15	28.73	29.48	29.01	31.44	33.99	35.66	35.23	35.02
2013	34.83	33.67	34.77	32.37	31.47	30.4	29.87	32.21	34.94	35.73	36.48	34.63
2014	33.83	30.49	31.36	30.78	30.3	30.73	30.49	33.27	33.47	34.63	35.24	33.61
2015	31.16	33.68	34.19	32.19	30.94	31.19	31.06	31.85	35.83	35.12	34.95	35.65
2016	33.58	31.49	32.51	28.96	28.91	28.6	29.44	31.04	32.3	35.11	35.76	36.01
2017	35.42	35.29	28.95	31.3	30.06	29.8	29.76	32.02	33.48	36.15	34.89	35.4
2018	28.45	33.12	28.46	28.8	29.22	29.46	28.98	30.66	33.44	34.79	35.73	36.27
2019	32.86	33.78	34.24	32.65	29.96	30.03	30.75	32.08	34.57	34.86	34.05	32.19
2020	29.16	28.87	27.58	27.35	26.96	25.99	26.08	29.2	32.83	33.5	34.01	31.23

Appendix XV: Monthly average minimum temperature (°c) for Kondoa

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	11.96	13.57	13.8	14.19	10.91	8.29	5.9	8.68	11.06	10.98	13.9	14.39
1991	14.65	12.27	12.65	12.2	11.81	8.96	6.78	8.01	10.76	12.86	11.4	13.83
1992	13.76	13.19	12.33	14.65	10.43	8.44	6.4	6.27	10.87	11.72	13.78	13.51
1993	13.74	10.82	12.22	14.12	11.55	8.08	5.68	5.87	9.12	11.65	11.79	12.66
1994	14.22	14.01	13.27	10.76	11.33	7.14	6.67	8.61	10.4	11.49	13.58	13.27
1995	12.7	12.48	13.1	14.01	8.73	9.01	6.8	9.42	8.36	12.78	12.34	13.33
1996	13.8	13.99	12.66	13.26	12.1	8.23	6.27	7.1	9.3	10.96	13.26	13.21
1997	13.53	13.32	12.95	12.15	8.91	10.94	6.84	7.51	9.43	12.31	14.79	15.18
1998	15.09	13.15	13.53	13.19	9.67	7.65	7.2	10.78	12	11.86	11.87	14.63
1999	12.81	13.38	14.76	13.32	10.9	8.41	8.44	11.62	11.01	9.9	13.32	12.95
2000	13.17	13.13	15.16	12.8	12.26	8.15	7.55	10.44	11.22	11.61	14.12	15.08
2001	13.96	14.97	13.61	14.1	8.91	7.58	7.33	8.27	9.71	11.73	14.22	14.22
2002	13.97	12.84	15.23	14.51	12.01	8.87	8.9	8.84	12.01	12.3	13.3	14.25
2003	11.84	11.31	12.52	13.59	12.22	9.28	7.23	8.14	12.15	11.66	13.69	12.79
2004	15.4	13.09	12.87	13.16	10.13	7.58	7.08	8.08	12.75	12.03	14.07	14.36
2005	13.86	11.08	13.38	13.33	11.55	10.1	8.06	8.82	11.45	12.73	13.35	13.64
2006	14.55	14.25	13.37	13.5	11.94	8.81	9.12	8.37	11.02	12.41	14.53	14.33
2007	13.51	10.83	13.18	13.21	12.75	6.4	9.02	8.74	10.58	13.4	13.01	13.32
2008	14.01	13.42	13.79	12.54	11.64	7.4	8.36	11.1	9.91	12.55	14.19	14.25
2009	14.38	14.7	14.22	13.27	12.03	10.28	8.16	11.1	13.07	12.88	13.05	14.08
2010	13.33	13.58	12.97	14.98	12.08	9.55	7.77	7.33	8.72	11.92	14.69	13.08
2011	12.87	13.36	13.17	14.12	12.8	9.27	6.99	10.86	12.7	13.55	13.94	14.37
2012	11.18	11.96	12.76	13.3	12.37	9.09	8.4	8.74	10.01	13.25	14.48	13.62
2013	14.24	12.98	13.37	14.26	10.51	7.99	7.86	9.68	10.59	11.81	13.94	14.87
2014	13.43	12.77	14.46	14.37	10.84	9.12	8.06	11.96	11.81	13.02	12.82	15.37
2015	12.4	14.19	13.12	13.59	12.26	9.89	8.92	10.2	11.83	14.38	13.41	15.62
2016	15.37	14.8	16.03	15.02	10.56	10.26	6.84	9.46	10.98	11.62	12.04	15.15
2017	13.93	13.94	14.76	13.06	12.62	11.76	9.94	10.71	10.91	13.36	14.42	14.89
2018	13.75	14.65	12.55	12.73	11.4	9.56	9.38	10.03	12.3	12.56	13.86	13.84
2019	14.04	13.01	13.59	14.51	12.91	9.9	7.72	10.15	11.56	13.04	13.75	15.27
2020	15.19	13.22	15.08	14.21	11.14	10.14	6.05	9.13	9.81	12.11	14.56	13.88

Appendix XVI: Monthly average minimum temperature (°c) for Chemba

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	15.21	16.4	15.4	15.53	13.3	10.3	9.07	11.58	13.13	13.37	16.13	16.7
1991	17.31	15.26	16.1	15.09	14.2	12.2	9.9	11.31	13.19	15.4	14.83	16.6
1992	16.19	16.34	13.9	16.8	12.9	11.87	10.31	10.38	12.07	13.85	14.94	14.5
1993	15.42	14.56	15.3	16.04	13.7	10.51	8.81	9.62	10.89	13.68	15.3	13.7
1994	16.47	16.44	15.3	12.7	13.9	10.06	9.91	11.04	12.91	13.91	14.48	16.6
1995	16.25	15.69	14.9	15.49	12.1	10.3	9.36	11.07	11.93	14.54	13.74	15.3
1996	16.5	14.93	15.1	14.91	14.4	10.55	9.31	10.37	11.48	14.37	15.61	15.9
1997	16.26	15.69	14.7	14.69	11	13.18	9.95	11.15	13.62	14.29	16.62	17.4
1998	17.68	16.48	16.1	15.08	11.6	10.76	10.62	12.48	14.03	13.88	13.72	17.3
1999	15.58	14.86	16.9	14.98	13.4	10.24	10.69	12.89	12.69	13.47	14.4	14.1
2000	16.55	15.66	17	14.85	13.8	11.16	10.68	12.6	12.8	14.92	15.98	16.9
2001	16.3	16.19	14.7	15.76	12.6	10.76	10.71	11.25	12.43	14.48	16.73	17.3
2002	15.58	15.62	17.2	16.52	13.9	12.01	12.18	12.21	14.06	14.71	16.12	16.7
2003	15.4	14.89	16.4	16.66	15.2	12.9	10.48	11.42	14.22	14.55	16.62	15.6
2004	17.35	16.49	15	14.61	12.3	10.95	10.62	11.19	14.37	14.2	16.66	16.3
2005	15.42	15.46	16.6	15.86	14.4	12.94	11.12	12.38	13.99	14.23	15.54	16.6
2006	17.19	17.88	15.1	15.12	13.2	10.68	10.65	11.96	13.27	13.96	17.3	16.9
2007	15.85	14.59	15.7	14.96	14.6	9.94	10.98	12.46	13.57	15.32	15.35	16.3
2008	16.31	15.57	16.1	14.39	13.3	9.66	11.02	12.28	12.82	16.48	17.42	16.8
2009	16.44	15.73	16.1	14.82	13.9	12.47	10.07	12.95	14.19	14.98	15.4	16.9
2010	15.82	14.84	16.4	16.52	14.8	12.68	11.53	11.12	11.23	13.94	16.32	15.9
2011	16.07	16.16	15.6	15.3	14.9	11.87	10.12	13.14	13.73	15.69	16.06	16.3
2012	13.66	14.26	15.2	14.37	13.6	11.51	10.97	12.33	13.38	15.66	16.05	14.1
2013	16.94	15.39	15.9	15.78	13.6	11.03	11.47	12.66	14	15.04	16.66	17.4
2014	15.62	16.6	15.5	16.07	13.1	10.76	11.18	13.26	13.81	15.44	15.26	17
2015	15.3	16.06	16.3	16.01	13.6	12.84	11.76	12.76	14.54	16.81	15.34	17.4
2016	17.12	16.69	17.5	16.49	12	11.22	9.5	11.63	12.57	13.8	15.49	17.7
2017	16.84	16.3	16.6	15.23	14.6	13.26	11.54	13.04	13.68	15.68	16.33	17.7
2018	15.79	15.67	14.3	15.08	13.7	10.3	10.83	11.92	14.05	14.72	16.55	16.6
2019	16.12	15.76	15.6	16	14.4	12.24	10.84	12.7	14.3	14.92	15.58	16
2020	16.73	16.66	16.8	16.22	12.4	11.08	8.4	9.59	11.83	15.03	17.11	16.9

Appendix XVII: Monthly average minimum temperature (°c) for Kongwa

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	14.62	16.2	15.52	15.03	13.28	9.87	7.9	11.89	12.57	13.26	15.48	16.25
1991	17.7	15.14	15.92	14.73	13.61	11.19	8.98	10.94	12.04	14.48	14.02	16.79
1992	15.44	16.6	13.58	16.73	13.63	11.01	9.31	9.05	11.65	12.8	14.42	13.83
1993	15.08	14.66	14.7	15.7	13.15	9.66	7.91	9.28	10.48	12.97	14.56	13.92
1994	16.68	16.52	14.65	12.2	12.74	9.36	9.05	10.69	11.43	14.24	13.95	15.98
1995	15.9	15.15	14.28	15.44	11.65	9.51	8.88	11.33	11.48	13.37	12.13	14.4
1996	15.62	14.97	14.69	14.7	13.79	9.44	8.1	9.08	9.99	13.39	14.61	15.33
1997	16.13	15.29	14.48	14.19	10.9	12.51	8.14	10.3	13.28	13.79	15.95	16.74
1998	16.95	16.77	15.58	14.58	10.51	9.87	9.98	11.88	13.67	12.8	12.99	16.47
1999	16.73	14.47	16.19	14.94	13.5	10.36	10.19	12.94	12.4	12.7	13.49	14.21
2000	16.29	15.38	17.05	15.42	12.61	9.91	9.73	12.1	12.34	14.05	15.5	16.54
2001	16.12	16.19	14.46	15.58	11.52	9.8	9.31	10.33	12.19	13.97	15.41	16.87
2002	15.36	15.33	16.83	15.99	12.78	11.21	11.71	11.55	13.75	14.14	15.73	16.57
2003	15.31	14.11	15.37	16.3	14.49	12.11	9.8	10.01	13.13	13.7	15.99	16.26
2004	16.69	16.36	16.35	13.11	11.26	10.18	9.86	10.37	13.2	13.76	15.97	16.29
2005	14.43	15.12	16.65	14.85	14.07	12.15	10.25	12.08	13.15	14.02	14.68	15.66
2006	17.27	17.56	14.36	14.31	11.62	9.62	9.79	11.63	12.71	13.61	16.47	16.89
2007	15.98	14.15	15.62	15.09	14.03	9.59	10.3	11.93	13.39	14.66	14.44	15.8
2008	16.07	14.29	15.37	14.54	12.74	8.7	9.65	12.32	12.23	15.67	16.32	16.4
2009	15.94	15.44	16.06	14.11	13.32	11.46	9.63	12.42	13.62	14.63	14.53	16.73
2010	15.03	14.23	16.48	16.82	14.33	12.05	10.98	9.99	10.31	13.45	14.77	15.66
2011	15.97	16.11	15.07	15.09	14.3	10.93	8.85	12.17	13.3	15.56	15.66	16.61
2012	13.89	14.01	15.5	13.9	12.56	10.96	10.44	11.22	13.07	15.17	15.58	14.22
2013	16.68	15.56	15.3	15.43	13.25	10.56	10.6	12.14	12.64	14.19	15.37	16.87
2014	16.31	16.09	15.45	15.9	13.12	11.05	9.98	12.62	13.34	14.58	14.89	17.05
2015	15.61	15.48	15.91	16.4	13.54	11.92	10.17	12.39	13.1	15.88	15.01	16.3
2016	17.45	15.81	16.95	16.02	11.35	10	8.94	10.9	12.22	12.94	15.02	17.02
2017	16.82	15.55	16.23	14.79	14.13	12.68	10.62	12.37	12.83	14.92	15.22	17.12
2018	15.63	15.14	14.02	14.57	13.1	9.67	10.08	11.09	12.69	14.22	15.56	16.43
2019	15.88	15.14	15.54	15.61	13.98	11.59	10.08	12.13	13.2	14.41	15.29	16.65
2020	17.02	16.75	16.69	16.26	11.66	10.05	8.65	8.87	12.26	15.01	16.57	16.15

Appendix XVIII: Monthly average minimum temperature (°c) for Dodoma

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	15.47	16.95	16.04	15.62	13.97	10.52	9.39	12.3	13.21	14.09	16.4	17.54
1991	17.94	15.25	16.19	15.4	14.51	12.46	10.32	11.39	13.21	15.63	14.87	17.08
1992	16.19	15.87	13.9	17.43	13.96	12.19	10.65	10.93	12.52	13.83	15.58	14.74
1993	15.42	15.08	15.92	16.37	14.12	10.66	9.31	9.98	11.52	13.69	15.76	14.23
1994	16.65	16.71	15.79	12.95	13.98	10.18	10.01	11.48	12.94	14.77	14.35	16.96
1995	16.37	16.05	15.04	15.98	12.95	10.05	9.8	11.69	12.32	14.38	13.65	15.46
1996	16.26	14.97	14.96	15.31	14.55	10.43	9.23	10.63	11.35	14.33	15.69	16.03
1997	17.19	16.08	14.49	15.17	11.56	13.23	9.9	11.44	14.34	14.81	16.66	17.78
1998	18.22	16.64	16.06	15	11.72	10.87	10.8	12.87	14.56	13.69	14.54	17.45
1999	16.12	15.25	17.01	15.99	14.06	10.69	10.54	13.53	13.36	13.56	14.71	14.74
2000	16.82	15.09	17.25	15.84	13.62	11.35	11.23	12.99	13.57	15.09	16.25	17.24
2001	16.62	16.92	14.9	16.4	12.62	11.01	10.93	11.79	12.82	14.5	16.65	17.62
2002	15.23	15.73	17.55	16.9	13.97	11.98	12.83	12.52	14.37	14.87	16.67	17.6
2003	15.74	15.12	16.3	17.05	15.75	13.32	10.58	11.65	14.46	14.65	16.71	15.98
2004	17.4	16.98	16.48	14.93	12.62	11.23	10.83	11.82	14.44	14.33	16.94	16.59
2005	16.3	16.24	17.01	15.87	14.72	13.34	11.26	12.71	14.15	14.61	15.58	16.61
2006	17.62	18.26	15.28	15.4	13.33	10.71	10.8	12.25	13.31	14.71	17.8	17.62
2007	16.11	14.34	16.28	15.72	14.87	10.5	11.12	12.82	13.79	15.4	15.58	16.51
2008	16.47	15.56	16.14	15.42	13.66	9.85	10.94	12.54	13.36	16.39	17.29	17.29
2009	16.62	16.05	16.92	14.98	13.48	12.58	10.12	13.24	14.37	15.44	15.65	17.4
2010	16.08	14.94	16.5	17.37	15.12	13.01	11.89	11.38	11.71	14.3	15.69	16.14
2011	16.37	16.59	15.66	15.9	15.31	12.12	10.34	13.23	13.93	16.33	16.62	16.73
2012	14.02	14.86	15.81	14.19	13.15	11.7	11.28	12.54	13.55	15.73	16.2	13.71
2013	17.29	15.56	16.44	16.25	14.1	11.53	11.75	13.05	14.47	15.44	16.98	17.81
2014	16.37	16.74	16.13	16.57	13.6	10.98	11.22	13.35	14.34	15.51	15.34	17.46
2015	16.03	15.94	16.03	16.95	14.05	12.98	11.65	13.15	14.26	17.01	15.66	17.67
2016	17.47	17.2	17.67	16.8	12.43	11.25	9.86	11.87	12.79	13.82	16.12	17.97
2017	17.41	15.87	16.83	15.66	15.06	13.51	11.41	13.29	14.08	15.87	16.73	17.62
2018	16.38	15.91	15.09	15.21	14.28	10.55	10.98	11.94	14.23	15.07	17.05	16.95
2019	16.87	15.98	15.65	16.62	14.87	12.59	11.25	13.15	14.49	15.42	15.89	16.04
2020	17.51	17.08	16.63	16.67	12.77	10.96	8.73	9.76	12.76	15.3	17.27	17.05

Appendix XIX: Monthly average minimum temperature (°c) for Chamwino

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	15.7	17.28	16.93	15.48	14.4	10.7	9.7	12.9	13.74	14.69	17.3	17.78
1991	18.85	16.05	15.94	15.91	14.87	12.68	10.05	11.4	13.63	16.25	15.26	17.87
1992	16.58	16.44	14.51	17.51	13.58	12.54	11.04	11.49	13.12	14.44	16.2	15.13
1993	15.52	15.88	15.87	16.42	13.65	10.92	9.62	10.18	12.12	14.54	16.63	15.11
1994	17.08	17.53	16.24	13.51	13.76	10.76	10.14	11.51	13.05	16.08	15.1	17.39
1995	16.96	16.34	15.57	16.01	13.63	10.39	10.1	11.83	12.65	15.23	14.46	16.02
1996	16.5	15.55	15.63	15.08	14.16	10.28	9.37	10.69	11.77	14.9	15.87	16.39
1997	17.56	16.44	14.88	15.5	11.85	13.44	9.81	11.75	14.59	15.86	17.73	18.14
1998	18.25	17.93	16.27	15.47	12.28	10.87	11.46	13.09	15.44	14.12	15.23	18.12
1999	16.78	15.78	17.36	15.84	13.77	10.93	11.04	13.62	13.7	14.47	15.74	15.71
2000	17.55	15.45	17.74	16.15	13.08	11.77	11.58	13.27	14.25	15.42	17.16	17.54
2001	17.09	17.16	15.36	16.45	13.13	11.4	10.99	12.01	13.31	15.8	16.76	18.12
2002	15.49	15.9	17.83	17.16	14.62	12.25	13.11	12.99	14.51	15.75	17.89	18.32
2003	16.23	15.79	16.4	17.01	16.18	13.56	11.3	11.83	14.98	15.21	17.22	17.26
2004	17.9	17.32	17.76	15.13	13.64	11.9	11.31	11.94	14.89	15.61	17.89	17.14
2005	16.78	16.86	17.8	16.43	15.6	13.68	11.57	13.08	14.87	15.33	16.37	17.48
2006	18.39	18.9	16.22	15.91	13.32	10.86	11.12	12.31	13.94	16.2	18.48	18.21
2007	16.8	14.92	16.56	16.34	14.7	10.96	11.69	13.55	14.55	16.01	17.05	17.19
2008	16.57	15.42	16.35	16.29	13.96	10.43	10.79	12.88	13.54	16.89	17.65	17.67
2009	17.53	16.63	17.36	15.21	14.19	13.3	10.44	13.4	14.44	16.32	16.01	17.79
2010	16.79	15.13	17.06	17.87	15.3	13.45	12.24	11.51	12.31	15.08	15.94	16.4
2011	17.18	17.53	16.01	16.05	15.09	12.69	10.58	13.62	14.6	17.3	17.58	17.26
2012	14.87	16.61	16.23	14.99	13.05	11.92	11.69	12.97	14.02	16.52	16.71	14.65
2013	18.3	15.96	17.28	16.19	14.38	12.34	12.18	13.4	14.81	16.13	16.73	18.64
2014	17.42	16.96	16.8	17.12	13.76	11.8	11.19	13.44	14.98	16.12	16.9	18.26
2015	17.13	16.24	16.44	17.24	13.95	13.44	11.7	13.23	14.55	17.58	16.15	17.61
2016	18.33	17.95	17.94	17.01	12.7	10.7	10.37	12.32	12.76	14.43	17.23	18.44
2017	18.25	16.76	17.05	16.05	14.93	13.69	11.71	13.58	14.42	16.72	17.4	18.77
2018	17.13	16.19	15.87	15.51	14.41	11.21	11.84	12.42	14.18	15.8	18.03	17.39
2019	17.97	16.36	15.8	17.27	15.15	13.19	11.56	13.9	15.13	15.73	16.82	17.75
2020	18.32	18.16	17.22	16.97	12.9	10.36	9.62	10.26	12.64	16.27	18	16.7

Appendix XX: Monthly average minimum temperature (°c) for Mpwapwa

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	15.2	16.68	16.55	14.76	13.4	10.53	8.27	12.37	13.21	14.4	16.18	16.89
1991	18.07	15.73	15.94	15.18	13.24	11.65	9.12	10.96	12.62	15.2	14.15	17.13
1992	15.86	17	13.84	17.03	13.3	11.4	9.4	9.83	12.95	13.7	15.74	14.34
1993	15.52	15.15	15.09	15.89	12.94	10.29	8.37	9.99	11.28	13.7	15.22	14.85
1994	17.03	17.34	15.55	12.6	12.59	9.96	9.37	11.15	12.1	15.3	14.82	16.95
1995	16.08	15.23	14.85	15.28	12.15	9.58	9.19	11.42	12.19	14.3	13.07	14.57
1996	16.37	15.62	14.89	14.59	14	9.37	8.4	9.26	10.39	13.7	14.69	15.69
1997	16.87	15.8	15.23	14.39	10.69	12.52	8.2	10.62	14.26	14.9	16.98	17.23
1998	17.33	17.9	15.57	15.08	11.05	10	9.86	12.5	14.59	13.3	14.09	17.14
1999	17.23	14.85	16.81	15.35	13.51	9.9	10.25	13.28	13.05	13.2	14.7	15.3
2000	17.02	16.2	17.58	15.55	12.62	10.55	10.08	12.51	13.45	14	16.03	17.01
2001	16.64	16.82	15.24	16.1	12.05	10.07	9.46	10.7	12.83	14.8	15.46	17.42
2002	16.11	15.86	16.77	16.44	13.28	11.51	12.52	12.15	14.12	15.1	16.9	17.6
2003	15.78	15.42	15.54	16.33	15.13	12.54	10.52	10.42	14.1	14.5	16.58	17
2004	17.7	17.36	17.22	12.99	11.98	10.55	10.23	10.64	13.44	15.1	17.15	16.8
2005	15.69	15.9	17.32	15.49	14.65	12.7	10.55	12.5	13.63	14.8	15.15	16.31
2006	17.72	18.23	15.19	14.52	11.4	10.37	10.01	11.97	13.23	15.1	17.24	17.51
2007	16.55	15.14	16.15	15.37	13.96	9.92	10.83	12.91	14.38	15.4	16.06	16.49
2008	16.64	14.23	15.73	14.65	12.67	9.49	9.83	12.86	12.48	16.5	17.17	16.62
2009	16.67	16.07	16.89	14.14	13.1	12.05	9.73	12.81	14.05	15.9	15.14	16.94
2010	16.19	15.01	17.23	17.44	14.82	12.49	11.11	10.08	11.3	14.2	15.01	15.86
2011	16.37	16.69	15.64	15.51	14.16	11.3	9.2	12.31	14.12	15.9	16.48	17.05
2012	15.1	15.43	15.82	14.33	12.85	11.44	10.89	11.4	13.86	15.9	16.03	15.16
2013	17.44	15.95	16.49	15.3	13.51	10.93	11.03	12.84	13.25	14.8	15.82	17.79
2014	16.79	16.73	16.44	16.62	13.19	11.19	10.25	13	14.34	15.2	16.12	17.68
2015	16.42	15.7	16.37	16.79	13.06	12.37	10.36	13.12	13.69	16.6	15.6	15.82
2016	17.81	17.15	17.29	16.23	11.24	9.67	9.23	11.14	12.94	14	16.5	17.86
2017	17.31	15.87	16.95	15.23	14.19	12.37	10.62	12.55	13.07	15.8	16.28	17.94
2018	16.47	15.05	15.15	15.16	13.21	10.33	10.6	11.43	13.15	15.1	16.58	16.9
2019	16.82	15.53	15.79	16.05	14.22	12.18	10.56	12.48	14	15.8	16.41	17.87
2020	17.7	17.94	17.4	16.61	11.55	9.71	8.98	9.44	12.26	15.5	17.13	16.29

Appendix XXI: Monthly average minimum temperature (°c) for Bahi

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	15.47	16.95	16.04	15.62	13.97	10.52	9.39	12.3	13.21	14.09	16.4	17.54
1991	17.94	15.25	16.19	15.4	14.51	12.46	10.32	11.39	13.21	15.63	14.87	17.08
1992	16.19	15.87	13.9	17.43	13.96	12.19	10.65	10.93	12.52	13.83	15.58	14.74
1993	15.42	15.08	15.92	16.37	14.12	10.66	9.31	9.98	11.52	13.69	15.76	14.23
1994	16.65	16.71	15.79	12.95	13.98	10.18	10.01	11.48	12.94	14.77	14.35	16.96
1995	16.37	16.05	15.04	15.98	12.95	10.05	9.8	11.69	12.32	14.38	13.65	15.46
1996	16.26	14.97	14.96	15.31	14.55	10.43	9.23	10.63	11.35	14.33	15.69	16.03
1997	17.19	16.08	14.49	15.17	11.56	13.23	9.9	11.44	14.34	14.81	16.66	17.78
1998	18.22	16.64	16.06	15	11.72	10.87	10.8	12.87	14.56	13.69	14.54	17.45
1999	16.12	15.25	17.01	15.99	14.06	10.69	10.54	13.53	13.36	13.56	14.71	14.74
2000	16.82	15.09	17.25	15.84	13.62	11.35	11.23	12.99	13.57	15.09	16.25	17.24
2001	16.62	16.92	14.9	16.4	12.62	11.01	10.93	11.79	12.82	14.5	16.65	17.62
2002	15.23	15.73	17.55	16.9	13.97	11.98	12.83	12.52	14.37	14.87	16.67	17.6
2003	15.74	15.12	16.3	17.05	15.75	13.32	10.58	11.65	14.46	14.65	16.71	15.98
2004	17.4	16.98	16.48	14.93	12.62	11.23	10.83	11.82	14.44	14.33	16.94	16.59
2005	16.3	16.24	17.01	15.87	14.72	13.34	11.26	12.71	14.15	14.61	15.58	16.61
2006	17.62	18.26	15.28	15.4	13.33	10.71	10.8	12.25	13.31	14.71	17.8	17.62
2007	16.11	14.34	16.28	15.72	14.87	10.5	11.12	12.82	13.79	15.4	15.58	16.51
2008	16.47	15.56	16.14	15.42	13.66	9.85	10.94	12.54	13.36	16.39	17.29	17.29
2009	16.62	16.05	16.92	14.98	13.48	12.58	10.12	13.24	14.37	15.44	15.65	17.4
2010	16.08	14.94	16.5	17.37	15.12	13.01	11.89	11.38	11.71	14.3	15.69	16.14
2011	16.37	16.59	15.66	15.9	15.31	12.12	10.34	13.23	13.93	16.33	16.62	16.73
2012	14.02	14.86	15.81	14.19	13.15	11.7	11.28	12.54	13.55	15.73	16.2	13.71
2013	17.29	15.56	16.44	16.25	14.1	11.53	11.75	13.05	14.47	15.44	16.98	17.81
2014	16.37	16.74	16.13	16.57	13.6	10.98	11.22	13.35	14.34	15.51	15.34	17.46
2015	16.03	15.94	16.03	16.95	14.05	12.98	11.65	13.15	14.26	17.01	15.66	17.67
2016	17.47	17.2	17.67	16.8	12.43	11.25	9.86	11.87	12.79	13.82	16.12	17.97
2017	17.41	15.87	16.83	15.66	15.06	13.51	11.41	13.29	14.08	15.87	16.73	17.62
2018	16.38	15.91	15.09	15.21	14.28	10.55	10.98	11.94	14.23	15.07	17.05	16.95
2019	16.87	15.98	15.65	16.62	14.87	12.59	11.25	13.15	14.49	15.42	15.89	16.04
2020	17.51	17.08	16.63	16.67	12.77	10.96	8.73	9.76	12.76	15.3	17.27	17.05