RAINFALL AND TEMPERATURE TRENDS FOR SUITABLE ADAPTATION STRATEGIES IN AGRICULTURE: A CASE OF MOROGORO REGION

BY

Francis Michael Msangi

A Dissertation submitted in the Department of Geospatial Science and Technology in partial fulfilment of the requirements for the award of Bachelor of Science degree in Geoinformatics of Ardhi University

DECLARATION AND COPYRIGHT

I, Francis Michael Msangi, the undersigned, hereby declare that the contents of this dissertation are the results of my own findings, obtained through studies and investigation. To the best of my knowledge, similar work has never been presented anywhere as the thesis for an award of diploma, degree or any other profession in higher learning institution.

....

Francis Michael Msangi

Date...

CERTIFICATION

The undersigned certify that she has read and hereby recommend for acceptance by the Ardhi University as dissertation titled**: " Rainfall and Temperature trends for suitable adaptation strategies in agriculture a case of Morogoro region"** in fulfillment of the requirements for the Bachelor of science degree in Geoinformatics.

....

Dr. Dorothea Deus

(Supervisor)

Date...

....

Dr. Beatrice C. Tarimo

(Head of Department-DGST)

Date..

ACKNOWLEDGEMENT

I would like to express my special thanks of gratitude to Almighty God for granting me with knowledge and good health throughout my period of study. I would also like to appreciate the support offered by my supervisor; Dr Dorothea Deus for her time and guidance from the beginning to the end of my dissertation. Sincere thanks should also go to Dr Francis Muthoni and Mr Exavery Kigosi of the International Institute of tropical Agriculture (IITA) for their close support and assistance in my dissertation. I also extend much appreciation to members of Geospatial Science and Technology Department (DGST) and fellow students for their encouragement and support. The completion of this research could not have been possible without the participation and assistance of so many people who might have not been mentioned in this page, whose contributions are sincerely appreciated and gratefully acknowledged.

DEDICATION

I dedicate this work to my family (Michael's family), for always encouraging and motivating me to excel in my studies

ABSTRACT

Impacts of climate change and variability have already become eminent in most parts of the world due to the increase in rate and magnitude of climate extremes such as droughts and floods. Agricultural sector which is the main source of income for most countries such as Tanzania has been vulnerable to climate change and extreme events due to the limited capacity and adaptation strategies. This study was conducted in Morogoro region of Tanzania to determine trends of rainfall and temperature by analyzing changes that have occurred from the year 1988-2018. This was done to provide relevant information to support formulation of suitable climate change mitigation and adaptation strategies in Agriculture. To achieve this, the study employed Mann-Kendall and Theil Sen's slope estimator to analyse rainfall and temperature changes. This study identified that there is a decreasing trend in annual rainfall ($-2 \text{ to } -16\text{mmyear}^{-1}$) and monthly rainfall ($-1 \text{ to } -8\text{mmyear}^{-\mathbf{1}}$). With an increasing trend in annual maximum temperature from $0.005 \text{ to } 0.025℃\, year^{-1}$ and minimum temperature from $0.010 \text{ to } 0.030℃\, year^{-1}$. The study also described trend in paddy production against rainfall and temperature for 12 years from 1999 to 2010 and discovered that low rainfall and higher temperatures causes a decrease in production. This study finally concluded that analysis of spatial temporal trends in rainfall and temperature are crucial for developing and improving adaptation strategies in agriculture and therefore recommended the use of modern farming techniques, improved seed varieties, changing of the cropping calendar year and adaptation through soil and water conservation techniques as ways of coping with climate change effects in Agriculture for Morogoro region . This study also recommended that the government should make use of the results on the trends of rainfall and temperature to ensure effectiveness of implementation of climate change adaptation strategies in agriculture.

Table of Contents

List of tables

List of figures

List of Acronyms

FAO	Food Agricultural Organization
GDP	Gross Domestic Product
GIS	Geographic Information System
IPCC	Intergovernmental Panel on Climate Change
JFM	January February March
LTM	Long-term Mean
MAM	March April May
NAPA	National Adaptation Programme of Action
OND	October November December
URT	United Republic of Tanzania

CHAPTER ONE

INTRODUCTION

1.1 Background

Climate change and variability is one of the most extreme challenges facing the world today (Rao and Legesse, 2013). Global warming is one factor that leads to greater climatic volatility such as changes in precipitation patterns, increased frequency and intensity of extreme weather events and has led to a rise in mean global sea levels (Rao and Legesse, 2013). The rate and magnitude of climate extremes such as droughts, floods and heat waves have been increasing on a global scale and have significantly contributed to loss of lives, properties and severe damage in infrastructure at different areas of the world (Chang'a, et al., 2017). According to the Intergovernmental Panel on Climate Change (IPCC) the extent of climate change effects on individual regions will vary over time and with the ability of different societal and environmental systems to mitigate or adapt to change (IPCC, 2007). Africa is one of the regions that are vulnerable to climate variability and extreme events due to the limited capacity to adapt. In recent years East Africa has suffered from extreme droughts and excessive rainfall events which created the need for humanitarian assistance (Gebrechorkos, et al., 2018).

Climate change adaptation and mitigation measures are considered to be the keys in combating climate change throughout the world (Shrestha, et al., 2018). According to (Shaftel, et al., 2020)mitigation involves reducing climate change by reducing the flow of heat-trapping greenhouse gases into the atmosphere either by reducing sources of these gases (for example the burning of fossil fuels for electricity, heat or transport) or enhancing the “sinks” that accumulate and store these gases i.e. the oceans, forests and soil.

Adaptation involves adjusting to actual or expected future climate or adapting to life in a changing climate. (Hepworth, 2010) describes adaptation as adjustments in ecological, social or economic systems in response to actual or expected climate stimuli and their effects. A research by (Akinnagbe and Irohibe, 2015) describes adapting to climate change as taking the right measures to reduce the negative effects of climate change or exploiting the positive ones by making the appropriate adjustments and changes. Adaptation has three possible objectives which are to reduce exposure to risk of damage, to develop the capacity to cope with unavoidable damages and taking advantages of new opportunities.

Adaptation to climate change initially involves having a clear perception that climate is changing and then finding ways to respond to those changes (Rao and Legesse, 2013).A research by (Maddison, 2006) addressed this two-step process of adaptation at the regional level for Africa, but results from this study are highly aggregated and hence have little relevance for addressing country specific perceptions and adaptations to climate change.

According to the report on National Climate change strategy in Tanzania of the year 2012 which states that although some of the existing environmental planning in the context of the Environmental Management Act, 2004 addresses certain aspects of climate change, enhancement of climate change existing governance strategies and institutional arrangements is still required to address all aspects of climate change mitigation and adaptation.

Over 80% of the total physical agricultural area globally practices rain fed agriculture (Mongi, et al., 2010). In Sub-Sahara Africa, agriculture plays a very important role in providing food and income for the majority of the population. Over 70% of the population in East Africa depend on subsistence agriculture which is almost entirely rain fed. It accounts for an average of 50% of Gross Net Product and about 66% of total export earnings (Lema, 2009). According to NAPA (2006), agriculture in Tanzania has been identified to be the second most vulnerable sector to the impacts of climate change.

A number of studies conducted recently in Tanzania have recognized that climate change and variability is happening and is tied with significant impact on various sectors including agriculture which is a main source of income in rural areas (Lema, 2009). In Tanzania agriculture is an important economic sector and contributes about 29.1% of Gross Domestic Product (GDP) and it is the main source of food, employment, raw materials for industries and foreign exchange earnings (URT, 2017).However, over the last few decades Tanzania has experienced several incidences of extreme climate events particularly floods and droughts that have been associated with socio- economic and ecological implications together with bringing about adverse effects on agriculture (Chang'a, et al., 2017).

Understanding the occurrence of extreme weather events is an important element for decision making and a key factor in prediction (Teshome, 2019), also identifying and analyzing the spatial temporal patterns of climate change and variability is a crucial step towards designing and targeting appropriate adaptation strategies (Muthoni, et al., 2018).This study intends to analyze the trends and variability of the climatic variables impacting agriculture production such as temperature and rainfall using GIS and remote sensing applications so as to address suitable adaptation strategies to cope with climate change effects on Agriculture.

1.2 Statement of the research problem

Climate change has proven to be one of the most global environmental challenges, with implications in food production and security, water supply, health, wildlife, energy, biodiversity etc. (Rao and Legesse, 2013). In Tanzania agriculture has been identified to be the second most vulnerable sector to the impacts of climate change (NAPA, 2006). Understanding the spatial and temporal patterns of climate change and variability is a key step towards designing and targeting appropriate adaptation strategies (Muthoni, et al., 2018). Studies conducted by (Muthoni, et al., 2018) and (Gebrechorkos, et al., 2019) have tried to explore the long-term trends in climate variables in East Africa. However, studies at a local scale where most of agricultural activities happen are limited, such that suitable climate change mitigation and adaptation strategies cannot be planned and implemented properly. Therefore, there is a need for investigating climate trends in local environment such as Morogoro region to support suitable adaptation strategies in Agriculture.

1.3 Objectives of the study

1.3.1 Main Objective

The main objective of this research is to determine trends by analyzing changes in rainfall and temperature from the year 1988-2018 to support suitable adaptation strategies in Agriculture.

1.3.2 Specific Objectives

The specific objectives of this research are:

- To determine the annual and monthly Long-term means of rainfall and temperature from the year
- Determining and mapping of the annual rainfall anomalies in Morogoro
- To examine the spatial temporal variation in rainfall
- To evaluate the slope of the trend for rainfall and temperature in Morogoro region from
- Analyze the monthly and annual significant trends in rainfall and temperature

1.4 Research Questions

The research questions are:

i. What is the distribution of rainfall and temperature over the study area?
ii. What are the are rainfall annual anomalies?
iii. What is the annual and monthly variability in rainfall?
iv. What is the slope of trend for rainfall and temperature in Morogoro region?
v. What are the areas with significant trend of rainfall and temperature in Morogoro region?

1.5 Significance of the research

Better precautions measure will be employed in areas that are more prone to severe drought and floods through determination of annual rainfall anomalies which indicate the areas experiencing rainfall above normal and the ones experiencing rainfall below normal.

Better agronomic practices will be adapted by farmers which will reduce input costs in their products and increasing the quality and quantity of crop yields by identifying the areas that exhibit significance increase or decrease in rainfall (Muthoni, et al., 2018)

Adaptation strategies and mitigation measures to minimize the effects of climate change for sustainable development. Also, this research will be a base for other researchers who intend to do a similar research relating to climate change and agriculture.

1.6 Expected output

The following are the expected output of this research:

1. Annual and monthly Long-term mean maps for rainfall and temperature
2. Annual rainfall anomalies map describing the areas with rainfall above and below normal
3. Monthly and annual spatial temporal variation maps in rainfall
4. Monthly and annual trends of rainfall and temperature from 1988-2018
5. Maps describing the zones with significant trends of temperature and rainfall from 1988-2018

1.7 Beneficiaries

The beneficiaries of this research include:

Decision and policy makers will be able to come up with new policies and mitigation measures to cope with climate change after being aware of the spatial and temporal patterns of rainfall and temperature

Citizens will use the knowledge on the trend of rainfall and temperature in cooperation together with authorities such as the government to improve the adaptation strategies to cope with the impacts of changes in climate.

Scientists will use this research as a reference when conducting other researches relating to agriculture and climate change

1.8 Description of study area

Morogoro is one of the 31 regions in Tanzania. The region lies between latitudes 5º 58' and 10' south of the equator and between longitude 35º 25' and 38º 30' East Greenwich (Figure 1.1). It has a population of 2,218,492 and density of 31 people per square kilometer. It occupies a total area of 70,264 square kilometers and is bordered to the north by Tanga region, to the east by Pwani and Lindi regions, to the south by the Ruvuma region and to the west by Iringa and Dodoma Regions. Morogoro region has an average temperature of 24º C. The minimum is 18º C in mountainous areas and has a maximum of 30º C in lowland areas. The coolest months are identified to be May, June and July while the hottest months are September and October. The variation of rainfall is between 500mm in low areas and 2,200mm in the mountainous areas (URT, National sample census of Agriculture Volume Ve: Regional report : Morogoro Region, 2007). Morogoro is the region which is famous for agricultural activities. It produces both food and cash crop and also engages in livestock keeping activities.

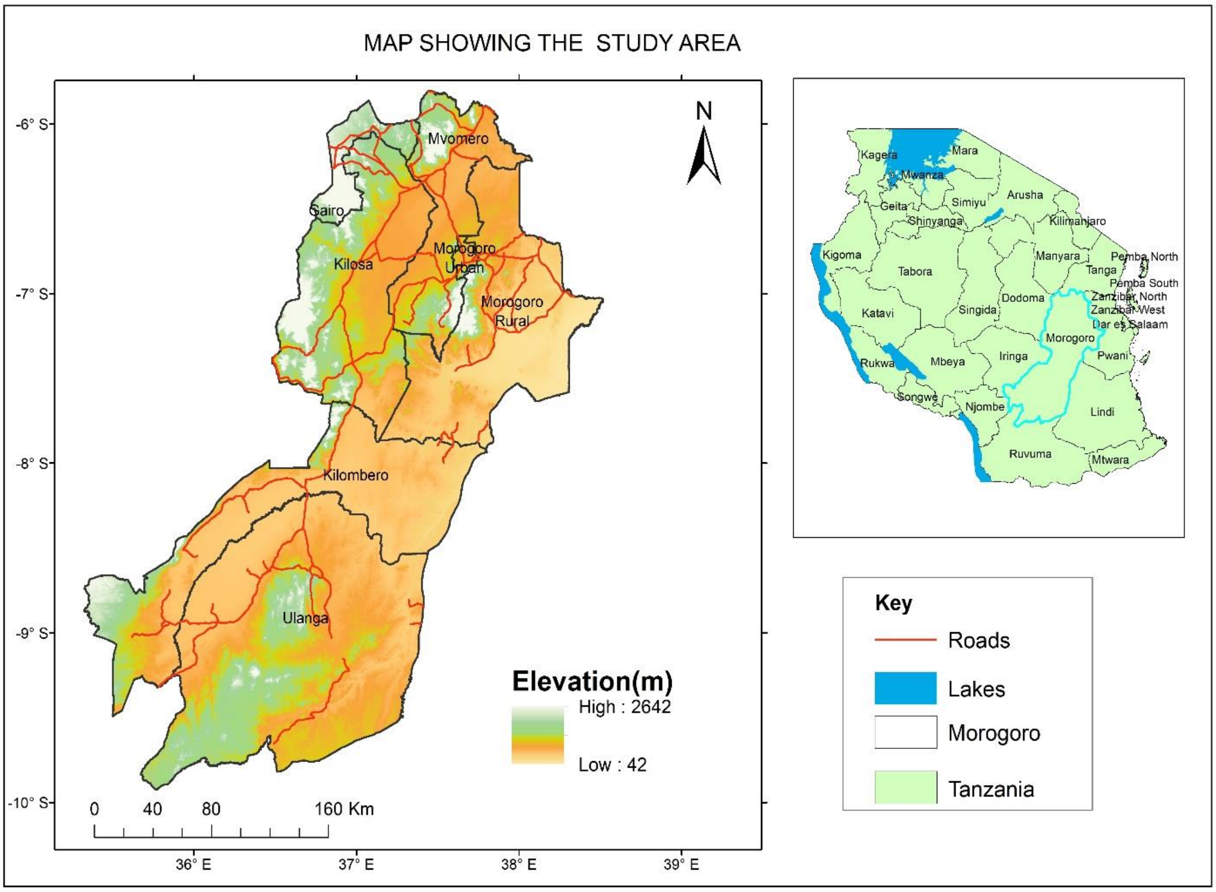

Figure 1.1 Map of the study area

1.9 Dissertation Structure

This dissertation consists of five (5) chapters that are associated to determine trends by analyzing changes in rainfall and temperature to support suitable adaptation strategies in agriculture.

Chapter 1

This chapter provides a brief background regarding the dissertation topic. It provides an overview of climate change, mitigation measures, adaptation strategies in relation to agriculture. It also clearly describes the research problem, aims and objectives, research questions, significance, study area and software utilized.

Chapter 2

This chapter provides a review of different literatures connected to the dissertation topic. It illustrates other studies that dealt with climate change, analyzing changes in rainfall and temperature to determine trends and adaptation strategies.

Chapter 3

Describes the overall methods and techniques used to obtain the results of the research. It fully describes all the processes from Data collection up to the last stage of obtaining results for research

Chapter 4

Reveals all the results that were obtained from research analysis according to the objectives. It contains the trends for rainfall and temperature and discussion section which tries to further describe effects of these changes in agriculture.

Chapter 5

This chapter contains the conclusion and recommendations for the research. It provides a conclusion based on the research objectives and recommendations based on the results obtained from the research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

This chapter provides a review of different literatures relating to climate change, climate variability, trend analysis of climate variables, methods used in detecting trends in climate variables and adaptation strategies.

2.2 Climate change and climate variability

Climate change refers to any change in climate over time, whether due to natural variability or anthropogenic forces. (Paavola, 2004) describes climate change as a systematic change in the key dimensions of climate including average temperature and wind and rainfall patterns over a long period of time. Climate variability refers to climatic parameter of a region varying from its long-term mean. Also refers to variations in the mean state and other climate statistics (standard deviations, occurrence of extremes etc.) For each year in a specific time period, the climate of a location is different. Climate variability describes the differences in averages of the same kind, such as weather conditions between two summers in the same region. Climate change involves longer time scales than that used to describe climate of an area (Wilson, et al., 2000)

Climate change is predicted to affect Tanzania in various ways, including rising in temperature and changes in the amount of rainfall together with increase of extreme events, sea level rise and water supply depletion. (Häckner, 2009) . According to (Munishi, 2009) analysis of recent climate trends reveals that climate change poses significant risks for Tanzania. Whereas projected changes in precipitation remain uncertain, there is high likelihood that there will be an increase in temperature as well as sea level rise.

Climate change scenarios across multiple general circulation models reveal an increase in country averaged mean temperature. According to the predictions mean daily temperature will rise 3ºC-5ºC throughout the country and mean annual temperature by 2ºC-4ºC. Rainfall is predicted to increase in some parts while other parts will experience a decrease in rainfall. As stated by (Paavola, 2004) People in the Morogoro region have lived with significant climate variability in the past and are likely to face increased climate variability and changing climate in the future.

2.3 Climate change impacts on agriculture

Climate change and variability has increased the burden on food security and income among farming families (Mongi, et al., 2010). Expected changes in climate conditions is said to have an effect on farming activities leading to decline of agricultural production, particularly food production, hence food insecurity, increased occurrence of floods, droughts and spread of diseases (Mngumi, 2016).

In most African countries agricultural production depends almost entirely on the rainy season, a situation that makes Africa vulnerable to climate change (Kangalawe and Lyimo, 2013) (Kangalawe, 2013). Predicted climate changes will significantly impact food production. A study by (Sivakumar, et al., 2005) explains that climate change is likely to cause greater environmental and social stress in many parts of Africa which are already having difficulties in coping with environmental stresses. Crop losses due to weeds, diseases and pests will increase as a result of warming conditions (Paavola, 2004). Changes caused by increased incidences of drought pose a great risk to agriculture, because many crops fail to cope with increasing temperature and changes in precipitation (Mngumi, 2016).

Relative to a no climate change baseline and considering domestic agricultural production as the principal channel of impact, food security in Tanzania appears likely to deteriorate as a consequence of climate change. Moreover, the relative decline comes about through reductions in agricultural production, principally food production due to increases in temperature and changes in rainfall patterns (Arndt, et al., 2012).

According to (Lema, 2009) increased droughts negatively affect food availability. Prediction by (Downing, 2002) suggest that Tanzania may loose 10% of its grain production by 2080. A study by (Paavola, 2004) suggest that since Morogoro region lies between the central highlands and the coastal region will experience a mixture of climate changes and climate change impacts. The study also indicates that the region already experiences significant variability in climate and that it has been experiencing droughts about once in every four years. It is also revealed that Monthly rainfall has varied even more which can lead to the reduction of crop yields

2.4 Trend analysis of rainfall and temperature

Trend analysis is crucial for analyzing spatial and temporal patterns in rainfall and temperature related extremes which are essential and critical inputs for effective designing and implementing coping and adaptation options to the impacts of climate change (Chang'a, et al., 2017). According to (Mahoo, et al., 1999) trends may serve as a basis for extrapolating future rainfall patterns in the area and provide evidence of existing differences.

A previous study by (Gebrechorkos, et al., 2019) on the long term trend analysis in seasonal rainfall in Ethiopia, Kenya and Tanzania showed a non-significant change in large parts of the region. The study also revealed a non-significant decreasing trend in rainfall during MAM season in the eastern parts of Ethiopia, Kenya and large parts of Tanzania. Moreover the study revealed a significant increasing trend in seasonal maximum temperature observed in large parts of the region. Similar to the change in maximum temperature a significant increasing trend in minimum temperature is observed in the region particularly Kenya and Tanzania. In the annual trends it was found that there are are few statistically significant trends in rainfall but significant increase trends in maximum temperature.

Another study by (Chang'a, et al., 2017) on the analysis of rainfall and temperature extreme indices in Tanzania from 1961-2015 revealed that both maximum and minimum temperature exhibit statistical significant increasing trends at monthly and annual time scales.For rainfall a non-statistical significant decreasing trend is depicted in percentage change in mean rainfall anomaly and in standardized precipitation index.

The use of statistical methods is necessary in order to detect trends in climatic and hydrological variables (Sonali and Kumar, 2013). Such statistical methods may be parametric or non-parametric.

2.4.1 Parametric and Non-parametric methods for trend analysis

Parametric methods rely on the assumption about the nature of distribution. The method supposes a fundamental distribution or normal distribution for the variables of interest an example of this method is least squares linear regression. Non-parametric method does not rely on the assumption that data should have a normal distribution (Sonali and Kumar, 2013). Hydro-meteorological time series data are characterized substantial departure from normality. For such data the non-parametric methods are preferred for detecting monotonic trends because they have higher power than parametric methods (Muthoni, et al., 2018)

The Non-parametric methods for detecting monotonic trends in time series data include Man-Kendall, Spearman's Rho and cumulative rank difference tests. A study by (Gebrechorkos, et al., 2019) and (Yue and Wang, 2004) suggests that Mann-Kendall test is one of the most popular and widely used to detect long-term seasonal and annual trends in and climate datasets.

2.4.1.1 Mann-Kendall Test

The Mann-Kendall test is a non-parametric method comonly employed to detect monotonic trends in series of environmental data, climate data or hydrological data (Pohlert, 2015). The null hypothesis, H_O is that the data come from a population with independent realizations and are identically distributed. The alternative hypothesis, H_A is that the data follow a monotonic trend. The Mann-Kendall test statistic is calculated according to equation 2.1 :

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(X_j - X_K) \tag{2.1}$$

With

$$sgn(x) = \begin{cases} 1 \quad if \quad x > 0 \\ 0 \quad if \quad x = 0 \\ -1 \quad if \quad x < 0 \end{cases} \tag{2.2}$$

The mean of S is E[S] = 0 and the variance σ^2 described by equation 2.3 is

$$\sigma^2 = \left\{ n(n-1)(2n+5) \; = \sum_{j=1}^{p} t_j\left(t_j - 1\right)\left(2t_j + 5\right) \right\} /18 \tag{2.3}$$

where p is the number of the tied groups in the data set and t_j is the number of data points in the j^{th} tied group. The statistic S is approximately normal distributed provided that the following Z-transformation in equation 2.4 is employed:

$$Z = \begin{cases} \dfrac{S-1}{\sigma} \quad if \quad S > 0 \\ \quad 0 \quad if \quad S = 0 \\ \dfrac{S+1}{\sigma} \quad if \quad S > 0 \end{cases} \tag{2.4}$$

The statistic S is closely related to Kendall's τ as described in equation 2.5:

$$\tau = \frac{S}{D} \tag{2.5}$$

Where

$$D = \left[\frac{1}{2}n(n-1) - \frac{1}{2}\sum_{j=1}^{p} t_j(t_j - 1)\right]^{1/2} \left[\frac{1}{2}n(n-1)\right]^{1/2} \tag{2.6}$$

In order to determine the magnitude or slope of a trend Theil-Sen method is necessary

2.4.1.2 Sen's slope

This test computes both the slope (i.e. linear rate of change) and intercept according to Sen's method (Pohlert, 2015). A set of linear slopes is calculated as shown in equation 2.7:

$$d_k = \frac{X_j - X_i}{j - i} \tag{2.7}$$

For ($1 \leq i \leq j \leq n$), where d is the slope, X denotes the variable, n is the number of data and i, j are indices

Sen's slope is then calculated as the median from all slopes: $b = Median\ d_k$. The intercepts are computed for each timestep t as given by equation 2.8

$$a_t = X_t - b * t \tag{2.8}$$

2.5 Climate change adaptation strategies

The adaptation to climate change involves the adjustment in natural or human systems in response to the projected climatic conditions or their effects which will minimize the harm (Bakari, 2015). According to (Prof.Majule, et al., 2014) the Tanzania government has put in place several policies that are directly addressing issues pertaining to climate change and their impacts on various sectors. These sectors, which are highly affected by climate change, have put in place policy statements and directives that seek to provide the remedies to the impacts of climate change.

2.6 Climate Change adaptation strategies in Agriculture

Significant research in Tanznania focuses on climate change adaptations or coping measures in agriculture. Most of these studies have focused on various communities' adaptive strategies that aim at improving the production of food crops under current climate variability (Kahimba, et al., 2015).

CHAPTER THREE

METHODOLOGY

3.1 Overview

This chapter describes overall the methods ranging from data collection to results. It includes the data collection, data pre-processing and data analysis methods that were used in obtaining the results. Figure 3.1 shows the workflow of the research:

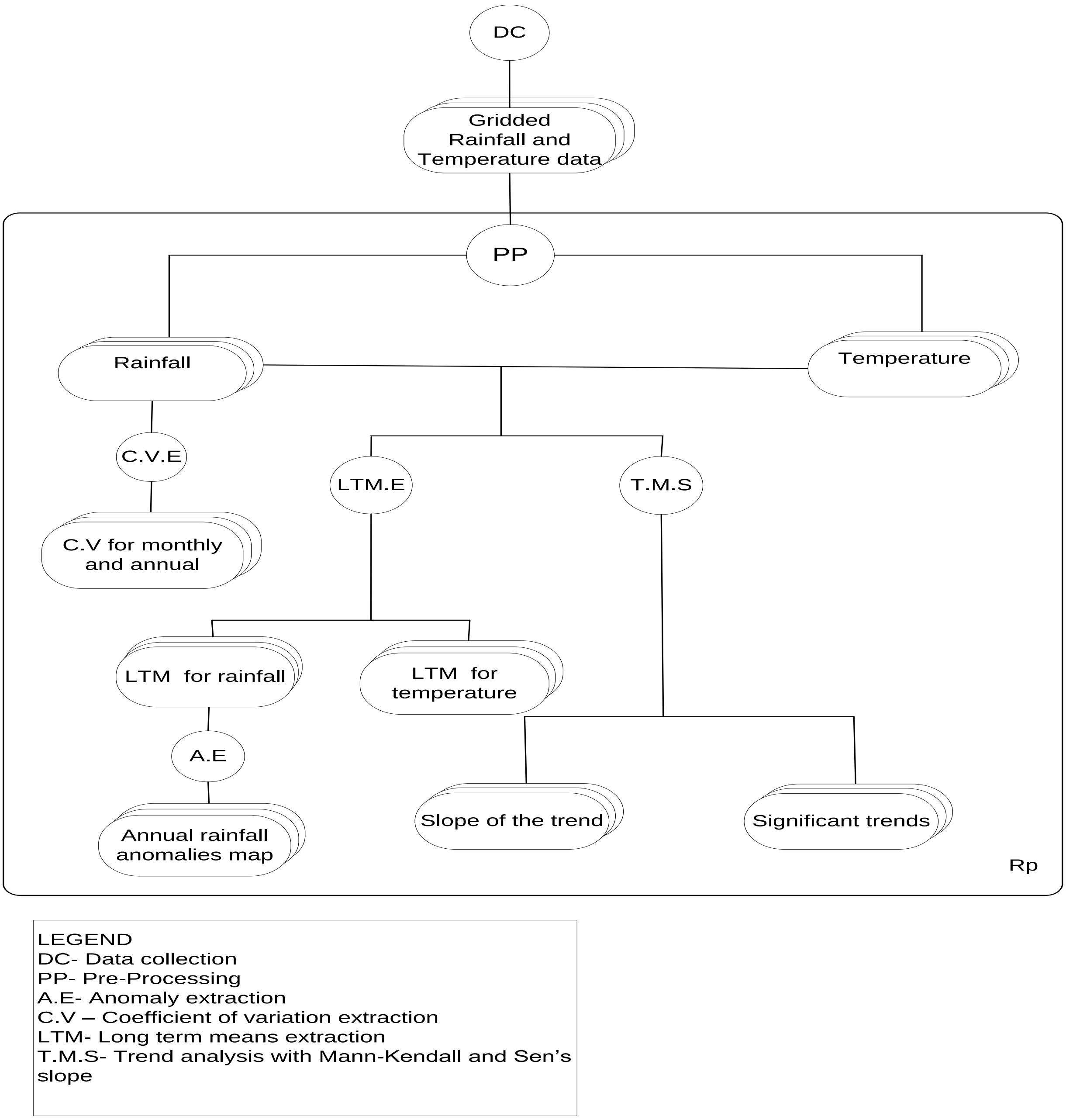

Figure 3.1 Methodological work flow

3.2 Data collection

The data used in this research is remote sensing data that include temperature and rainfall data downloaded from the Climatology lab with a monthly temporal resolution and approximately 4km (1/24th degree) spatial resolution. The downloaded rainfall and temperature data were from the year 1988-2018 (31 years). Table 1 is a summary of the data collected and associated sources.

Table 3.1: Summary of collected data and sources

Data	Characteristics	Epoch	Source
Rainfall	Monthly, 4km spatial resolution	1988-2018	Climatologylab: http://www.climatologylab.org/terraclimate.html
Maximum temperature	Monthly, 4km spatial resolution	1988-2018	Climatologylab: http://www.climatologylab.org/terraclimate.html
Minimum temperature	Monthly, 4km spatial resolution	1988-2018	Climatologylab: http://www.climatologylab.org/terraclimate.html

3.3 Software utilized

In this research the software used was R programming language through the R studio platform. R programming language was used in the data processing of rainfall and temperature data such processes include the extraction of rainfall and temperature data for the study area, manipulation of the data to obtain the monthly and annual Long-term means (LTM), determination of the anomalies in rainfall, coefficient of variation, determining the trend and zones with significant trend of monthly and annual temperature and rainfall.

3.4 Data Preparation

In order to use the remote sensing data pre-processing was required so as to prepare the data for further analysis. The preprocessing steps involved in both the rainfall and temperature data are Stacking, Projection, Extraction and Aggregation.

3.4.1 Layer Stacking

The monthly rainfall and temperature data according to each year was combined into one layer so that further pre-processing steps can follow to make the data ready for analysis. This was done using R programming language through the RStudio platform with the package “raster”.

3.4.2 Reprojection

The satellite data for rainfall and temperature was found to be in a different coordinate reference system in relation to the study area shapefile to be used to extract the data. Therefore, projection was done so as the rainfall and temperature data and the study area shapefile to have the same coordinate reference systems which is geographic WGS84 reference system. This was also performed using the “raster” package in R.

3.4.3 Extraction

After the projection of the rainfall and temperature data to the same coordinate reference system of the study area shapefile data for rainfall and temperature for the specific study area was extracted using the crop and mask functions from the package “raster” in R.

3.4.4 Aggregation

Aggregation of the monthly rainfall and temperature data was done so as to obtain the annual estimates of the variables which is required for analysis of the annual trends and also in the determination of annual anomalies for rainfall.

3.5 Data analysis

3.5.1 Long term means for monthly and annual rainfall, maximum temperature and minimum temperature estimation

This process was conducted in R using the package “raster”. The extracted monthly rainfall, maximum temperature and minimum temperature data for Morogoro region was used to generate the monthly Long term means from January to December from the year 1988 to 2018.Similar process was conducted for annual aggregates of all the three variables to generate the annual Long term means and visualized as maps showing the spatial temporal patterns.

3.5.2 Standardized rainfall anomalies

Standardized annual rainfall anomalies were generated by taking the difference between total rainfall for each year and the annual Long-term mean divided by the standard deviation using the “raster” package in R which indicate the departure from LTM where the negative values usually represent periods below normal rains while positive values reveal above normal rains.

3.5.3 Spatial temporal variations in rainfall

The spatial temporal variations for annual and monthly time series was derived by calculating the coefficient of variation using the raster package which allowed detection of seasonality of monthly and annual time series and plotted as maps using the packages rasterVis and Biodiversity R.

3.5.4 Trend analysis of rainfall, maximum temperature and minimum temperature

For analysis of trends of hydro-meteorological time series data (rainfall, temperature) the non-parametric methods are mostly preferred because such kind of data are characterized by significant departure from normality. Non-parametric trend tests require only that the data be independent and can tolerate outliers in the data (Hamed and Rao, 1998).

Despite there being different non-parametric methods such as Mann-Kendall, Spearman's Rho and cumulative rank difference tests the one that was chosen for this research was the Mann-Kendall method. Mann-Kendall was chosen because it is more commonly used for the analysis of trends in hydro-meteorological times series data and various forms of algorithms are incorporated in many R packages (Muthoni, et al., 2018). The null hypothesis for the Mann-Kendall test is that the data are independent and randomly ordered i.e. there is no trend or serial correlation structure among the observations. (Hamed and Rao, 1998)

A modified Mann-Kendall statistic was used to test the significance ($p < 0.1$) of trends for each of the input climate variable. The magnitude of the trend was computed using the Theil-Sen's median slope estimator. The trend analysis process was accomplished using the "eco.theilsen-2" function from the "EcoGenetics" R package. This function produces two rasters showing the p-values from Mann-Kendall significant test and the Theil-Sen's slope estimator. Theil-Sen's slope for those areas with $p < 0.1$ were regarded as significant while the ones with $p > 0.1$ were considered as non-significant. The slope and the significant trends for the three climate variables was presented in maps raster, rasterVis and BiodiversityR packages in R.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Overview

In this chapter the results obtained through the implementation of the research methodology and discussion are presented according to the intended objective of this research which was to analyze the trends of rainfall and temperature to support the suitable adaptations in agriculture. The results include LTM for monthly and annual rainfall, maximum temperature and minimum temperature, standardized annual rainfall anomalies, spatial temporal variations in monthly and annual rainfall, slope of the trend for both monthly and annual time series of the variables and areas where the trend was significant at $p < 0.1$. In the discussion section the existing adaptation strategies in agriculture were reviewed in relation to the trend in yield per hectare for rice from the year 1998 to 2010 in Morogoro region so as to identify the suitable adaptation strategy that should be recommended while looking at climate condition using the results from the research analysis.

4.2 Long-term means for monthly and annual rainfall and temperature

The spatial distribution of rainfall, maximum temperature and minimum temperature was described using the Long-term means of these variables for both monthly and annual time series.

4.2.1 Long-term means for monthly and annual rainfall

LTM monthly rainfall for 31 years (1988-2018) in Morogoro region ranged between 0 and 400mm with January, February, March, April and December being the months experiencing large amounts of rainfall. The LTM for monthly rainfall also reveals that June to September are dry seasons. In terms of the administrative areas Ulanga, Kilombero and Morogoro rural were the districts that experience highest amounts of rainfall of up to 400mm. Figure 4.1 describes the monthly LTM for rainfall in millimeters.

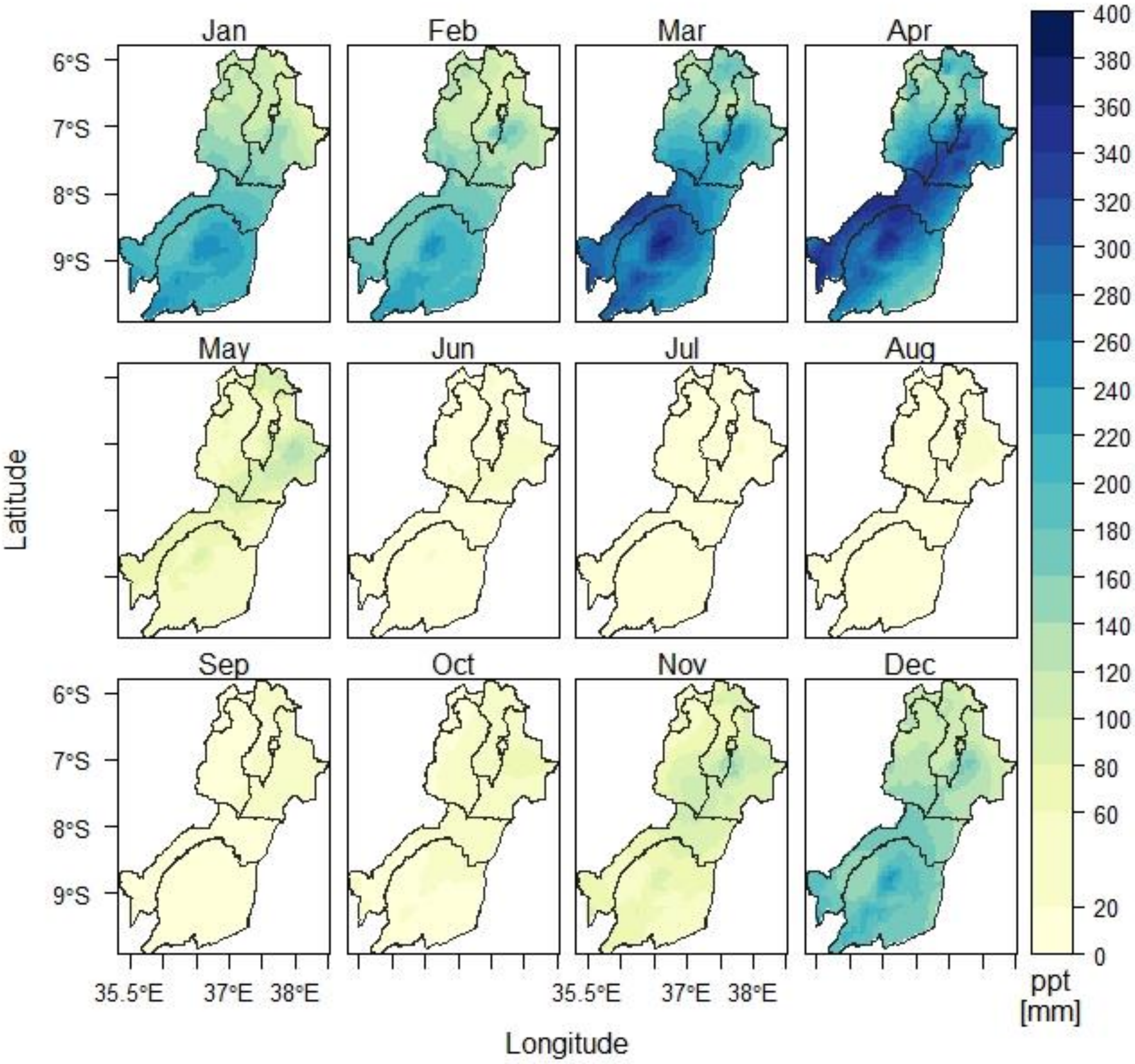

Figure 4.1 Long-term mean (LTM) of total monthly rainfall(mm) for 31years (1988-2018) in Morogoro region

The annual LTM of rainfall in Morogoro region for 31 years was found to range from around 500mm up to 1800mm. Ulanga, Kilombero and Morogoro rural were the districts that experience very high amounts of rainfall. Figure 4.2 illustrates the LTM for annual rainfall in millimeters.

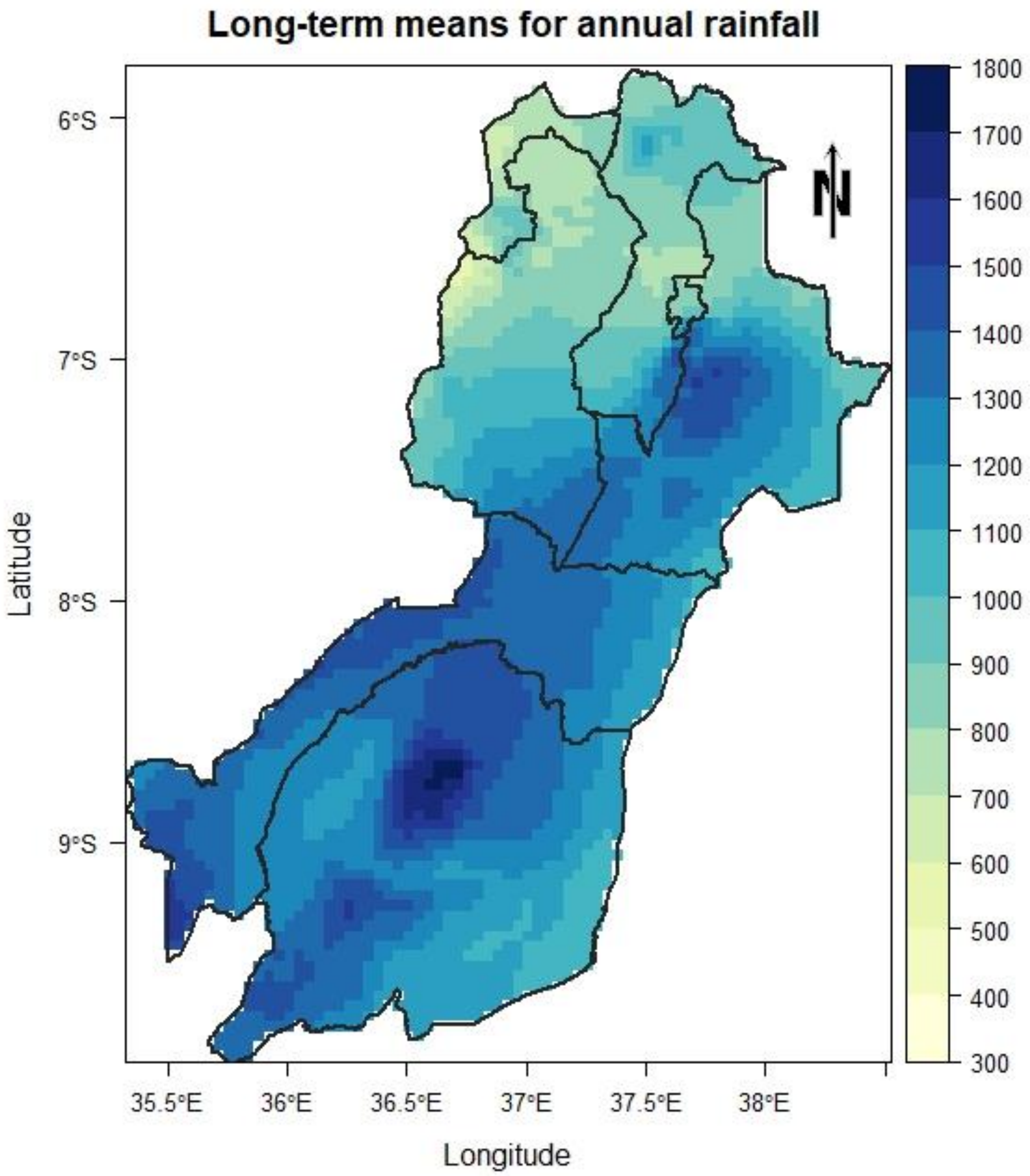

Figure 4.2 Long-term mean annual rainfall(mm) for 31years (1988-2018) in Morogoro region

4.2.2 Long-term means for maximum and minimum temperature

4.2.2.1 Monthly LTM

The LTM for monthly maximum temperature for 31 years in Morogoro was found to range from 16℃ to 34℃ . The months which exhibit high temperature values were found to be January to March (JFM) and October to December (OND). Figure 4.3 describes the monthly LTM for maximum temperature.

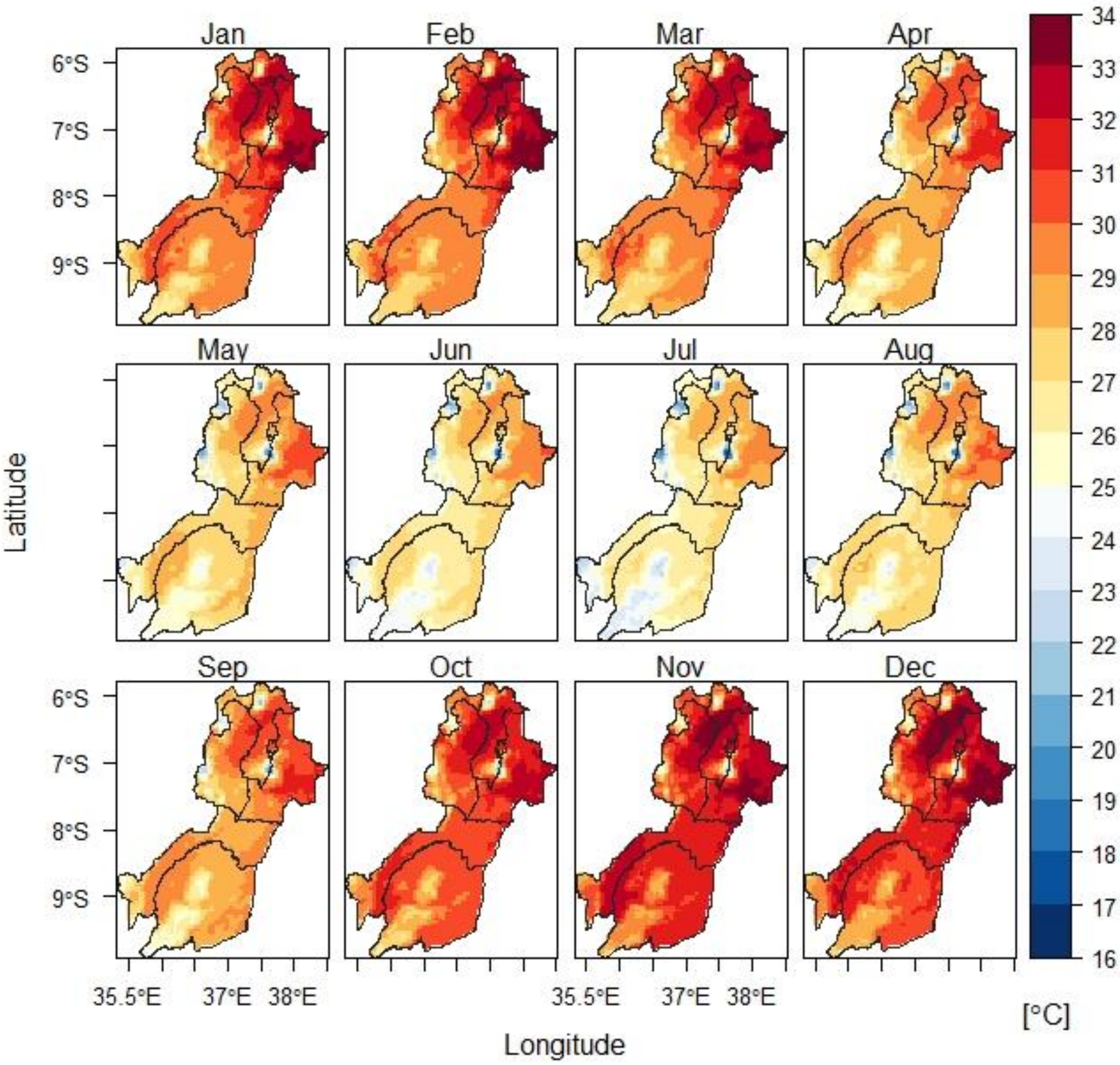

Figure 4.3 Long-term mean monthly maximum temperature for 31years (1988-2018)

The monthly minimum LTM values for 31 years in Morogoro region ranged from 6℃ to 26℃. Months with the highest values were found to be January to March (JFM), November and December. Figure 4.4 illustrates the monthly LTM for minimum temperature.

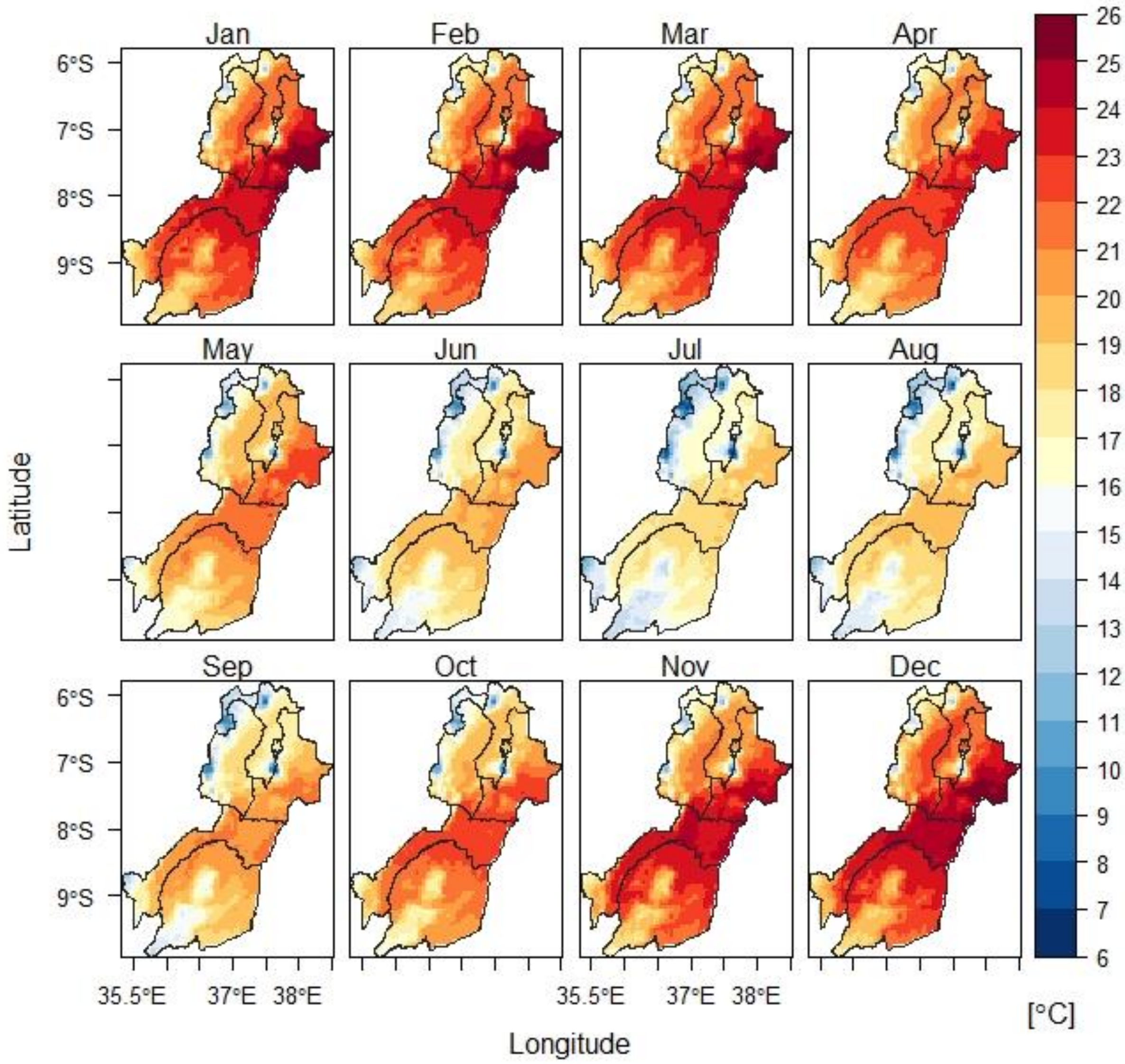

Figure 4.4 Long-term mean monthly minimum temperature for 31years (1988-2018)

The annual LTM for maximum temperature for 31 years ranged between around 20℃ up to about 32℃ while for minimum temperature it was found to range between 8℃ up to 24℃. Figure 4.5 Illustrates the LTM for both maximum and minimum temperature where the map on the left shows LTM for annual maximum temperature and the one on the right is for minimum temperature in degrees Celsius.

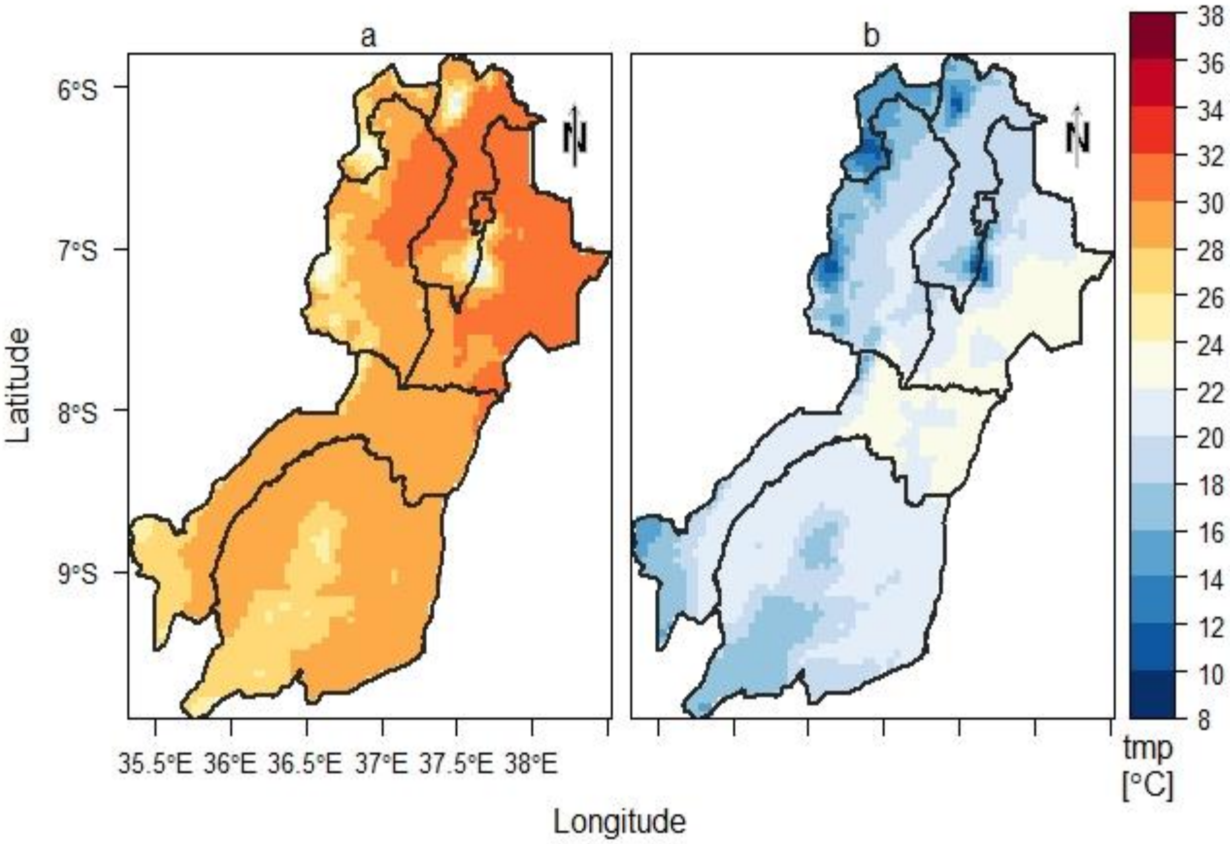

Figure 4.5 Long-term mean annual maximum(a) and minimum(b) temperature for 31 years (1988-2018)

4.3 Standardized anomalies for annual rainfall

The standardized annual rainfall anomalies for Morogoro revealed that the region had experience rainfall above normal in 1989, 1991, 1997, 2002, 2004 and 2006. The results also reveal that a number of areas in Morogoro region experienced droughts (rainfall below normal) in the years 1993, 2001, 2003, 2005, 2007, 2009, 2010, 2012 and 2016. Figure 4.6 describes the standardized anomalies for annual rainfall in Morogoro showing the strength of departure from the long-term mean rainfall from 1988 to 2018. Negative values describe the rainfall below normal while positive values represent rainfall above normal.

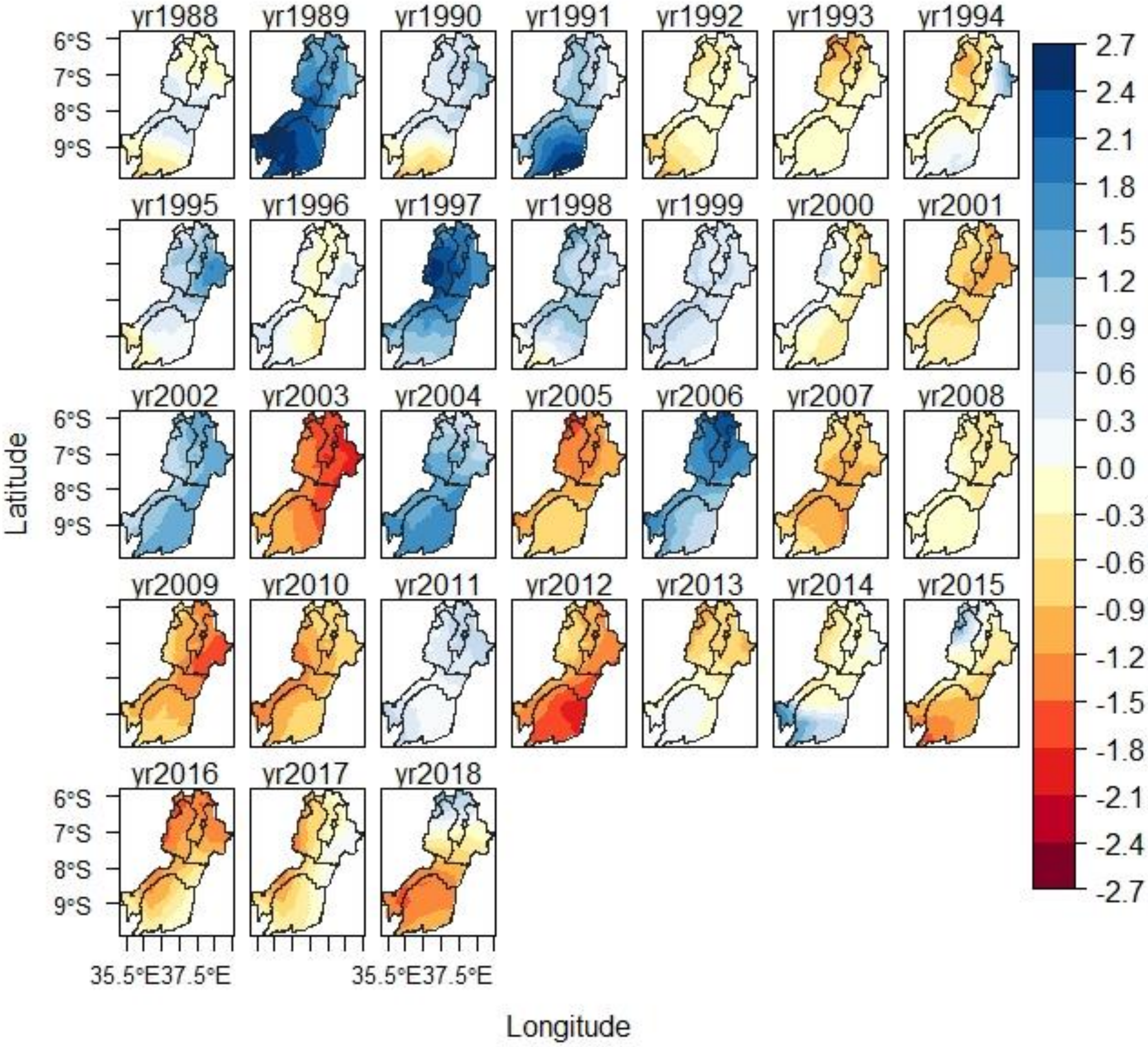

Figure 4.6 Standardized anomalies for annual rainfall in Morogoro region (1988-2018)

4.4 Spatial temporal variability in Rainfall

Inter-annual variability was highest in North eastern part of Morogoro region (Morogoro rural district) where CV=21% while areas of south west part of Morogoro region had low value of up to 13% CV in annual rainfall as described in Figure 4.7. Monthly rainfall was characterized by higher inter-annual variability up to 240% with rains of June to September being the most variable from 60%-240% presented in figure 4.8.

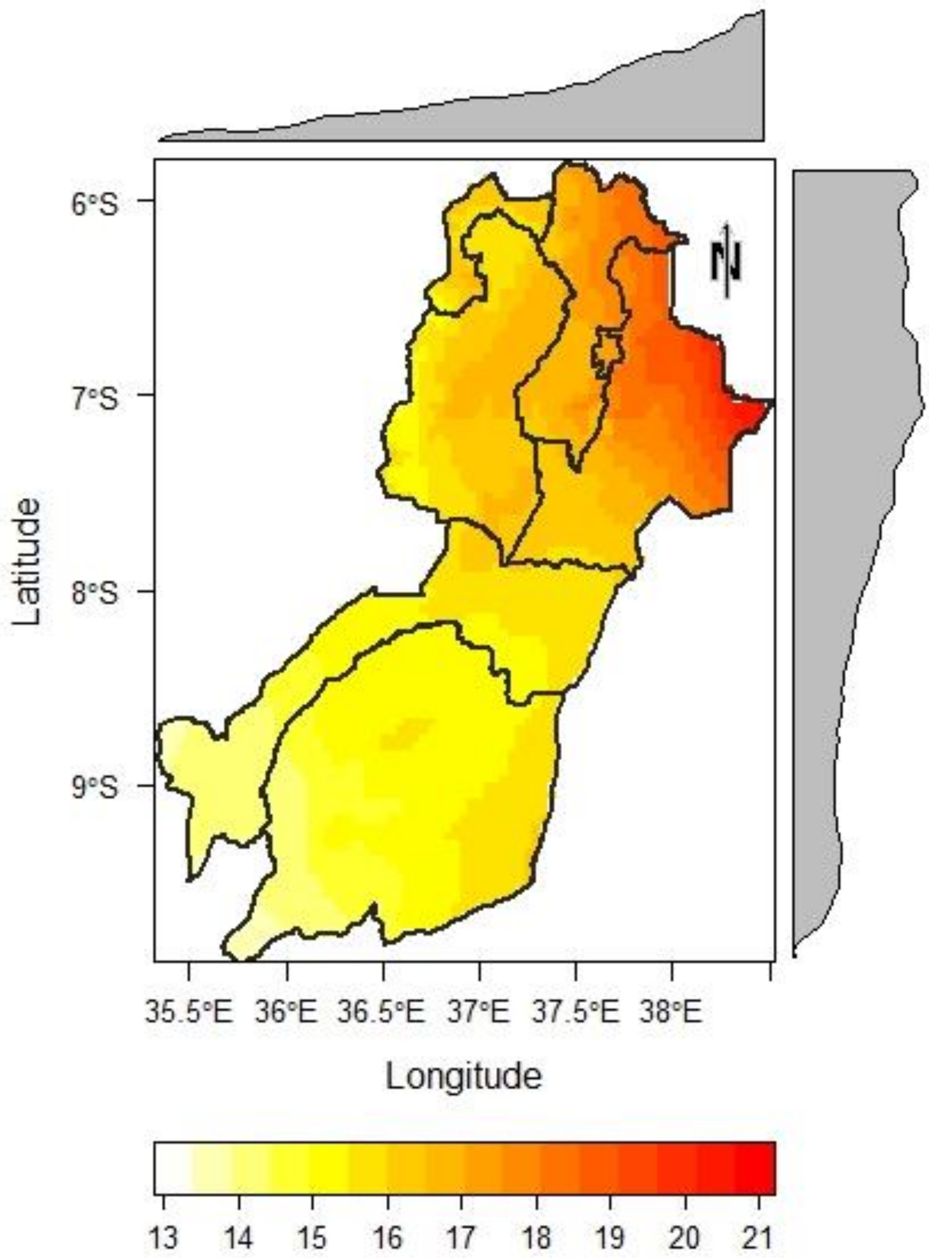

Figure 4.7 Coefficient of variation (%) in annual rainfall (1988-2018) in Morogoro region

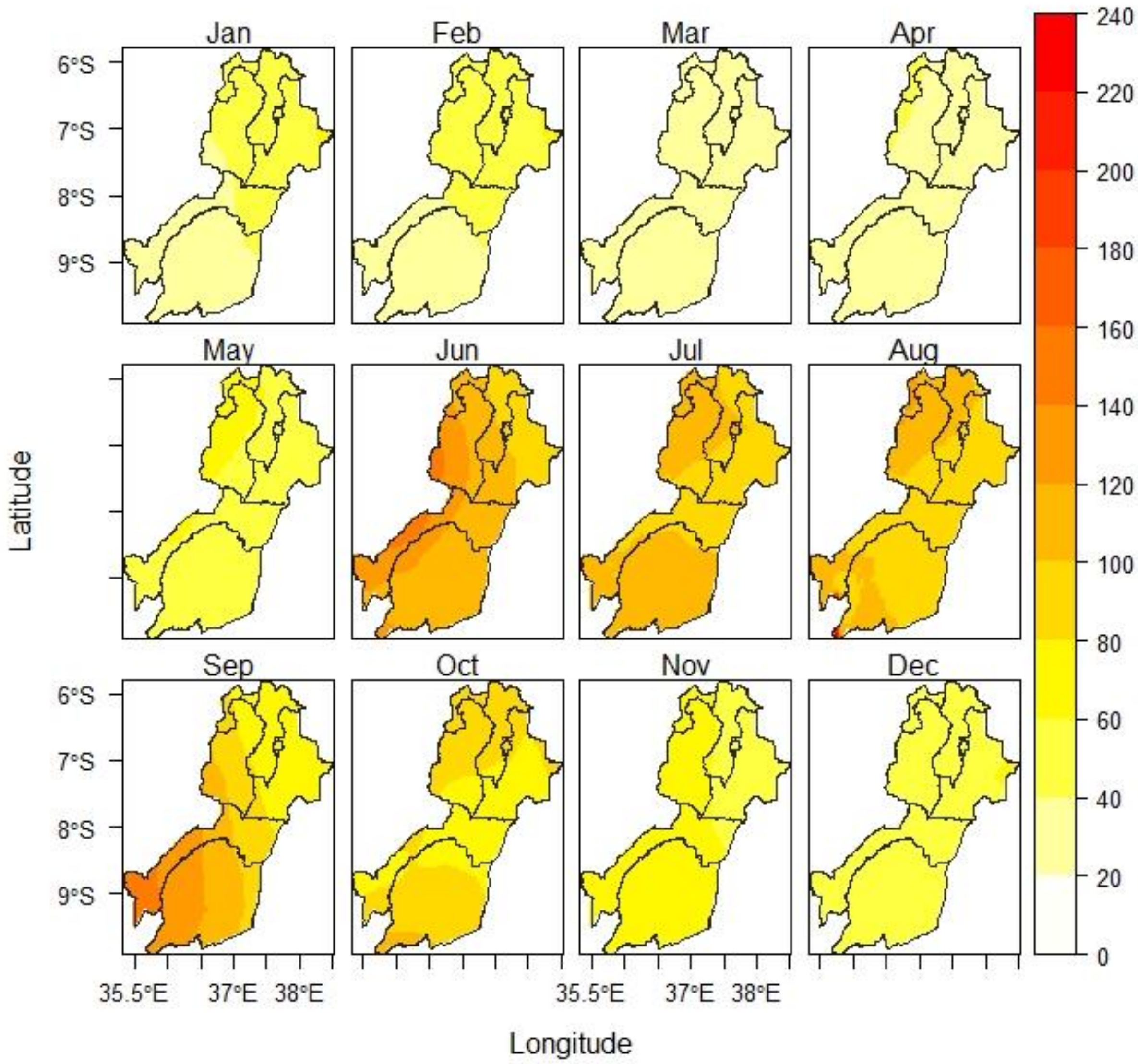

Figure 4.8 Coefficient of variation (%) in monthly rainfall (1988-2018) in Morogoro region

4.5 Long-term trends in rainfall, maximum temperature and minimum temperature

4.5.1 Long-term trends in annual and monthly rainfall

Results of trend analysis in rainfall revealed spatial temporal trends in annual and monthly rainfall with significant increase or decrease in different areas of Morogoro region. Figure 4.9 represents the trend in annual rainfall where figure 4.9(a) shows the Theil-Sen's slope for annual rainfall while figure 4.9(b) shows places where it was significant. Generally annual rainfall in Morogoro region showed a declining trend from -2 to -16mmyear^{-1}. Results also reveal that Kilombero, Ulanga and Morogoro rural are the areas which have experienced a higher decrease in annual rainfall. The decreasing trend in annual rainfall was significant ($p < 0.1$) in most locations with only few areas in the north and south of Morogoro revealing non-significant trend.

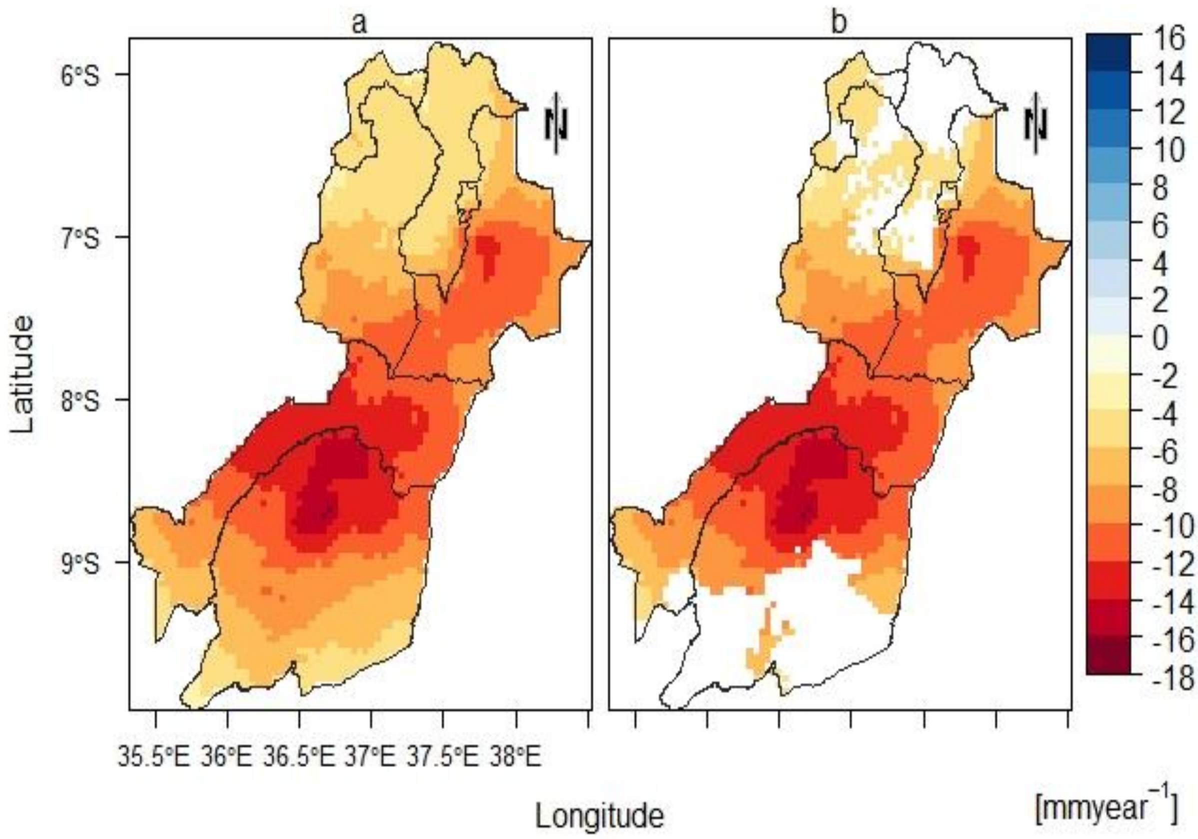

Figure 4.9 Long-term trends in annual rainfall(mmyear-1) in Morogoro for 1988 to 2018(a) and zones with significant increase of decrease in rainfall(b)

Monthly rainfall for Morogoro region also showed varied spatial temporal trends. Figure 4.10 shows the monthly trends in rainfall while Figure 4.11 shows the locations in which the slopes were significant ($p < 0.1$). Results reveal that some locations in Morogoro region experienced an increase trend in rainfall for the months April, September, October to December of about 1mmyear^{-1}. A high decreasing trend in monthly rainfall was experienced in the months January to March (JFM) ranging from -1 to -8mmyear^{-1} while in other months there was only a slight decrease in rainfall. Significant decrease in monthly rainfall was experienced in some locations in Morogoro region for the months January to May.

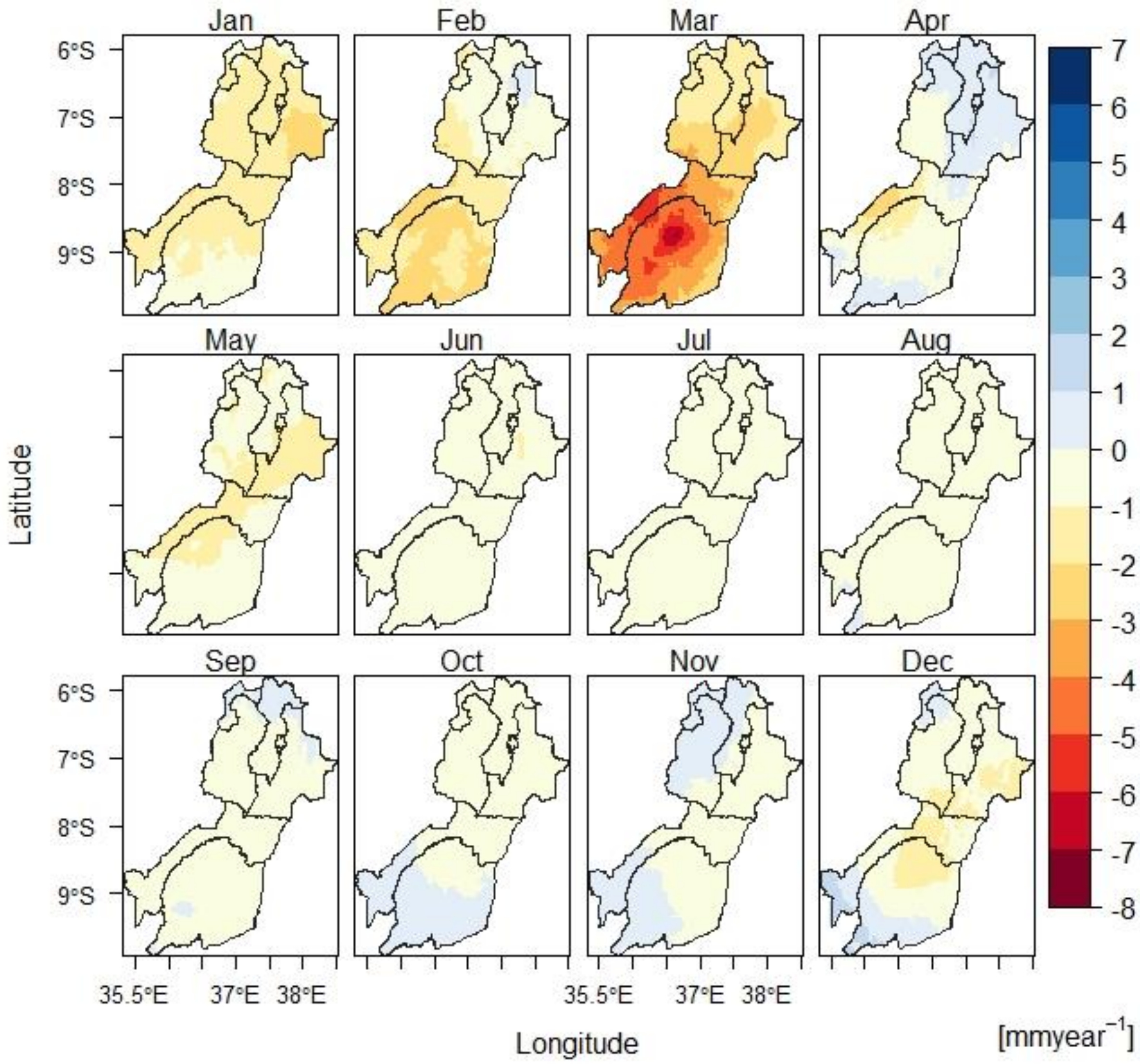

Figure 4.10 Long-term trends in monthly rainfall(mmyear-1) for 1988-2018 in Morogoro region

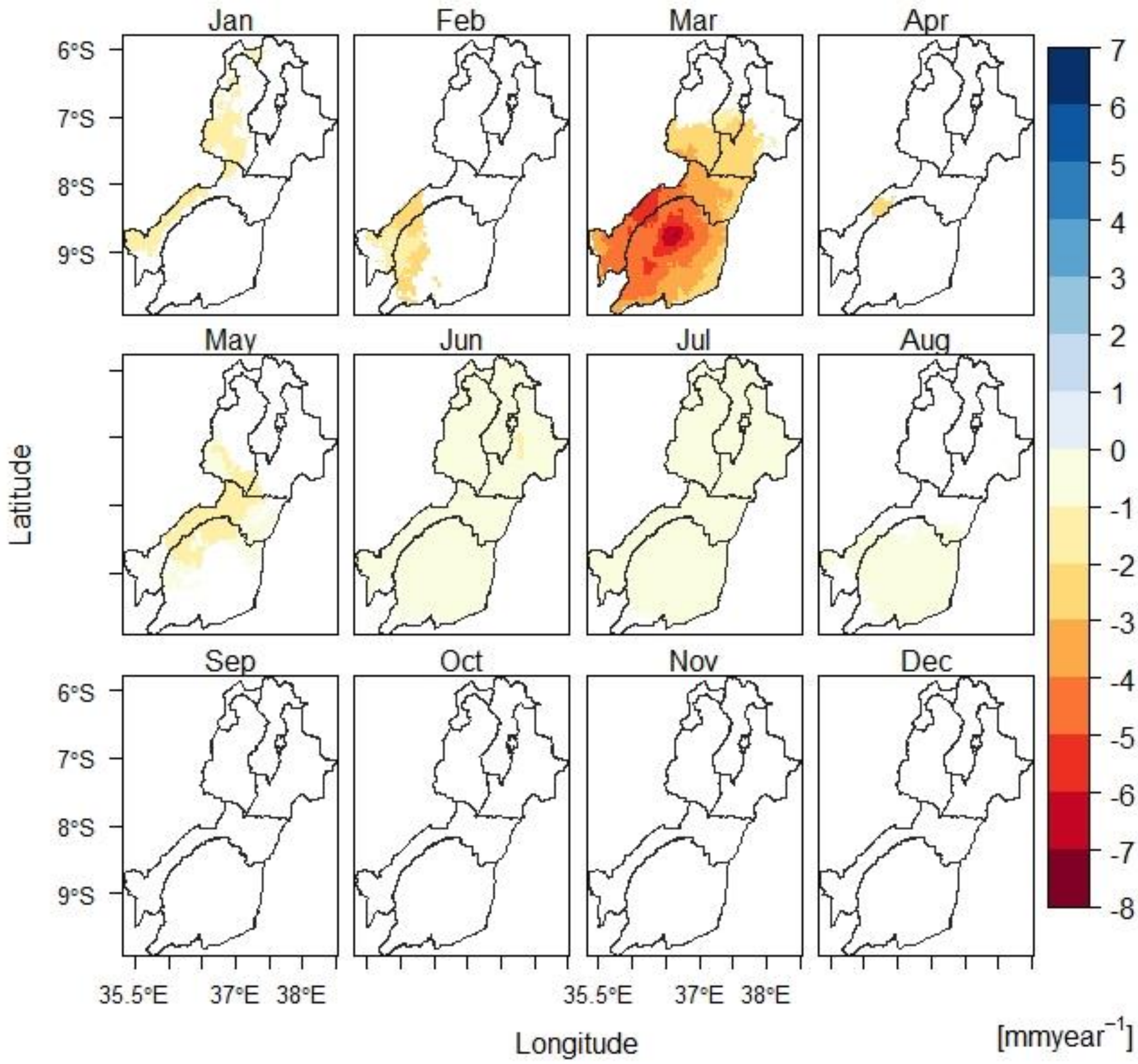

Figure 4.11 Significant (p<0.1) trends for monthly rainfall (1988-2018) in Morogoro

Trend analysis of annual maximum temperature revealed that most areas in Morogoro experienced a significant ($p < 0.1$) Increase in maximum temperature. Figure 4.12 (a) shows the slope where by Morogoro is observed to experience an increase of maximum temperature from 0.005 to 0.025℃ $year^{-1}$. Northern part of Morogoro experienced a much higher increase than the southern part. The locations that experienced significant trends in annual maximum temperature are presented in figure 4.12 (b) in which reveals that in almost all locations the trend was significant.

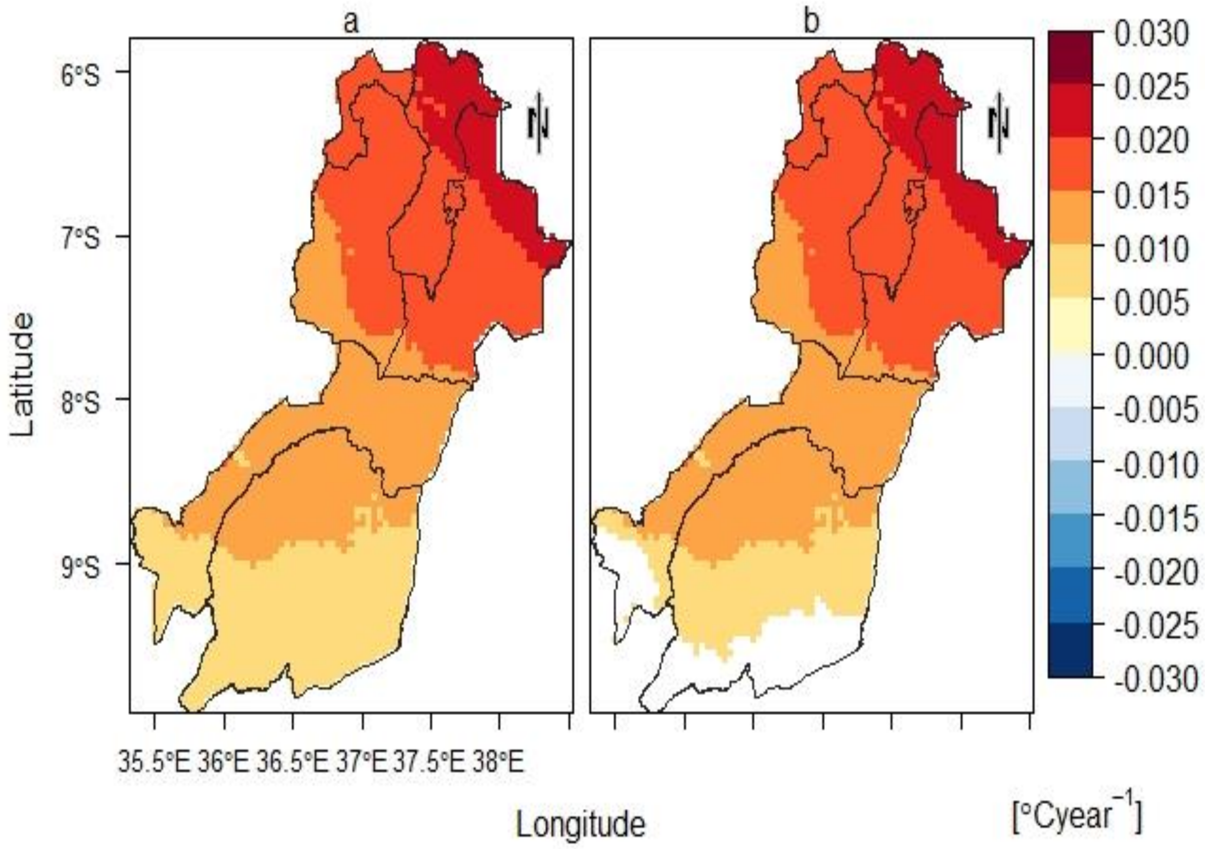

Figure 4.12 Trends in annual maximum temperature(a) and zones with significant trends(b) for 1988-2018 in Morogoro

Similarly results from the analysis of monthly maximum temperature revealed that there were increasing and decreasing trends. Figure 4.13 shows the slope of the trend where by March to May (MAM) showed a high decreasing trend of monthly maximum temperature from -0.01 to -0.06°C $year^{-1}$. The months that experienced most increase in monthly maximum temperature were August, October to December (OND) where the values ranged between 0 to 0.06°C $year^{-1}$. Figure 4.14 shows the locations where the trend was significant.

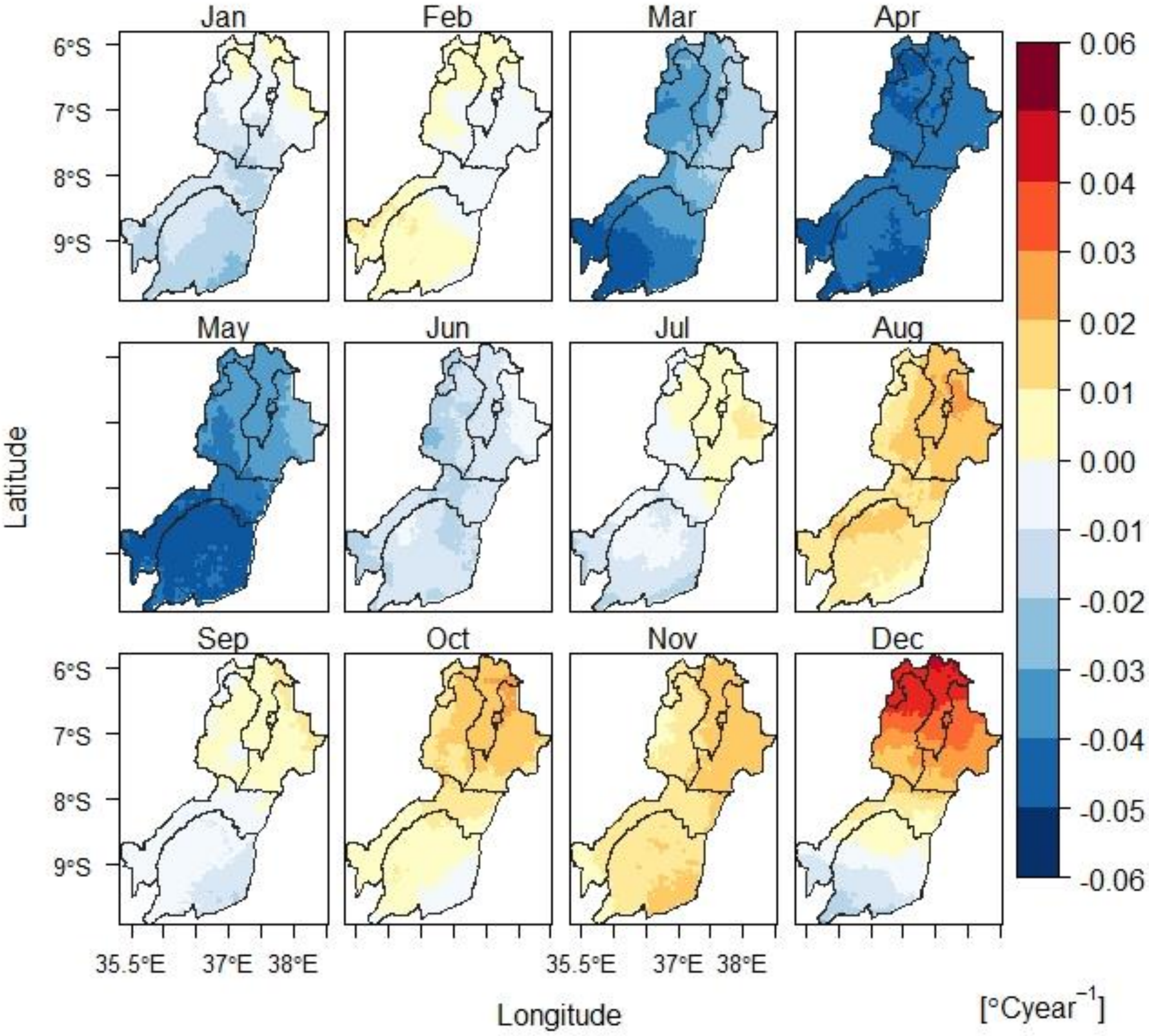

Figure 4.13 Trends in monthly maximum temperature for 1988-2018 in Morogoro

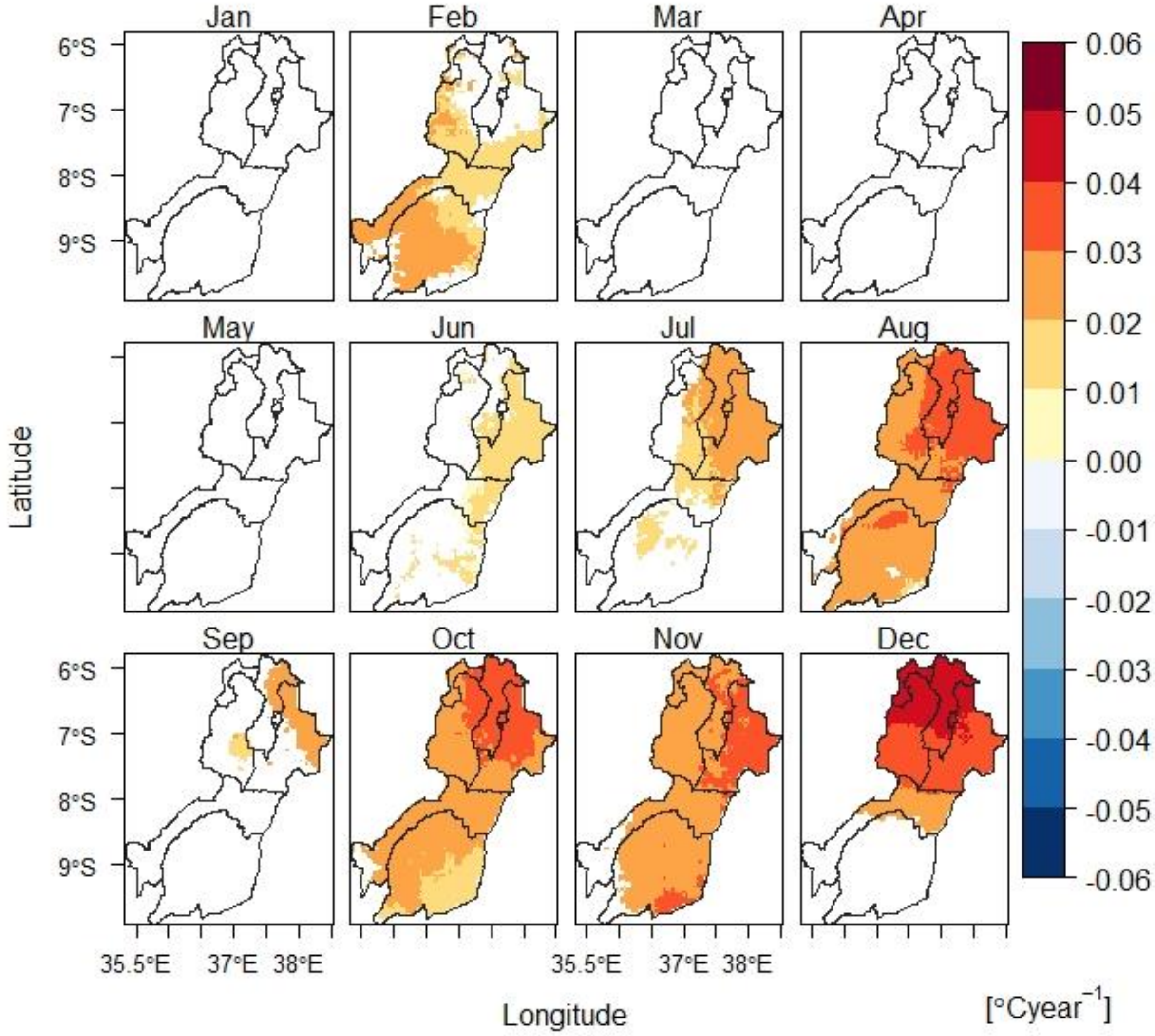

Figure 4.14 Significant trends in monthly maximum temperature for 1988-2018 in Morogoro

4.5.2 Long-term trends in annual and monthly minimum temperature

Results from analyzing the annual minimum temperature revealed varying spatial temporal trends. Figure 4.15(a) shows the slope of trend where by Morogoro is observed to experience an increase of minimum temperature between 0.010 to $0.030°\text{C}\ year^{-1}$. Northern part of Morogoro experienced a much higher increase than the southern part. Figure 4.15(b) represents the areas where the slope was significant.

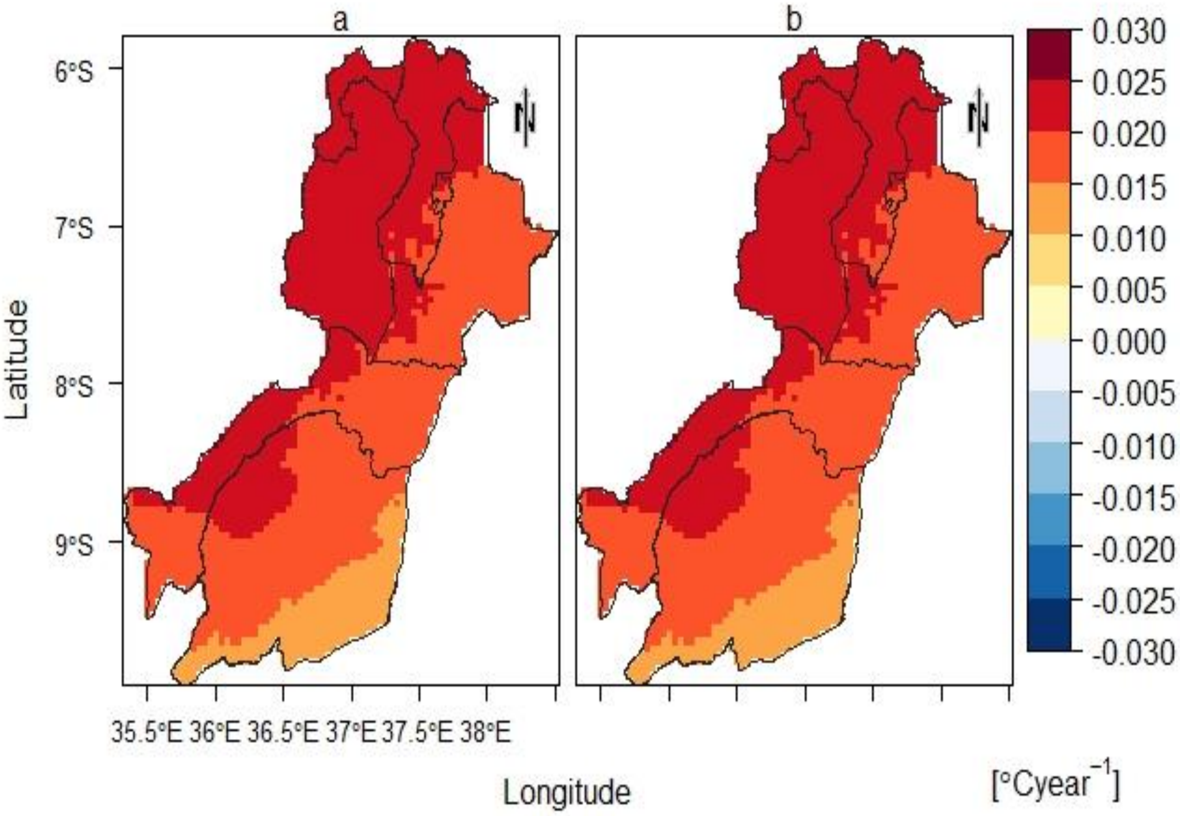

Figure 4.15 Trends in annual minimum temperature(a) and zones with significant trends(b) for 1988-2018 in Morogoro

Analysis of monthly minimum temperature also revealed spatial temporal trends, in which figure 4.16 represents the slope whereby there is a high decreasing trend in months March to May(MAM) at range from $-0.01 \text{ to} - 0.06$ ℃ $year^{-1}$ and for months October to December(OND) there is high increasing trend ranging between $0 \text{ and } 0.06$℃ $year^{-1}$. Figure 4.17 shows the locations where the monthly trend in minimum temperature was significant ($p < 0.1$).

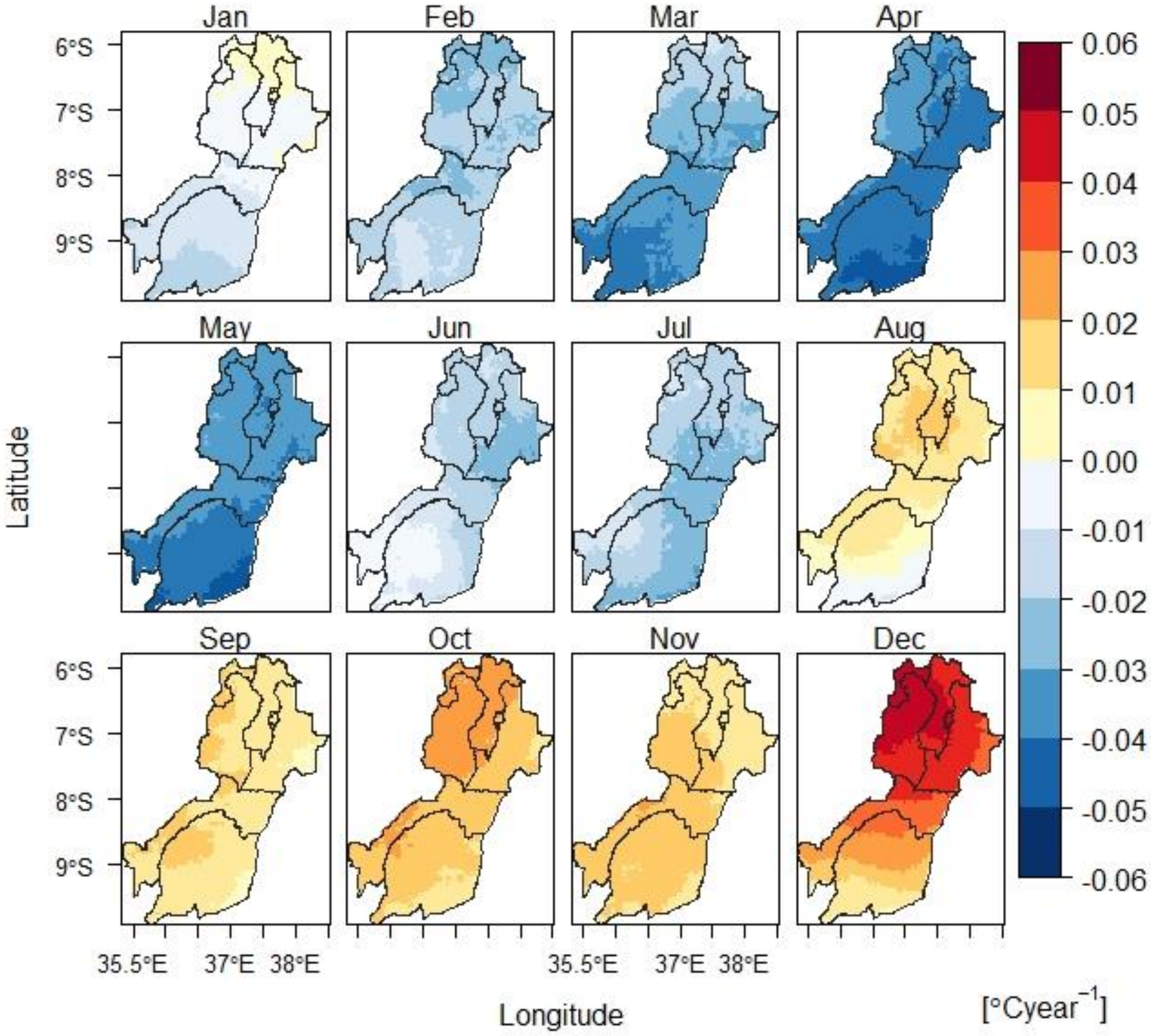

Figure 4.16 Trends in monthly minimum temperature for 1988-2018 in Morogoro

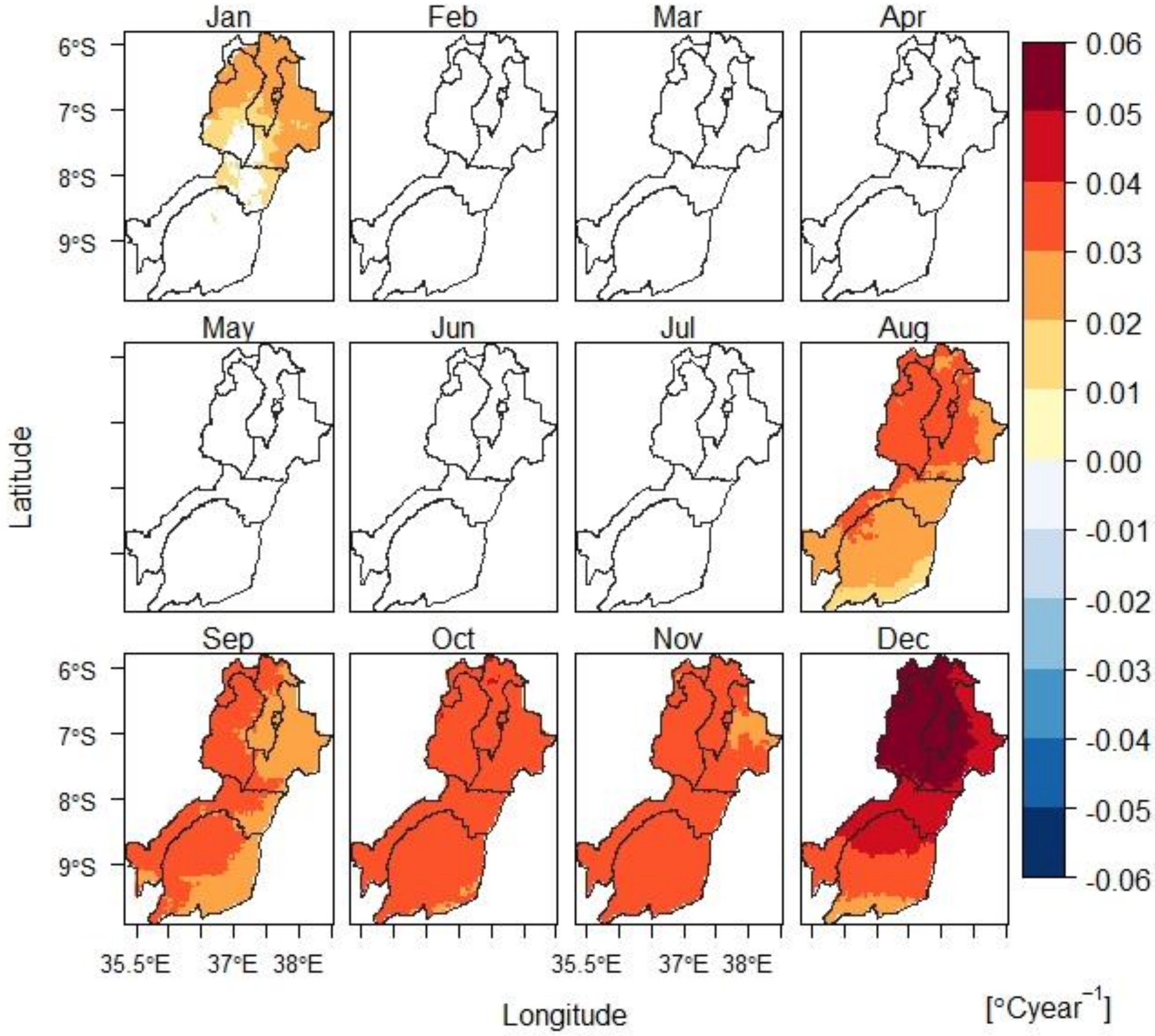

Figure 4.17 Significant trends in monthly minimum temperature for 1988-2018 in Morogoro

4.6 Discussion

The research objective required the use of trend results of rainfall and temperature to support suitable adaptation strategies in agriculture. In order for that to be achieved there was a need of reviewing some of the current available adaptation strategies in relation to the production or yield per hectare in specific crop, in which for this study paddy(rice) production was chosen because according to FAO is the second most grown crops in the region and also productivity in the country is low leading to food insecurity due to the impacts of climate change. The research analyzed the yields of rice(paddy) from the year 1999 to 2010 in relation to the extracted mean annual rainfall (Figure 4.18), mean annual maximum temperature (Figure 4.19) and mean annual minimum temperature (Figure 4.20). The year 2003 was seen to have the lowest amount of yield in tonnes/hectare(ha) which concurs with the mean annual rainfall for the year 2003 that was observed to have low amount of rainfall. The mean annual maximum and minimum temperature for the year 2003 was also observed to be high which explains that high temperature negatively affect production. In the year 2006 yield in rice was high which also corresponds to mean annual rainfall anomalies for 2006 in which Morogoro experienced high rainfall amounts which indicates increase in rainfall leads to increase in production. The mean annual maximum and minimum temperatures for the year 2006 were observed to be low which indicates that when temperature levels are not high production increases.

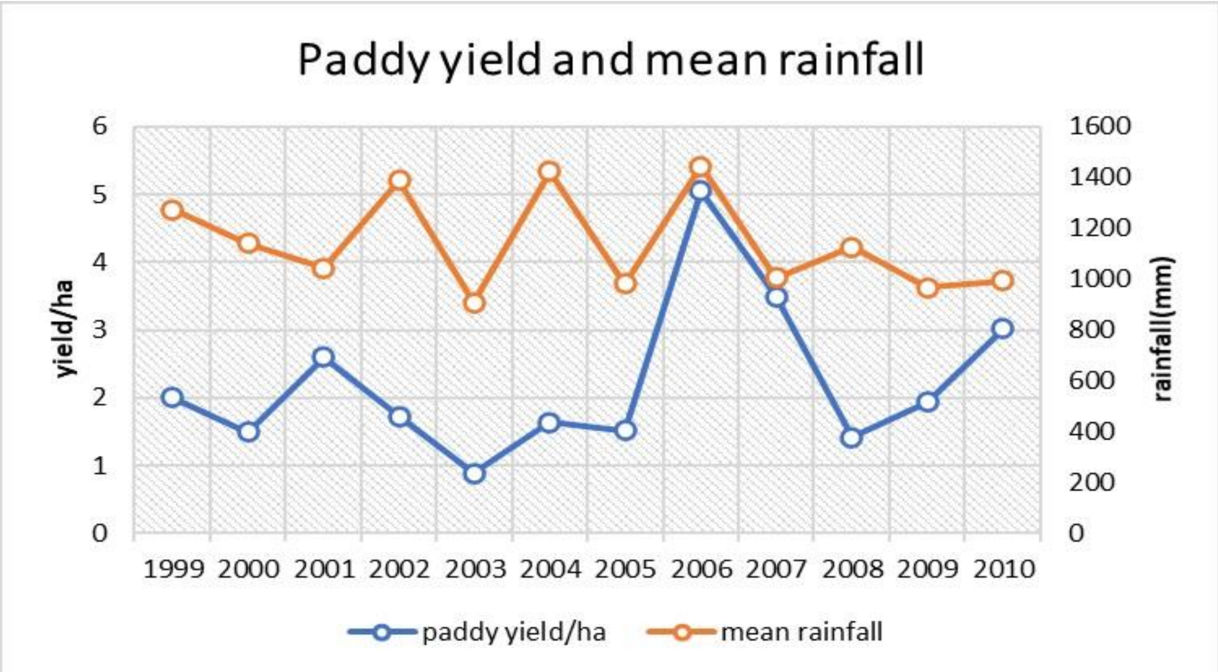

Figure 4.18 Paddy yield in tonnes/hectare and mean annual rainfall

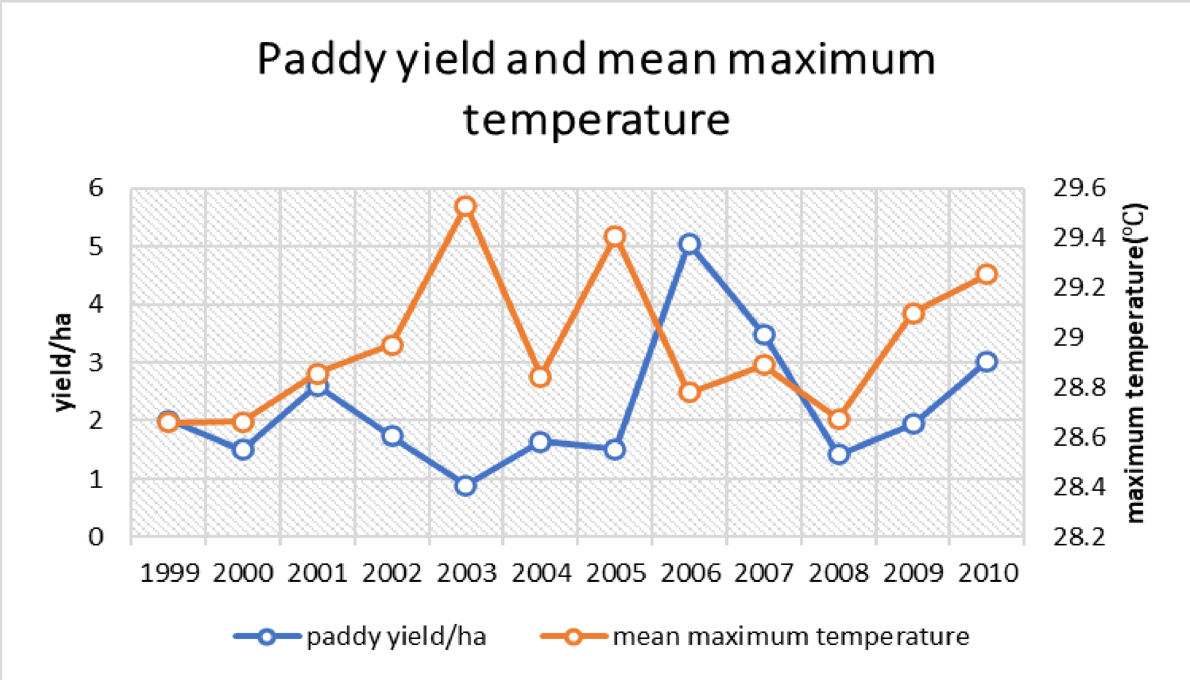

Figure 4.19 Paddy yield in tonnes/hectare and mean annual maximum temperature

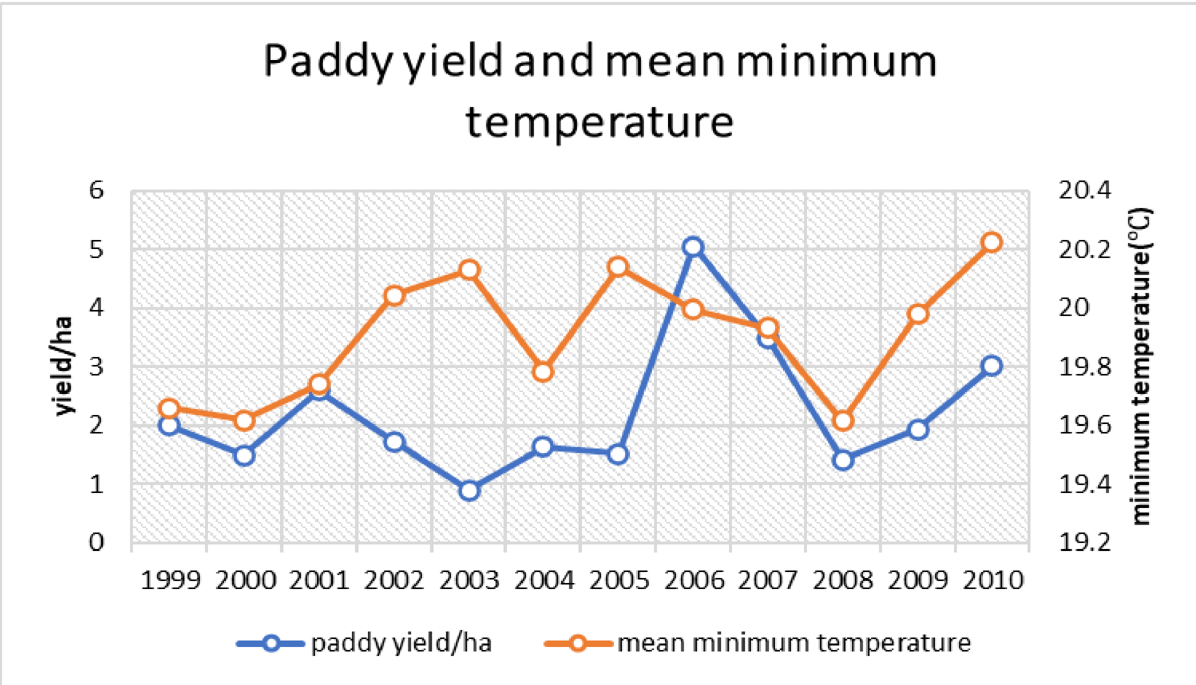

Figure 4.20 Paddy yield in tonnes/hectare and mean annual minimum temperature

For the case of trends in rainfall, the annual rainfall was found to fall at range of $-2 \text{ to} - 16\text{mmyear}^{-1}$ which means that in 31years(1988-2018) annual rainfall has declined at range of -62 to -496mm in Morogoro which indicates there is a need to put efforts on adaptation strategies so as to cope with the effects of such changes given that rice or paddy requires much more water than any other crop. Likewise, for the case of monthly rainfall results revealed that there is a fall in rainfall at range of $-1 \text{ to} - 8\text{mmyear}^{-1}$ which is about a fall of -31 to -248mm of rain in 31 years.

Maximum and minimum temperatures of the region was found to rise in the 31years (1988-2018). Temperature was observed to rise at range of $0.005 \text{ to } 0.025℃\, year^{-1}$ for maximum temperature and $0.010 \text{ to } 0.030℃\, year^{-1}$ for minimum temperature, which means that maximum temperature rose at range of $0.155 \text{ to } 0.775℃$ in 31 years (1988-2018) and minimum temperature rose at range of $0.31 \text{ to } 0.93℃$. This indicates that as time goes these temperatures are increasing which is likely going to affect agricultural production since maximum temperatures optimal amounts are important for the growth and development of the crop and minimum temperature are crucial for the germination of the crop seed. For the monthly maximum and minimum temperatures results revealed that there is significant rise in months August to December.

There are a number of adaptation strategies that have been identified by various authors as a means of coping with impacts of climate changes on agricultural production. (Balama, et al., 2013) research in Kilombero district in Morogoro identified various strategies employed which are crop diversification, changing cropping calender year and adopting modern farming techniques. Another common adaptation strategy is through irrigation and use of soil and water conservation systems.All these adaptation strategies identified can be adapted in other parts of the region to cope with the impacts of climate change in agriculture. Considering the changes in rainfall, maximum and minimum tempearature in relation to the yield in rice which according to FAO is generally low there is a need of improving and increasing efforts on the implementation of adaptation strategies so as to ensure food security in Morogoro and Tanzania in general.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The analysis of spatial temporal trends in climate variables such as rainfall, maximum temperature and minimum temperature play a crucial role in developing and improving adaptations strategies in various sectors such as agriculture. This study has been able to reveal that rainfall has been decreasing significantly and that both maximum and minimum temperature has been increasing thereby negatively affecting the agricultural sector in terms of production. The study analyzed the condition of rice production and identified some of the adaptation strategies which could be improved as a means of coping with the effects of climate changes. The identified strategies include changing cropping calendar year, using modern farming techniques and adaptation through irrigation and adaptation through soil and water conservation techniques.

5.2 Recommendation

This study in view of the findings and conclusion made recommends the following

Further studies should be conducted to analyze the trends of rainfall and temperature using indices i.e. total rainfall amount, consecutive dry days, consecutive wet days and simple daily intensity which will further describe the changes and assist in improving adaptation strategies in agriculture. The government working together with the local authorities to utilize results on trends of rainfall and temperature attained in this research to ensure effectiveness of implementation of climate change adaptation strategies in agriculture such as the use of modern farming techniques, improved seed varieties, changing cropping calendar year and adaptation through soil and water conservation techniques so as to minimize the impacts of changes in rainfall and temperature which play a big role in agricultural production.

REFERENCES

Akinnagbe, O. M., & Irohibe, I. J. (2015). Agricultural adaptation strategies to climate change impacts in Africa: a review. *Bangladesh J. Agril. Res. 39(3)*, 407-418.

Arndt, C., Farmer, W., Strzepek, K., & Thurlow, J. (2012). *Climate Change, Agriculture and Food Security in Tanzania.* Agriculture and Rural Development Team, Development Research Group.

Bakari, M. S. (2015). *Climate Change Impacts and adaptation strategies of small scale agriculture production in Michiweni District Pemba, Tanzania.*

Balama, C., Augustino, S., Eriksen, S., Makonda, F. S., & Amanzi, N. (2013). Climate Change Adaptation Strategies by Local farmers in Kilombero District, Tanzania. *Ethiopian Journal of Environmental Studies and Management Vol. 6 Supplement 2013* , 724-736.

Chang'a, L. B., Kijazi, A. L., Luhunga, P. M., Ng'ongolo, H. K., & Mtongori, H. I. (2017). Spatial and Temporal Analysis of Rainfall and Temperature Extreme Indices in Tanzania. *Atmospheric and Climate Sciences,7*, 525-539.

Downing, T. (2002). Protecting the Vulnerable: Climate Change and Food Security.. In J. C.Briden, and T. E. Downing (eds). *Managing the Earth: The Linacre Lectures.Oxford: Oxford University Press*, 5-34.

Gebrechorkos, S. H., Hülsmann , S., & Bernhofer, C. (2019). Long-term trends in rainfall and temperature using high-resolution climate datasets in East Africa. *Scientific reports 9, 11376*, 1-9.

Gebrechorkos, S. H., Hülsmann, S., & Bernhofer, C. (2018). Changes in temperature and precipitation extremes in Ethiopia,Kenya, and Tanzania. *International Journal of Climatology*, 18-30.

Häckner, L. (2009). *Climate Change and Agriculture in Babati Awareness Strategies Constraints.* Huddinge municipality: Södertörns University Collage.

Hamed, K. H., & Rao, A. R. (1998). A modified Mann-Kendall trend test for autocorrelated data. *Journal of Hydrology 204*, 182-196.

Hepworth, N. (2010). *Climate Change Vulnerability and Adaptation Preparedness in Tanzania.* Nairobi, Kenya: Heinrich Böll Foundation.

IPCC, I. P. (2007). *CLIMATE CHANGE, Impacts, Adaptation and Vulnerability Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* .

Kahimba, F. C., Sife, A. S., Maliondo, S. M., Mpeta, E. J., & Olson, J. (2015). Climate Change and Food Security in Tanzania: Analysis of Current Knowledge and Research Gaps. *Tanzania Journal of Agricultural Sciences Vol.14 No. 1*, 21-33.

Kangalawe, R. Y., & Lyimo, J. G. (2013). Climate Change, Adaptive Strategies and Rural Livelihoods in Semiarid Tanzania. *Narural Resources*, 266-278.

Lema, M. A. (2009). Impacts of climate change, variability and adaptation strategies on agriculture in semi arid areas of Tanzania:The case of Manyoni District in Singida Region,Tanzania. *African Journal of Environmental Science and Technology Vol. 3*, 206-218.

Maddison, D. (2006). *The Perception of and Adaptation to Climate Change in Africa. CEEPA Discussion Paper No.10.* Centre for Environmental Economics and Policy in Africa, University of Pretoria, South Africa. .

Mahoo, H. F., Young, M. D., & Mzirai, O. B. (1999). Rainfall Variability and its implication for the Transferability of Experimental Results in the Semi Arid Areas of Tanzania. *Tanzania J. Agric.Sc. Vol. 2*, 127-140.

Mngumi, J. (2016). *Perceptions of climate change, environmental variability and the role of agricultural adaptation by small scale farmers in Africa: the case of Mwanga district in northern Tanzania.PhD.thesis.* Scotland: University of Glasgow.

Mongi, H., Majule, A. E., & Lyimo, J. G. (2010). Vulnerability and adaptation of rain fed agriculture to climate change and variability in semi-arid Tanzania. *African Journal of Environmental Science and Technology Vol. 4(6)*, 371-381.

Munishi, P. K. (2009). *Analysis of Climate Change and its Impacts on Productive Sectors, Particularly Agriculture in Tanzania.* Morogoro: Sokoine University of Agriculture.

Muthoni, F. K., Odongo, V. O., Ochieng , J., Mugalavai, E. M., Mourice, S. K., Zeledon, I. H., . . . Bekunda, M. (2018). Long-term spatial-temporal trends and variability of rainfall over Eastern and Southern Africa. *Theoretical and Applied Climatology (2019) 137*, 1869-1882.

NAPA. (2006). *National Adaptation Programme of Action.*

Paavola, J. (2004). Livelihoods, vulnerability and adaptation to climate change in the Morogoro region, Tanzania. *CSERGE Working Paper EDM, No.04-12*.

Pohlert, T. (2015). *Non-Parametric Trend Tests and Change-Point Detection, R package version 0.0.1.10.13140/RG.2.1.2633.4243.*

Prof.Majule, A. E., Rioux, J., Mpanda, M., & Karttunen, K. (2014). *Review of Climate Change Mitigation in Agriculture in Tanzania.* FAO.

Rao, P. P., & Legesse, S. A. (2013). Trend Analysis and Adaptation Strategies of Climate Change in North Central Ethiopia. *International Journal of Agricultural Science and Research(IJASR) vol3 ,issue 1*, 253-262.

Shaftel, H., Jackson, R., Callery, S., & Bailey, D. (2020, August 25). *Global Climate Change Vital Signs of the Planet*. Retrieved from NASA: https://climate.nasa.gov/solutions/adaptation-mitigation/

Shrestha, R. P., Raut, N., Swe, L. M., & Tieng, T. (2018). Climate Change Adaptation Strategies in Agriculture: Cases from Southeast Asia. *Sustainable Agriculture Research; Vol. 7, No. 3; 2018*, 39-51.

Sivakumar, M. V., Das, H. P., & Brunni, O. (2005). Impacts of present and future climate variability and change on agriculture and forestry in the arid and semi-arid tropics. *Climate Change ,70*, 31-72.

Sonali, P., & Kumar, N. (2013). Review of trend detection methods and their application to detect temperature changes in India. *Journal of hydrology*, 212-227.

Teshome, Z. (2019). Increase of Extreme Drought over Ethiopia under Climate Warming. *Advances in Meteorology volume 2019, Article ID 5235429, 18 pages*.

URT. (2007). *National sample census of Agriculture Volume Ve: Regional report : Morogoro Region.*

URT. (2017). *2016/17 Annual Agriculture Sample Survey Initial Report.*

Wilson, R. C., Drury, S. A., & Chapman, J. L. (2000). *The Great Ice Age Climate Change and life.* London: Routledge.

Yue, S., & Wang, C. (2004). The Mann-Kendall Test Modified by Effective Sample size to Detect Trend in Serially Correlated Hydrological Series. *Water Resources Management 18:*, 201-218.

APPENDICES

Appendix 1: Paddy yield in tonnes per hectare from year 1999 to 2010

Year	Paddy yield(tonnes/ha)
1999	2
2000	1.5
2001	2.6
2002	1.7333
2003	0.89312
2004	1.6431
2005	1.51704
2006	5.05
2007	3.49
2008	1.42
2009	1.94
2010	3.02

Source: https://www.kilimo.go.tz/index.php/en/resources/category/statistics

Appendix 2: Extracted time series mean annual rainfall and temperature (1999-2010)

Year	mean rainfall (mm)	mean maximum temperature (°C)	mean minimum temperature (°C)
1999	1274.203	28.65934	19.66017
2000	1142.125	28.66215	19.61796
2001	1042.928	28.8561	19.74021
2002	1387.951	28.97219	20.04393
2003	908.5497	29.52872	20.13091
2004	1423.322	28.84493	19.78577
2005	980.742	29.40809	20.14018
2006	1444.35	28.78147	19.99523
2007	1006.301	28.89001	19.93204
2008	1124.874	28.67382	19.61676
2009	968.4828	29.09944	19.97972
2010	992.7853	29.25175	20.22325