University of Nairobi
Faculty of Engineering

DEPARTMENT OF GEOSPATIAL AND SPACE TECHNOLOGY

Assessing Climate Variability in Wajir County using Remote Sensing

By

Maryan Sheikh Ali

F56/38053/2020

Research submitted for the Degree of Master of Science in Geographic Information Systems, in the Department of Geospatial and Space Technology of the University of Nairobi

July 2022

DECLRATION

I, Maryan Sheikh Ali, hereby that this project is my original work. To the best of my knowledge, the work presented here has not been presented for a degree in any other university.

STUDENT:

Maryan Sheikh Ali - F56/38053/2020:

SIGNATURE…Maryan DATE…26th of July 2022…….

This Project report is submitted with our approval as University supervisor:

<u>SUPERVISOR:</u>

Prof. Dr.-Ing. John Bosco Kyalo Kiema:

SIGNATUR Kyalo Kiema ……. DATE……28th July 2022…...…………….

July 2022

DEDICATION

This research project is dedicated to my parents, siblings, friends, supervisor, fellow classmates, and colleagues who have been extremely supportive throughout the process. Thank you so much to everyone.

ACKNOWLEDGEMENTS

First and foremost, I give thanks to the Almighty God for my health, grace, and blessing throughout this process. Second, I'd like to thank my supervisor, Prof. Dr.-Ing. John Bosco Kyalo Kiema, for his outstanding commitment, guidance, and understanding in assisting me in meeting my goal for this project report. Third, I'd like to express my gratitude to the entire Department of Geospatial and Space Technology for their assistance in completing this course during the global pandemic.

Finally, I'd like to express my gratitude to my family, friends, colleagues, and classmates for their emotional and physical support throughout this time.

Declaration of Originality

Name of student: Maryan Sheikh Ali
Registration: F56/38056/2020
Faculty/School/Institute: Faculty of Engineering
Department: Geospatial and Space Technology
Course Name: Research Project
Title of work: Assessing Impact of Climate Variability in Wajir County using Remote Sensing

1) I understand what plagiarism is and I'm aware of the university policy in this regard
2) I declare that this research proposal is my original work and has not been submitted elsewhere for examination, award of a degree or publication. Where other works or my own work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi's requirements
3) I have not sought or used the services of any professional agencies to produce this work
4) I have not allowed, and shall not allow anyone to copy my work with the intention of passing it off as his/her work
5) I understand that any false claim in respect of this work shall result in disciplinary action in accordance with University of Nairobi anti-plagiarism policy

Signature: Maryan

Date: 26th of July 2022

Turn it in report summary

<u>STUDENT:</u>

Maryan Sheikh Ali - F56/38053/2020:

SIGNATURE…Maryan DATE…26th of July 2022…….

<u>SUPERVISOR:</u>

Prof. Dr.-Ing. John Bosco Kyalo Kiema:

SIGNATURE Kyalo Kiema DATE……28th July 2022……….

Assessing Climate Variability in Wajir County using Remote Sensing

ORIGINALITY REPORT

11%	10%	5%	7%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

Table of Contents

List of Figures

Abstract

This study is aimed at assessing climate variability on drought in Wajir County using Remote Sensing techniques. Climate variation is one of the factors being assessed with regards to how they affect the drought status of the county. The county faces challenges, especially when it comes to precipitation and temperatures that later affect the drought levels in the county. The main objective of the study is to assess climate variables on drought in the county. Specifically, the study seeks to: assess and analyse the trends of different climate variables; understand how climate change affects the land use land cover and its impact on the drought index of the county.

To monitor drought in the study area three main indices are mapped including: vegetation index, this involves the greenness or the crop yield capability of different parts of the County, climate indices where climatic variables are used, these are: rainfall, temperature and evapotranspiration. Evapotranspiration values are used to generate the soil moisture content. Soil moisture detects the wetness or dryness of the ground, and hydrological index where flow accumulation was detected. Correlation Analysis is done between the three indices resulting in maps that represent drought severity indices. Variation of the different climate variables resulted to different interpretations of drought indices.

According to the selected indices done in the study, i.e., climatic indices, vegetation indices and hydrological indices, Wajir County lies between Slightly wet and extreme drought of the Palmers Drought Severity Indices. These indices relate to the condition of drought in Wajir County. Currently, the horn of Africa has been identified to be one of the areas that is severely drought stricken hence the need for the study. The study seeks to identify the condition of drought in the study area, and this was achieved using the use of GIS and Remote Sensing Techniques.

CHAPTER ONE: INTRODUCTION

1.1. Background

Kenya is one of the countries in the Horn of Africa that experience acute food shortages in drought periods of the year. Counties in northern Kenya, including Wajir, rely on pastoralism as the primary source of livelihood. This is because the land cannot support rain-fed agriculture. However, the counties face existential livelihood threats from climate change. The effects of climate change are felt in the economic, environmental and human spheres, whose costs are borne by the communities in this region as the survival of the communities' livestock is solely dependent on prevailing weather patterns (Bardsley & Wiseman, 2012). Recently, the region has faced unprecedented droughts, floods, and locust invasions, all which have contributed to climate variability.

Studies have shown a strong correlation between climate variability, particularly drought and poverty. When droughts occur, water and pasture dry up, forcing communities to destock due to fear of losses from deaths (Qutbudin et al., 2019). As a mitigation mechanism, farmers are forced to move to other areas with better water and pastures, heightening the risk of disease and inter-community conflicts. As a result, communities become vulnerable to food shortages, on top of the economic impacts.

Subsequent effects of drought continue to impact a large proportion of communities in pastoralist areas of Eastern Kenya. In the first month of 2022, the Food and Agricultural Organization (FAO) released a new report highlighting the near-catastrophe situation in the Horn of Africa. The report shows that three countries in the region-Kenya, Ethiopia and Somalia area facing an acute 'La Nina' induced drought, the third in a decade (FAO, 2022). The report calls for an urgent humanitarian assistance lest the region plunges into a humanitarian catastrophe, in addition to the civil strife in the areas and the effects of Covid-19. Apart from depleting food, water and pastures, drought also disrupts markets, causing localised inflation on food commodities. In its extreme form, drought is likely to result to direct human deaths (FAO, 2022). In the 2010/2011 episode of the drought, it was estimated that 1.4 million pastoralists in Kenya were directly affected (Wheeler, 2022). In the report, the Kenya Food Steering Group (KFSG) indicated that the drought not only led to decline of livestock production, but caused acute food scarcity, and precipitated rapid livestock morbidity and mortality. KFSG was formed in 1998 as a multi-agency group, coordinated by the World Food Programme (WFP) with membership including the Kenyan Government and like-minded Non-governmental Organizations (NGOs) to provide early warning systems on food security (Wheeler, 2022).

At the same time Covid-19 was being declared a global health emergency in 2020, the same region [Horn of Africa] was grappling with locust infestation. Before this addition, the region was already a known food-insecure region as a result of unprecedented flooding and elongated droughts. In this episode of locust infestation, FAO (2022) estimated that 2.5 million people were affected in 2020 and a million more in 2021 as a direct effect of locusts. As a result, the agency was forced to mount a high decibel donation campaign to mitigate these effects. Consequently, 1.7 billion U.S dollars were used to treat 2 million hectares of land from locust invasion, protect 40 million livelihoods and directly supported four million people in the hard-hit areas (FAO, 2022). Whereas locust's clear vegetation equivalent to their body weight, the effects are felt by both the communities and the livestock. Food crops as well as pastures are destroyed in the process, exacerbating the food crisis.

Past efforts to mitigate climate variability include formation of several steering committees to act as sources of information. For instance, the KFSG was formed as a result of uncoordinated and inconsistent early warning reports from two donors Agencies-Brought Drought, Preparedness, Intervention and Recovery Project (DPIRP) and Arid Lands Resource Management Programme (ALRMP) (Wheeler, 2022). The formation of KFSG was accompanied with formation of Geographic Review Teams (GRTs) that met monthly to give localised early warning systems. Current efforts to check climate variability are coordinated by among others, the Kenya Meteorological Department (KMD).

As a government agency, KMD is primarily charged with issuing weather forecasts for the whole country. This means that the responsibility of tracking climate variability is dependent on non-governmental organizations because the endeavour is resource-intensive and time consuming. For tracking of the trends and variation of Climate characteristics, there is need to integrate modern technology to track impacts of climate variability. This project proposes to adopt remote sensing technology as an impact assessment tool in Northern Kenya. As a modern technology, remote sensing can monitor soil moisture, changes in grassland, and moisture content to track changes over time.

1.2. Statement of the problem

Climate change is buzzword that has been used for decades to generally describe noticeable changes in atmospheric conditions. While the debate on climate variability has been carried out mostly at a national level, the real variation of climate change at the local level has been largely ignored. As climate variation takes long periods of time, current generations can hardly tell the difference between what is happening currently and how the situation used to be in the past. This can partly be attributed to lack of indigenous knowledge information systems that generations can use as a point of comparison. This means that the debate on climate change remains among the elite, despite its visible debilitating effects.

Past efforts to track climate variability and early warning systems have borne little to no fruits. As a result, communities continue to face uncertain future, characterised by untimely rainfall seasons, floods, locust invasions characterised by acute food shortages, and economic depravity. Wajir county is one of the Northern Frontier counties, in the heart of pastoralist communities of Kenya. Like other neighbouring counties, Wajir has suffered massive losses as a result of climate variability.

The reliance on national institutions such as the Kenya National Meteorological Department (KMD) and other forecast agencies has proved inadequate information for mitigation against changes in climate for specific regions. Furthermore, KMD provides day-to-day weather conditions that one can hardly use to track climate variability.

However, advancements in technology can now provide localised climate changes. Such technologies such as the use of remote sensing to assess climate variability and develop early warning systems can provide near real-time information. The information can be on such variables as changes in vegetation, soil moisture and an areas moisture level and compare with similar periods in the past. However, counties such as Wajir are yet to implement such technologies. Therefore, there is need to assess climate variability using remote sensing to demonstrate the usefulness of such technology in tackling effects of climate variability. Using this technology, this study aims at answering the following questions:

a) What has been the effect of climate variability in Wajir county?

b) What is the trend of climate variability in Wajir County?

1.3. Research Objectives

The overall objective of this study is to assess climate variability on drought in Wajir county, Northern Kenya using Remote Sensing techniques.

1.4. Specific Objectives

The study seeks to achieve the following specific objectives in Wajir County:

1. To assess the change and trends of climate.
2. To assess climate variation on the land use land cover.
3. Develop drought index maps and analyse the trends and impact on drought levels.

1.5. Justification of the Study

Climate variability is a natural event that has both direct and indirect effects on human life. Directly, climate variability results in unpredictable weather conditions. Locust invasions, droughts, and floods have often resulted in spread of human diseases, livestock morbidity and mortality, and loss of livelihoods. Most developing countries, Kenya included, depend on rural economies such as livestock rearing for livelihoods. Studies have shown that weather patterns have become increasingly unpredictable, to the detriment of the farmers. Studies (Ochieng, Karimi, & Mathenge, 2016) have shown that for instance, as a result of climate variability, variables such rainfall and temperature, prerequisite for most agricultural activities in Kenya, would particularly affect small scale farmers for two decades from 2020, unless drastic actions are taken to educate farmers on the reality and available mitigation measures.

Whereas mechanisms are in place to mitigate these effects, they have proved to be inadequate early warning systems as there is no available consistent pattern that inferences can be drawn from. This study intends to use remote sensing to assess the impact of climate variability in Wajir county for the selected time frame. Comparing the analysis with past reports, trend maps will be produced. The study hopes that the findings can be used as an incentive to the county leadership to adopt such technologies to develop reliable early warning systems to supplement national efforts.

1.6. Scope of Work

1.6.1. Geographical Area

The geographical analysis of this project is limited to Wajir County. Wajir County is located in the former North Eastern province of Kenya. The county lies between coordinates 1.6360° N and 40.3089° E and covers an area of 56,685.9 Km^2. It borders Somalia to the East, Ethiopia to the North, Mandera County to the Northeast, Isiolo County to the South West, Marsabit County to the West and Garissa County to the South. Wajir County is to a large extent situated in the Middle and Lower Catchment of the Ewaso Ngiro which enters the county after the

Junction (confluence of Ewaso Ngiro and Ewaso Narok) and extends downstream to the Lorian swamp. The county has 6 constituencies and is divided into fourteen administrative divisions. Figure 1 shows the location of the study area in Kenya.

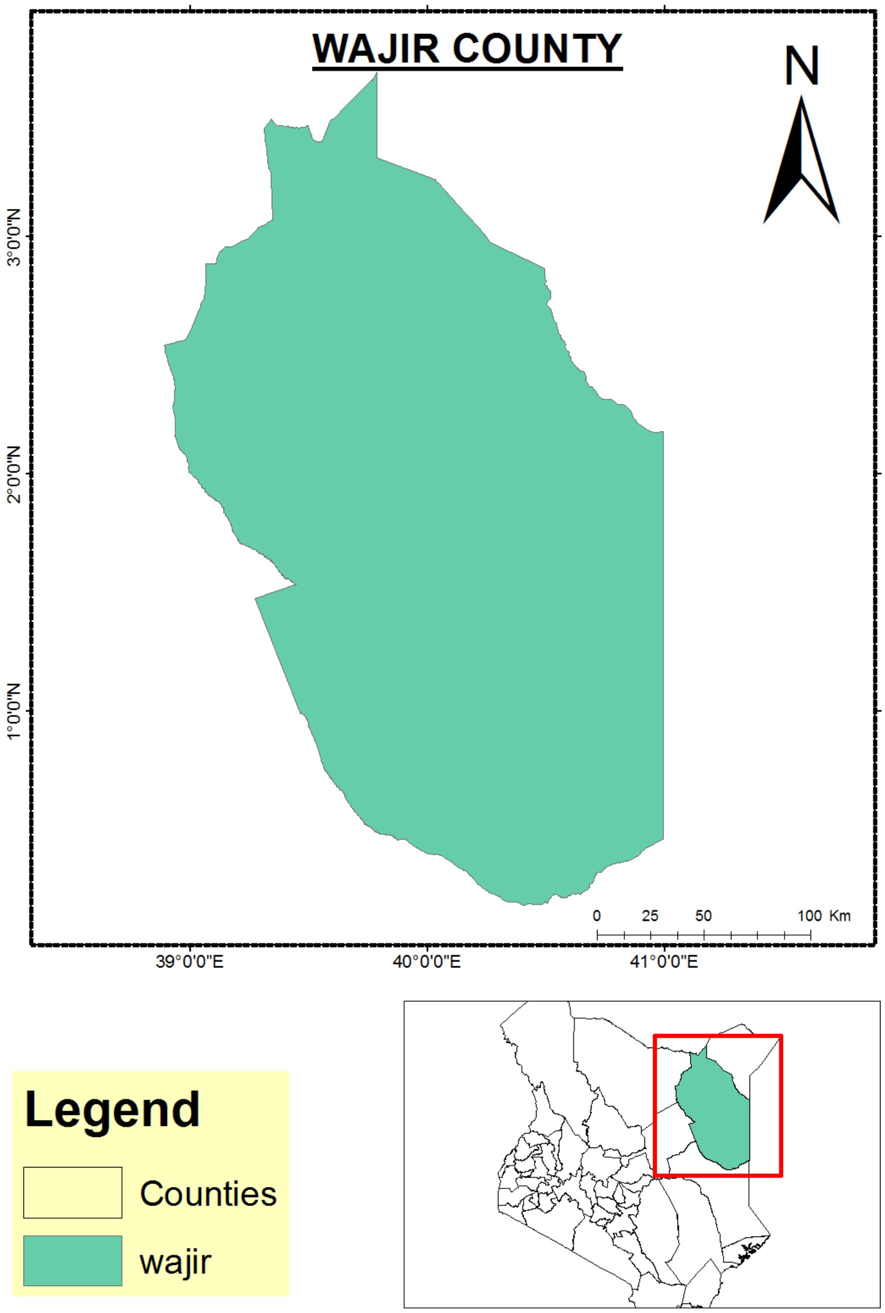


Figure 1: Study Area, Location of Wajir County

1.6.2. Time Frame

The time frame of this study is between 1990 and 2021. Generated maps are compared against a similar time period in future and the past.

CHAPTER TWO: LITERATURE REVIEW

2.1. Introduction

This chapter presents literature review for the study. It explores the development of measurement of climate variability and the related technologies thereof.

2.2. Impact of Climate Variability

Climate variability refers to variation of aspects of climate such as precipitation and temperature from the known averages (UCAR-Center for Science Education, 2022). Climate variability may occur due to natural changes or due to periodic changes in air circulation, flow of the ocean or volcanic eruptions. Other precipitators of climate variation include El Nino Southern Oscillation (ENSO) (https://scied.ucar.edu/learning-zone/how-climate-works/climate-variability Accessed on 17th February 2022). Unlike weather that can vary on a daily, weekly, monthly, or yearly basis, climate change takes a long period of time. Climate variation differs from climate change in the sense that while climate change is computed based on averages over a long period of time, climate variability refers to variation from these averages. This implies that climate variability is a function of climate change. For instance, if temperature deviates from the known averages for a couple of months with decreased precipitation, the period is likely to be drier than the previous years. Climate variability has several effects.

In a study to estimate the effects of climate variability on small scale farmers in rural Kenya, Ochieng *et.al* (2016) found that various weather variables had different effects on farm revenues. Using econometric analysis, the study found that variation in precipitation had a positive effect on all crops assessed in the study, including maize, except for tea where rainfall variation was accompanied by a negative effect. In contrast, the study also found that temperature variation had a positive effect on tea and a negative effect on all other crops. Based on the negative coefficients with significant quadratic terms, the findings suggested that excess temperature would have a negative effect on tea production. In the same breath, precipitation exhibited a positive quadratic term for tea, even though with a negative relationship with tea, suggesting that very low amount of rainfall was not helpful to the farmer. Low temperatures are associated with frosting, leading to scorching of the plants (Ochieng *et.al.*, 2016). As a result of low temperatures, the cell sap expands to an extent that it raptures the cell wall, leading to chemical reactions characteristic of green leaf fermentation, causing leaves to turn brown. The study concludes that farmers need to effectively adapt as long-term effects of variables such as temperature are adverse compared to short-term effects. The study used balancedpanel household datasets of 2000, 2004, 20007, and 2010 that comprised of 1243 households drawn from eight agro-regional zones spread across eastern and coastal lowlands, western transitional and central highlands.

In another study in Mali, Traore et al. (2013) investigated the effects of climate variability on crop production in Southern Mali. The study analysed climate variability from 1965-2005 which found that daily air temperature increased by 0.05 percent in the study period even though the maximum air temperature remained fairly constant. Even though seasonal rainfall showed large inter-annual variation, there was no significant change over the period. On the other hand, number of dry days varied by 30 percent over the study period (1965-2015). The number of dry days, total seasonal rainfall and maximum temperature all had negative effects on cotton production. The study concluded that climate variation, especially that related to rainfall distribution had the most impact on cotton production in Southern Mali.

Liu and Basso (2020) while investigating 'effects of climate variability and adaptation strategies on crop yields and soil organic carbon in the US Midwest', found that extended drought seasons, derived from comparing historical and future climates, led to further reduction in yields especially for maize and wheat cultivation. The study showed that maize production dropped further between 10-22 percent from 5-12 percent of the previous season and from 2-18 percent to 5-15 percent for wheat. Compared to conventional tillage, no tillage was found to be a suitable adaptation mechanism as it increased Soil Organic Carbon (SOC) between 1.4-2.0 tonnes per hectare. However, this was still found inadequate to reverse the effects of earlier adverse climate change, unless the farmers used early, and new maize cultivars were introduced to increase SOC.

2.2. Climate Variability Impact Evaluation Using Remote Sensing

Remote sensing is the acquisition of information of a particular place through measuring or quantifying the emission and reflectance values of the ground through their DN values. This is achieved by estimating the reflected and emitted radiations from a distance, usually from an aircraft or a satellite (https://www.usgs.gov/faqs/what-remote-sensing-and-what-it-used *Accessed on 18th February 2022*). Special cameras on these satellites are used to remotely sense images, helping those interested in researching a particular area or phenomenon. Remote sensing has been used to track clouds for weather forecasting, forest fires, tracking change of city occupation or use of farmland, and study of the rugged ocean floor. Typically, remote sensing uses electromagnetic energy in measuring physical characteristics of distant objects such as vegetation, weather variables such as precipitation, and cloud formation.

2.2.1. History of Remote Sensing

The history of remote sensing can be attributed to the discovery of photography. However, modern remote sensing can be attributed to World War II during which the sonar, radar and thermal infrared detection systems were invented (https://www.usgs.gov/faqs/what-remote-sensing-and-what-it-used *Accessed on 18th February 2022*). The speeding up of the Civil War fastened the invention of photographic cameras to take airborne photos by the United States. This advanced from aeroplane cameras to improved reconnaissance and interpreted photos and films. In the 1950s there was the emergence of the colour infrareds (CI). Progress made resulted to the invention of two radar: Synthetic Aperture Radar (SAR) and Side Looking Airborne Radar (SLAR).

In the 1960s, Television Infrared Observation Satellite (TIROS) was launched. By the year 1975, TIROS was funded, improved and renamed to National Oceanic and Artificial Administration (NOAA). Landsat 2 was launched in the year 1975 and Landsat 3 got launched in the year 1978. More advancements were made, and Landsat 4 launched in the year 1982. With the failure of launching the Landsat 6 in 1993, an improvement of the Thematic Mapper was launched in 199 as Enhanced Thematic Mapper (Landsat 7). Landsat 8 was later launched in 2013. These are sensors that are used in data collection in remote sensing by revolving around the orbit in relation to their design and technological advancements.

The main concept of remote sensing is the acquisition of information on the earth surface without coming into physical contact. The cameras fitted in the sensors that record emitted and reflected rays from the object on the ground. The rays are then converted into DN values that can be interpreted by a computer using different software then converted to a layer fitted for use in a particular study depending on the application needed.

2.2.2. Application of Remote Sensing in Climate Variability Impact Evaluation

Past attempts at monitoring the climate include techniques such as paleoclimatology and use of meteorological data. In paleoclimatology, past climate records are examined from tree rings (dendroclimatology), ice sheets, diatoms, rocks, and sediments (Bhaga *et.al.*, , 2020). Whereas these methods have been used for a long period, they have major shortcomings. For instance, these physical methods use in-situ measurement techniques, which for instance, may require physical measurement of water levels, using such techniques as pressure type equipment, buoy systems, floats or sensors. This implies that hard-to-reach areas such as mountainous or hilly areas cannot be served due to difficulties inherent in the process thereof (Bhaga, *et.al*., 2020). The process has also been associated with high costs. This calls for use of delocalised techniques such as remote sensing which uses images from satellites or aircrafts.

Remote sensing has widely been used to study climate variability. The technique is reliable in the sense that it provides continuous and consistent data that can easily be used for comparison, anytime it is needed. Unlike in-situ measurements, remote sensing is not affected by weather conditions. The growth of remote sensing is associated with growth in indices, which are algorithms that make the collected data clearer, thus providing an alternative source of data for both planners and researcher. There are there are several sources of the indices, including the Passive Microwave (PMW), Infrared (IR), and space-borne Precipitation Radar data (PR). If one is studying drought impact, the drought Index (DI) is used which can measure the drought intensity, duration, spatial extent, and severity (Bhaga *et al*., 2020). The indices use meteorological data such as soil moisture, temperature and precipitation. Different indices have been developed to measure both meteorological and hydrological drought. On one hand, meteorological drought can be detected by techniques such as Enhanced Vegetation Index (EVI), Standardised Precipitation Evapotranspiration Index (SPEI), Palmer Drought Severity Index, and the Standardized Precipitation Severity Index (SPI). On the other hand, hydrological drought can be detected using Anomaly Vegetation Index, Normalised Difference Water Index (NDWI), Normalised Difference Vegetation Index (NDVI), and Temperature Condition Index (TCI).

CHAPTER THREE: MATERIALS & METHODOLOGY

3.1. Introduction

This chapter presents the materials needed for the study and the methodology used to achieve the study objectives.

3.2. Materials

Materials used and the sources are given in Table 1 below:

Table 1: Materials

DATA	SOURCE
Precipitation Data	CHIRPS
Temperature Data	Terra Climate
Evapotranspiration	Terra Climate
Landsat TM, ETM+, OLI	USGS Earth Explorer
Soil Moisture	Terra Climate
SRTM 30m	RCMRD Geoportal

3.3. Methodology

This study applied the remote sensing technology to assess the climate variability in Wajir County. The use of correlation and empirical models are a technological approach towards attained assessment. The research process included data identification and collection, processing of the digital images (layer stacking, mosaicking, clipping and supervised classification). After this, the collected data underwent accuracy and validation assessments before the changes in the region were derived. Finally, the data was integrated and analysed before the trend maps processed.

3.3.1. Climate Variables

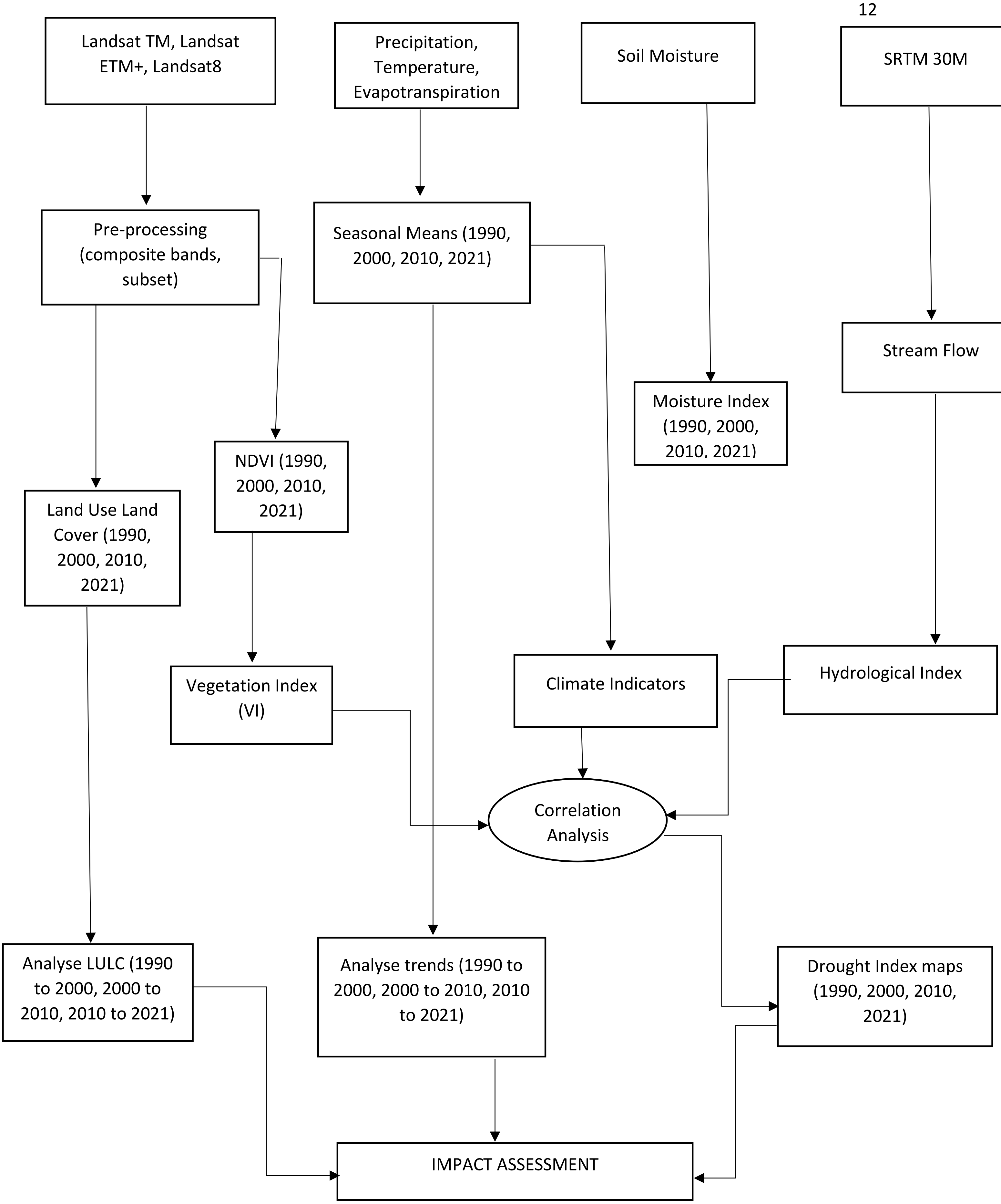
Precipitation, evapotranspiration and rainfall data constituted the climatic variables. In this case, seasonal mean was calculated for the data, in raster format and trend maps produced for the three entities. Thereafter, trends and analysis were done and assessed on how they affect the drought levels of Wajir County.

3.3.2. Vegetation Indicators

Vegetation indices (VIs) were derived from daily atmospheric-corrected and bidirectional reflectance. Medium resolution Landsat images was used for the detection of the vegetation Index. Landsat 5 was used for the year 1990, Landsat 7 for the year 2000 and 2010 and Landsat 8 for 2021 Bands 4 and 5 was used in the detection of vegetation indices. After achieving good quality VI values, another approach-the co constrained view angle was then used to select pixels to be represented as the compositing period-choosing from two highest NDVI (Normalised Difference Vegetation Index) values and selecting the pixel the closest pixel.

3.3.3. Hydrological Variables

Other important variables that were entities for the model were the hydrological variables. In this case, we produced stream flow values and maps on Wajir County. This therefore produced hydrological indicators of the model.


Landsat TM, Landsat ETM+, Landsat8
Precipitation, Temperature, Evapotranspiration
Soil Moisture
SRTM 30M
Pre-processing (composite bands, subset)
Seasonal Means (1990, 2000, 2010, 2021)
Stream Flow
Moisture Index (1990, 2000, 2010, 2021)
NDVI (1990, 2000, 2010, 2021)
Land Use Land Cover (1990, 2000, 2010, 2021)
Vegetation Index (VI)
Climate Indicators
Hydrological Index
Correlation Analysis
Analyse LULC (1990 to 2000, 2000 to 2010, 2010 to 2021)
Analyse trends (1990 to 2000, 2000 to 2010, 2010 to 2021)
Drought Index maps (1990, 2000, 2010, 2021)
IMPACT ASSESSMENT

CHAPTER FOUR: RESULTS AND ANALYSIS

4.1. Climatic Variables

Wajir County is characterized as one of the ASAL regions. This depicts that the climatic variables of the county are known to variate with respect to the heat wave, moisture index and the amount of rainfall in the region. Low rainfall condition is one of the factors attributeable to drought escalating as it affects both the living and growing conditions. Rainfall is characterized as one of the normal wet conditions of a certain area. It impacts greatly on the hydrological, environmental and agricultural aspect of the ecosystem. Having a standardized and monitored precipitation status of the county allows for proper planning and devising of mitigation measures towards drought indices of the area. Standardized Precipitation Index has been used in monitoring the drought index of Wajir County for over thirty years.

4.1.1. Precipitation Analysis

Trends of the precipitation indices were analysed for the year 1990, 2000, 2010 and 2020. Variations of the trends were measured in mm/yr. Further analysis was done for every month, for the years under study, which is an epoch of 10 years. The variations of the rainfall quantity attribute to the climatic changes in the county.

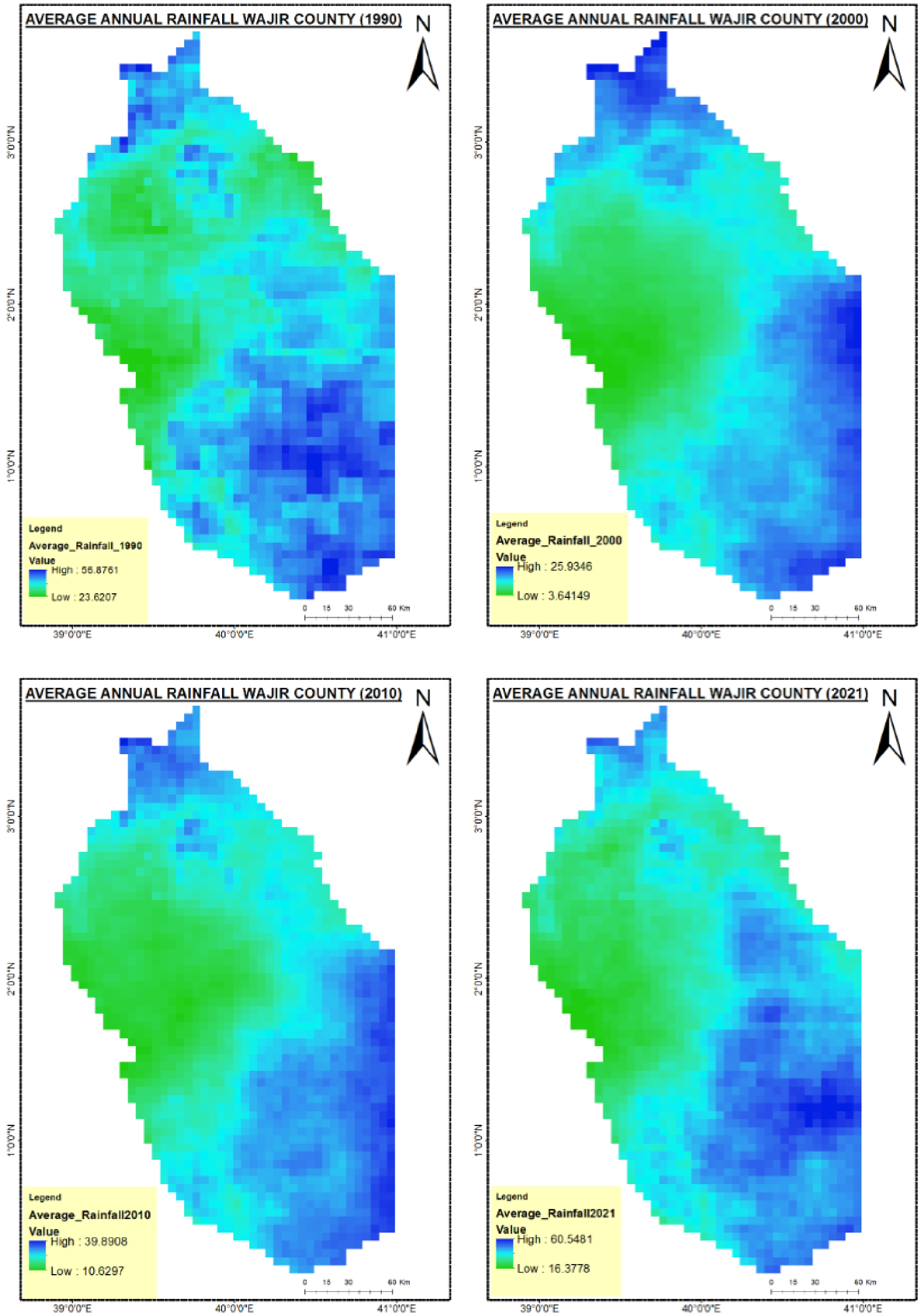


Figure 2: Annual Rainfall Wajir County (1990, 2000,2010 and 2021)

For 1990, it is clear that the southern part of the county experiences higher precipitation indices as compared to the centre and western side of the county. This was quantified in terms of mm/year and the results represented in both line and bar graphs in order to show trends of the same.

Table 2: Average Rainfall 1990

Month	Average Rainfall (mm)
Jan	6.10
Feb	58.89
Mar	103.57
Apr	170.56
May	22.41
Jun	20.67
Jul	156.89
Aug	75.90
Sep	10.60
Oct	32.61
Nov	93.83
Dec	83.63

The rainfall quantities represented on the table above were analysed on the basis of mm/month and represented on the bar and line graphs.

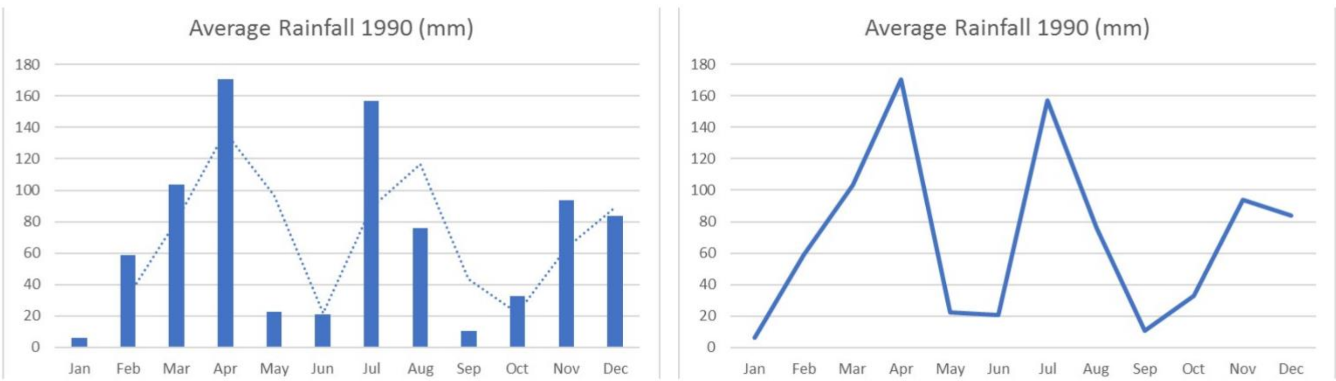


Figure 3: Rainfall Bar and Line Graphs 1990

For 1990, the rainfall quantity variated throughout the year such that April and July were having the highest rainfall quantities of 170.56 and 156.89 mm respectively. The amount of rainfall in Wajir County in 1990 clearly shows that Wajir received inadequate rainfall to support sustainable growth and living. This attributes to the area being an ASAL region hence high drought indices.

2000

In the year 2000, there were slight fluctuations on the rainfall quantities. The year 2000, Wajir received lower rainfall quantities as compared to the year 1990. In 1990, the highest rainfall quantity was 56.78mm, while in 2000 the highest amount was 3.64 mm. In the year 2000, Wajir experienced shorter summers where the climate was mostly cloudy and windy hence the dry season all year round.

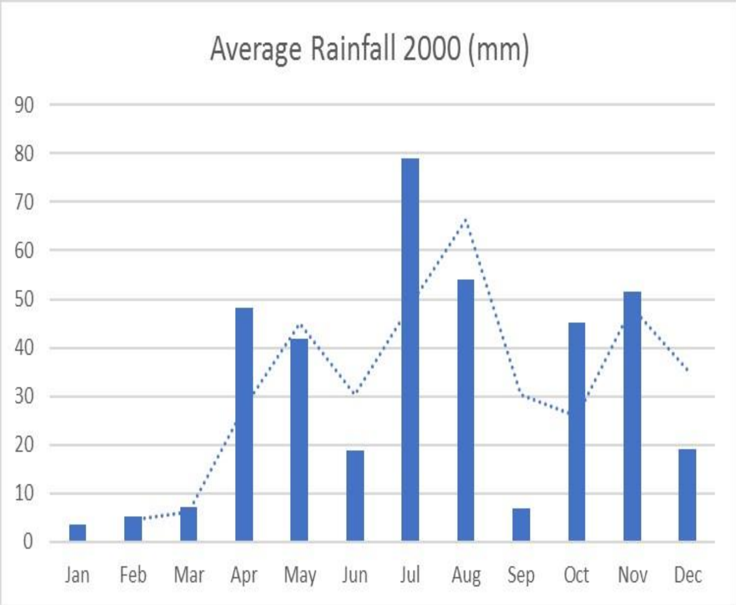
The rainfall amount was also analysed in mm and the average done for the whole year represented on the map above. The southern part is still receiving higher quantities as compared to the central and northern parts of the county. Table 3 shows the rainfall quantities in mm.

Table 3: Average Rainfall 2000

Month	Average Rainfall (mm)
Jan	3.55
Feb	5.28
Mar	7.11
Apr	48.08
May	41.79
Jun	18.86
Jul	78.98
Aug	53.90
Sep	6.87
Oct	45.11
Nov	51.54
Dec	19.19

Analysis of the same was done and represented in bar and line graphs

Bar graph



Line graph

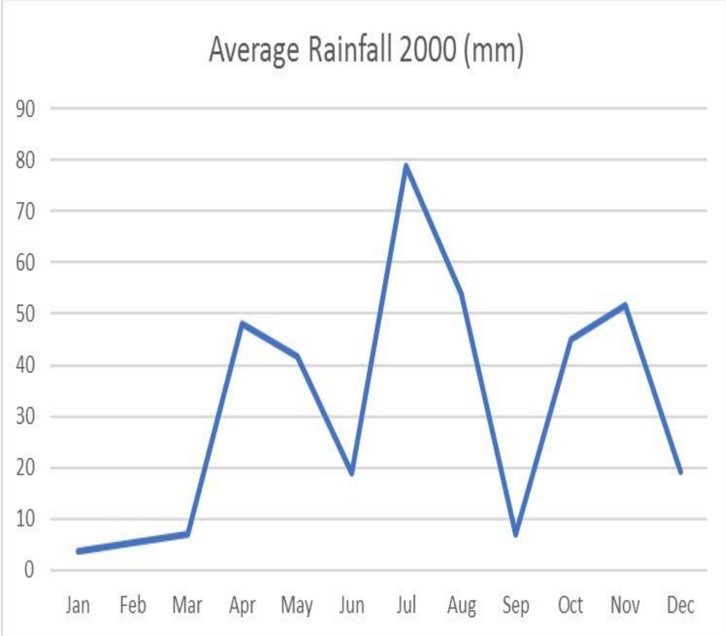


Figure 4: Rainfall Bar and Line graphs 2000

In the year 2000, the rainfall quantity is seen to be highest in the month of July. For April, August October and November, the rainfall quantities are seen to be almost equal, where for July, the rainfall was 78.98261mm.

2010

Since the County is characterized by nomadic practises, most of the areas receive low rainfall with the southern parts of the county receiving high capacities of rainfall as compared to the other parts of the county. The quantities of rainfall were analysed in mm and is shown **Error! Reference source not found.**

Month	Average Rainfall (mm)
Jan	8.95
Feb	15.08
Mar	87.84
Apr	122.00

May	39.22
Jun	33.87
Jul	82.65
Aug	51.07
Sep	6.48
Oct	46.32
Nov	46.32
Dec	9.98

The rainfall capacities were further analysed and represented in both lines and bar graphs.

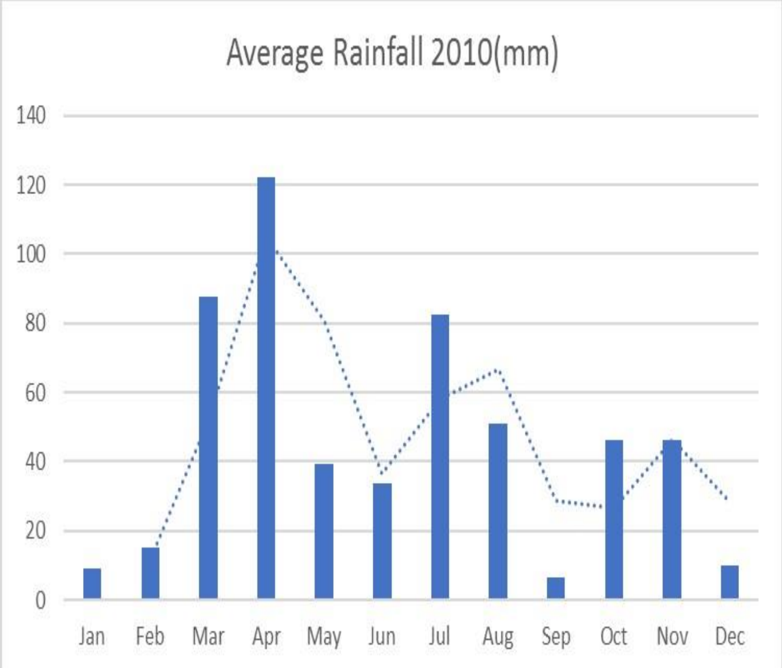
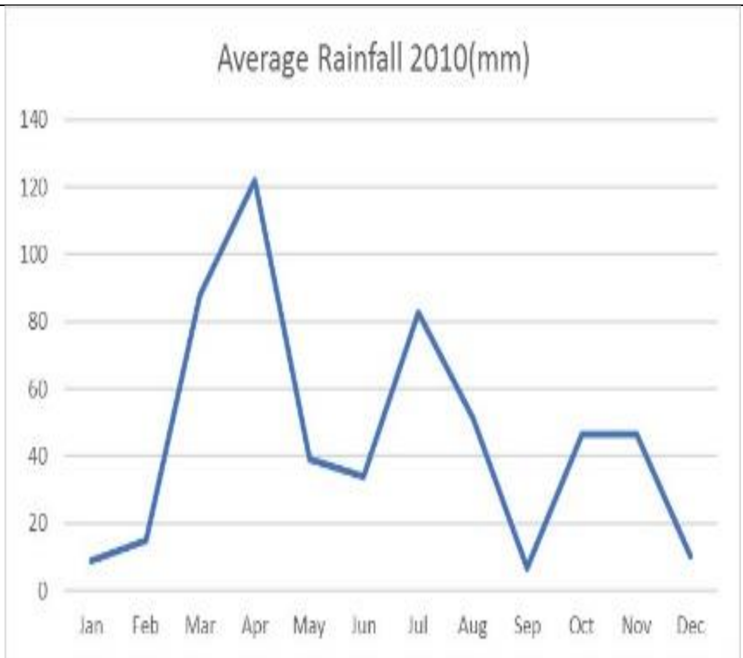
Bar graph	Line graph
	

Figure 5: Rainfall Bar and Line Graphs 2010

In 2010 on the other hand, higher rainfall capacities were witnessed in the month of April, March and July coming in second consecutively with 87.84605 and 82.65893 mm respectively.

For the year 2000 and 2010, there were very minimal rainfall capacity changes as seen on the figure above. Different adaptation strategies were put in place by the inhabitants that resulted in balancing of the biophysical environmental factors that resulted to the small shift in the rainfall capacities.

2021

For the year 2021, there were massive changes as the year was characterized by heavy rainfalls that resulted to changes on the rainfall indices all over the county. Some parts of the counties reduced from low rainfall indices to higher indices.

There are two ecological zones in the county with the higher side of the county being semi-arid in the higher plains which further goes to being arid in the lower plains. This explains why the southern part of the county has higher rainfall capacities as compared to the central and the northern sides of the county.

Like the other years, the results were analysed in mm as shown in Table 4.

Table 4: Rainfall 2021

Month	**Average Rainfall (mm)**
Jan	14.61
Feb	6.90
Mar	58.29
Apr	285.76
May	30.91
Jun	25.78
Jul	159.82
Aug	87.64
Sep	10.71
Oct	47.44
Nov	54.37
Dec	20.18

Further analysis was done and the trends monthly for the year 2021 were shown in both bar and line in Figure 6

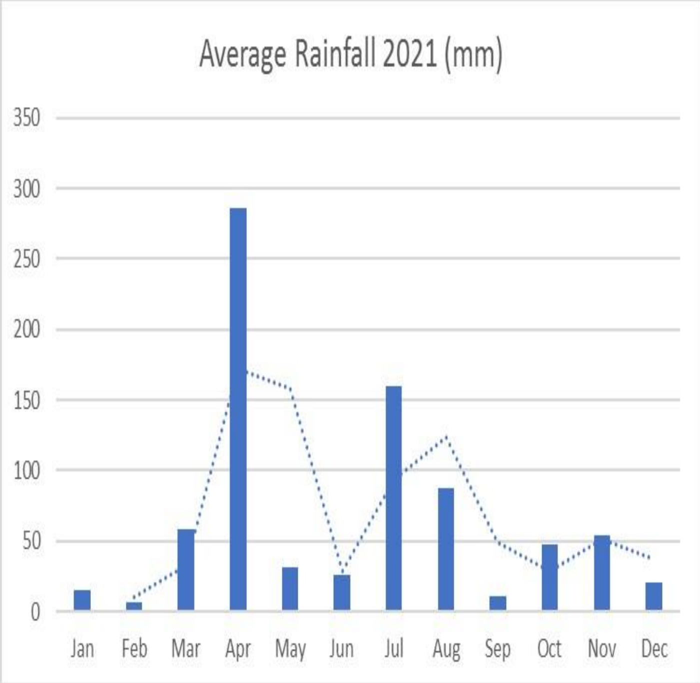
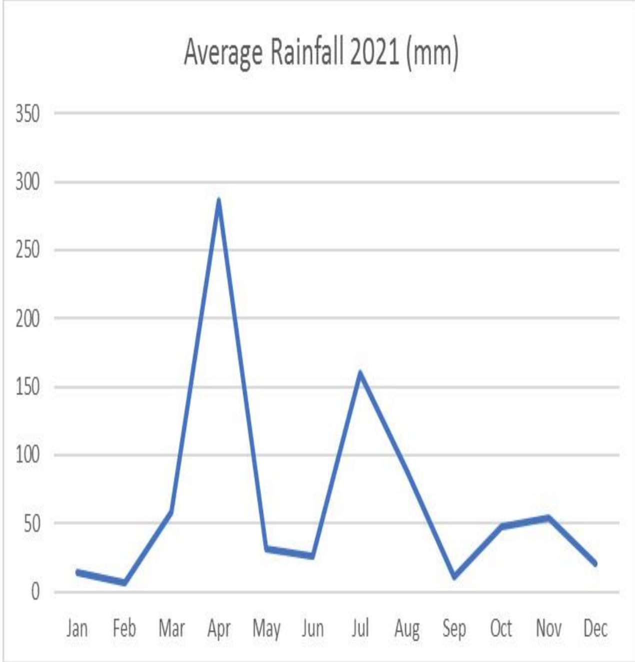
Bar Graph	Line Graph
	

Figure 6: Rainfall Bar and Line Graphs 2021

For the year 2021, the levels of rainfall capacities reduced for most of the months as compared to the previous years. The comparison for 2010 and 2021 is shown in the Figure 7: Average annual rainfall bar graph. Other parts had increased levels while other parts of the county had reduced levels of rainfall capacities.

For the different years under study, further analysis on the trend maps were done to show the total annual amount of rainfall and the annual mean rainfall and both were represented on bar graphs Figure 7.

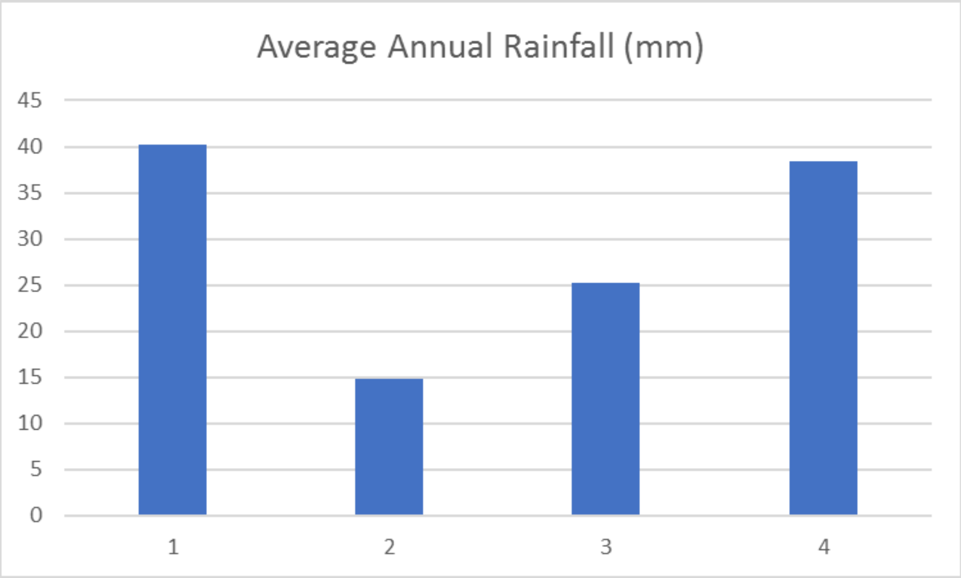


Figure 7: Average annual rainfall bar graph

The results above seek to contribute to the first objective of analysing the trends of climate in the region and their impacts in relation to drought. The results above depict that the area receives inadequate rainfall in the stipulated years of study. The trends were analysed to identify the characteristic events of the same in relation to drought conditions in the area.

The horn of Africa is currently facing drought due to different factors and one of the main factors is torrential rains. Food security and natural resources become inadequate due to the extreme conditions of climatic conditions in the area. Inadequate rainfall results to lack and inadequacy of water for basic needs and daily consumption. Inadequate rainfall also results to the invasion of desert locusts. This is a phenomenon that was witnessed recently in Wajir County hence threatening the livelihood of the inhabitants of Wajir County. According to the Food and Agriculture Organization of the United Nations (FAO), desert locusts are considered one of the most destructive, harmful and dangerous flying pests as it migrates quickly and can travel long distances.

FAO continues to explain that these invasive drought pests are destructive to an amount of 2 grams per day, per pest. These indicates that they can destroy food that can feed up to 35,000 people in a day. Croplands were destroyed by the invasive pests. The types of crops that are of preference to these locusts are mostly grasses, i.e wheat, millet and maize, but they also attack other crops like rice, coffee, vegetables and fruits. This threatens food security of the county, resulting to deteriorating food security.

The agricultural sector is destroyed due to the inadequate rainfall thus deteriorating the economy of the region. This further results to the drop of Gross Domestic Products (GDP) as the catastrophe limits production.

4.1.1. Standard Precipitation Index

Standard Precipitation Index can be used in drought monitoring by analysing the mean rainfall data in different time series. The time scales are selected depending on the availability of data. Daily precipitation values are used from CHIRPS data where the rainfall anomaly will be produced, and different indices read at different times. SPI can be determined in two ways, one being the common SPI where the data is analysed based on an interval in relation to the study conducted. It is calculated on monthly basis, i.e., 3, 4 or 6 months. The second one is the MODIS SPI. This encompassed of vegetation conditions of a certain area. Although, in our scenario, the variable of interest is precipitation, therefore the common SPI method was used.

SPI essentially has values where both negative and positive values are computed. This signified the wetness or dryness of the area of study. In a scenario where there were continuous negative values up to the value -1, indication of drought was indicated in this case. Drought events can be considered ongoing and continuous to a threshold value 0. Therefore, it can be said that drought begins at values less than -1.

There was an SPI classification index that can be used in drought monitoring. The classified indices are as shown in a table.

Table 5: SPI Classification

SPI Values	Dryness/Wetness Classes
2.0 +	Extremely Wet
1.5 to 1.99	Very Wet
1.0 to 1.49	Moderately Wet
-0.99 to 0.99	Near Normal
-1.0 to -1.49	Moderately Dry
-1.5 to -1.99	Severely Dry
-2 or less	Extremely Dry

Values of SPI in Wajir County are represented in a figure, represented as an anomaly that depicts the drought indices for different years and dates. In this case, the years of interest were represented in Figure 8.

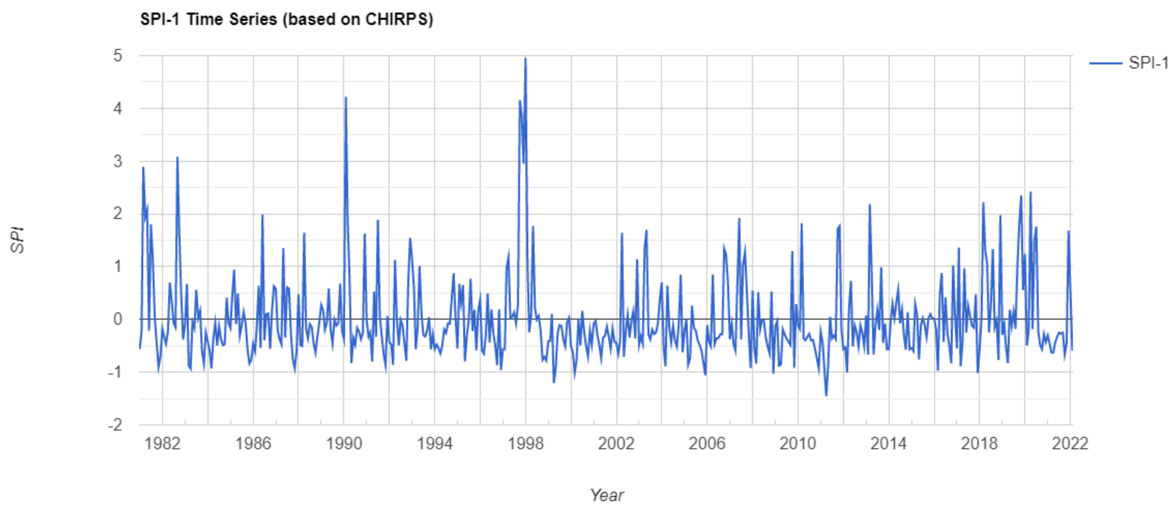


Figure 8: SPI Values

SPI values for the year 1990 were recorded at -0.831. This indicated that in 1990, Wajir County was moderately dry. In 2000, the SPI value was recorded at -1.013. This falls under the moderately dry class of drought monitoring. In 2010, the value was recorded at -0.927 which shows that the counties drought levels were near normal. This was because in 2010, the rainfall capacities were higher compared to the other years of study. In 2021 however, the SPI values reduced to -0.435 falling under the near normal. There were no level of wetness recorded in the years of study showing that Wajir is an ASAL region hence the SPI values recorded.

A map was produced to show the SPI values distributed across the County.

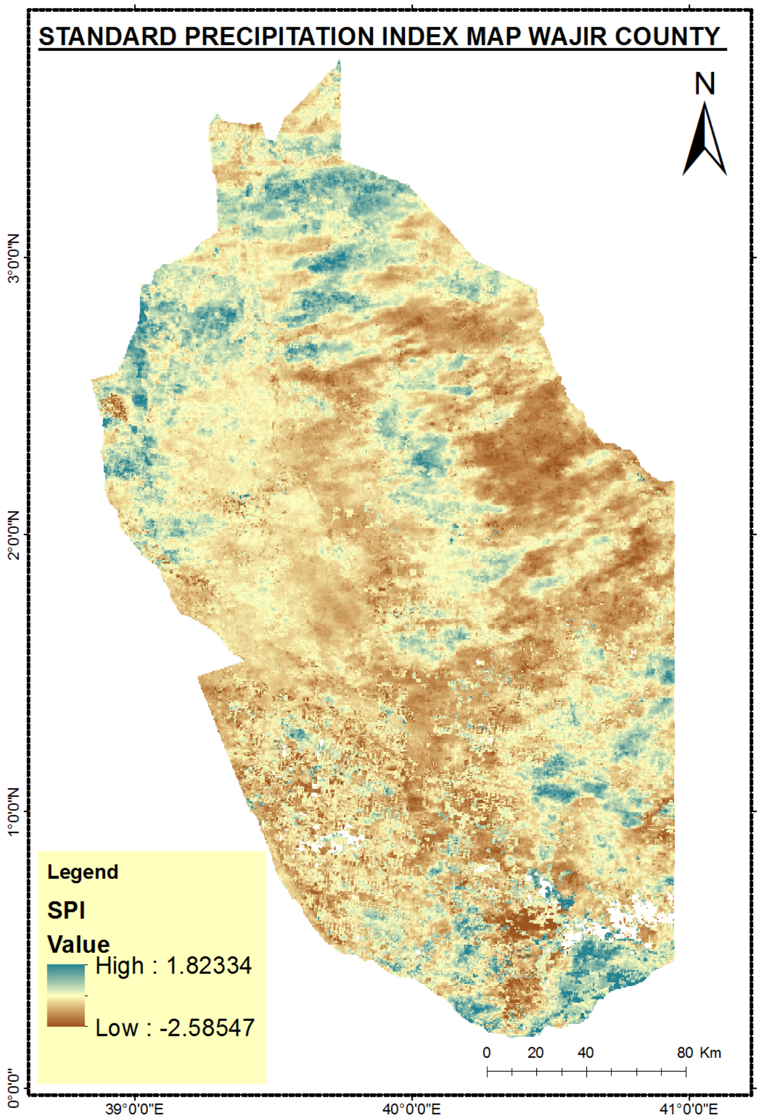


Figure 9: Standard Precipitation Index Wajir County

Standard Precipitation Index were used in determining the level of drought in the region with the threshold provided. The results depicted that Wajir County is moderately dry. This was directly related to the amounts of rainfall received in the area. Agricultural sector is affected in that the inadequacy of rainfall results to deteriorated food security.

4.1.2. Temperature Analysis

For the Palmers Drought Severity Index to be used, temperature trend analysis was one of the factors that is considered. Analysis of annual average temperature for the years of study was done and the results were represented in maps, bar and line graphs. Temperature was viewed as one of the most important aspects as temperature determines the level of dryness in a given area. The variation of temperature values results in different levels of drought indices that is an area of concern for Wajir County.

1990

For the year 1990, temperature levels variated between 37.44 and 30.58. This depicted high temperature levels that results to the variation of climate in Wajir County. The high levels of temperatures were attributed by the altitude. The lower the altitude, the higher the temperature levels.

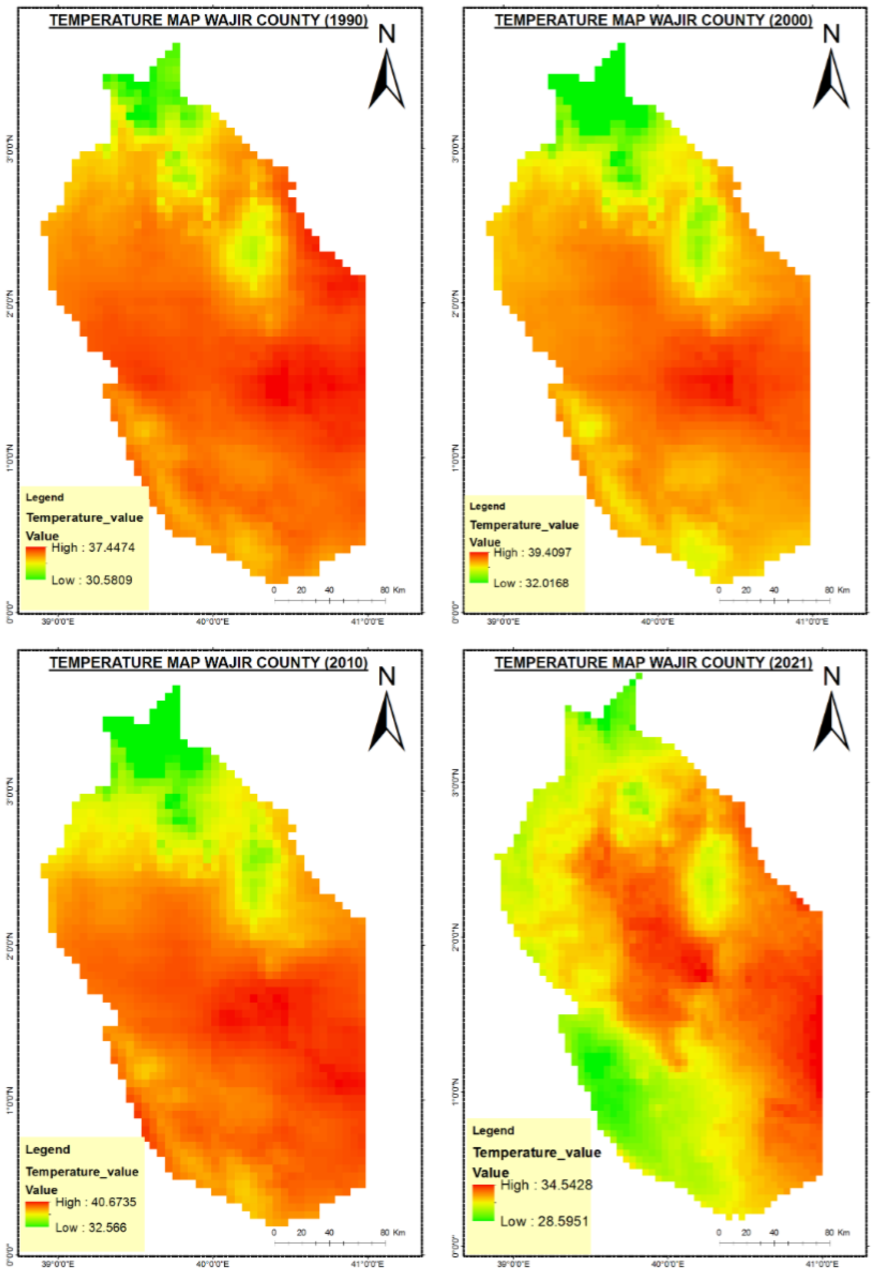


Figure 10: Temperature Value Wajir County (1990, 2000, 2010, 2021)

2000

Highest values were recorded for up to 39.40 and lowest values of temperature for 2000 were recorded up to 32.01. At the centre of the county, there seems to be very high temperature levels in both 1990 and the year 2000.

In as much as the highest temperature value recorded in 2000 was 39.40 and in 1990 was 37.44, from the map, it is clear that most parts of the county had extremely high temperature levels in 1990 as compared to 2000. The central part of the county maintains consistency of the high temperature values while the northern and south western part of the county experience medium to low values of temperatures recorded. In the year 2000, there was reduction of rainfall capacities. This explains why the temperature levels in 2000 are lower than in 1990.

2010

In 2010, the highest temperature value recorded was 40.67 while the lowest temperature value recorded was 32.52. The results show that in 2010, there were higher temperature values as compared to 2000. There are slight changes in the temperatures between the two years.

2021

For the year 2021, the temperature values slightly reduced as compared to the year 2010. In 2021, the rainfall capacity levels were higher therefore depicting lower temperature levels.

Wajir County being an ASAL region, temperature values are high whereas the rainfall capacity levels are low. Between the years 2010 and 2021, there were slight changes on the temperature values. This is attributed to the increase in rainfall capacity.

Wajir County falls under ecology zone V-VI. This is where the area receives an average annual rainfall of 300 to 600mm per annum. The total average annual rainfall of Wajir County in the years 1990, 2000, 2010 and 2021 are 482.98, 177.46, 303.12 and 461.55 respectively. The area has two seasons, short and the long rains. Areas around Dimanyale, Habaswein and Sabuli, that are close to the boarder of the county are some of the areas in the region that had increase in rainfall capacities and reduced temperature levels between the years 2010 and 2021.

Increased temperatures result to reduced rainfall capacities. This is attributed by the variation of the climatic variables in the region. This further affects the agricultural sector of the county. As stipulated by FAO, agriculture contributes to 26% of the GDP, in the year 2019. It is a key sector in the country as it adds up to the primary export product for the country. The deterioration of agriculture in Wajir County resulted to lack of food security in the region.

The invasion of locusts is now headed to the livestock-grazing lands thus destroying grazing lands of livestock. Wajir is known to be a pastoral-dominated area hence the encroachment to grazing lands results to impacts in both livestock and the inhabitants of the area. This is attributed to the hurricanes that have been received in the Indian Ocean that results to cyclones that leads to increased temperatures. Territories upstream become fragile, and this includes areas along the north eastern region of the country and the horn of Africa at large. This led to the suffering of substinence farmers that depended on domestic crops for daily consumption.

According to the results depicted above, Wajir County has very high temperatures that indicated that the area has frequent dry seasons. Dry seasons were unfavourable for the cultivation of crops as the conditions were not favourable. The results depicted that the dry seasons in wajir county are recurrent and as a result of global warming thus affecting the hydrological cycle of the area. This further causes water shortage in the area and affecting food security at large.

4.1.3. Soil Moisture

Soil Moisture is a factor that depicts the dryness or wetness index level of the top layer of the soil. It represents the unsaturated zone that is between groundwater and soil surface. Soil moisture is attributed by ground water, capillary rise from water underground, irrigation activities and precipitation. Soil moisture acts as a balance in the biosphere by providing nutrients to both living organisms and the ground.

Soil moisture is an essential factor in drought monitoring as it affects the ecological conditions of the environment, hydrology, agricultural activities where nutrients are passed to plants in lieu of their growth resulting to balancing the biosphere and solar energy, and meteorology.

1990

In 1990, the moisture level of Wajir County is represented in the map Figure 12: Soil moisture level Wajir County (1990, 2000, 2010 and 2021). The highest value of soil moisture was 28.52 and the lowest value being 1.082. Higher values of moisture index were seen towards the western side of the County where there were higher rainfall capacities as compared to the eastern and southern part of the county. Areas around the western side of the county is known to practise agro-pastoralism where the agricultural activities are in small scale. This explains the high soil moisture levels in the western side as compared to the other parts of the county.

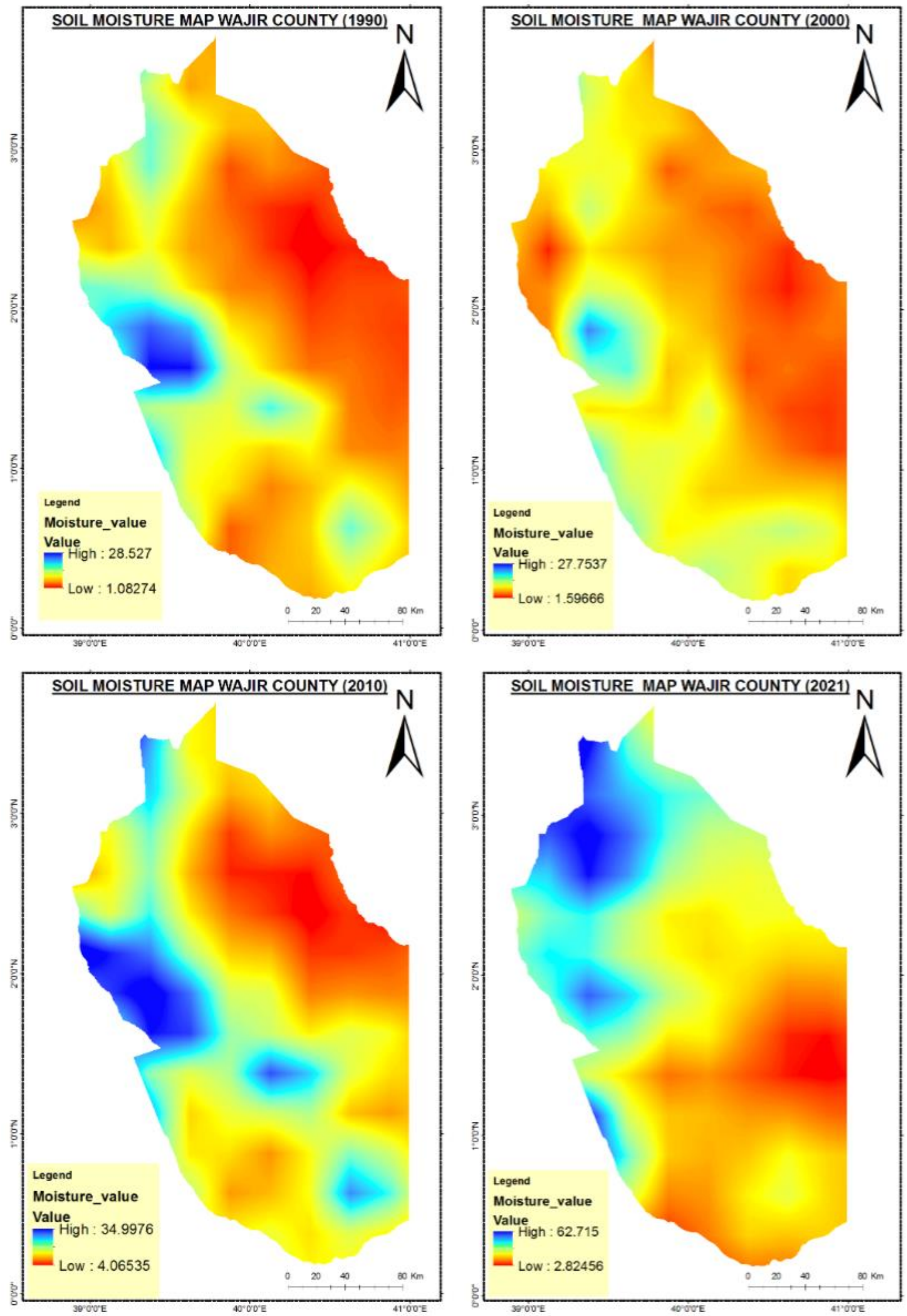


Figure 11: Soil moisture level Wajir County (1990, 2000, 2010 and 2021)

2000

In the year 2000, the moisture levels variated as a result of both temperature and rainfall capacities of the area. Since for plant growth to be sustainable, soil moisture becames a dominant factor as it acts as a providence of water and energy to the plants. There was a slight difference between the moisture values in 1990 and the year 2000. In 2000, the highest moisture value was recorded at 27.75 and the lowest value recorded as 1.59. Temperature levels reduced as well as the rainfall capacities in the year 2000. The balancing of the two factors results to retaining of water in the soil, resulting in lower levels of soil moisture in comparison to 1990. The reduction of the moisture indices in 2000 is as a resulted of the reduced rainfall capacities.

2010

In 2010, there was an increase in the rainfall capacities from the year 2000. This clearly indicated that there was an increase in the soil moisture content. West Wajir had higher soil moisture content as compared to the other parts of the county.

2021

There was a massive increase in the rainfall capacities in the year 2021 that resulted in the increase in the moisture indices. Highest value was recorded at 62.71 and the lowest value recorded at 2.82.

Soil moisture was an important factor in this study as it elaborated the first objective of analysing climatic trends of the region. Soil moisture refers to the wetness or dryness of the top layer of the soil. With this, the potentiality of the area to withstand crop production is determined. For Wajir County, the soil moisture levels were low compared to the needed threshold for agricultural production. This made the agricultural potentiality of Wajir county low. This resulted to limited natural resources and food, therefore leading to food insecurity.

Soil moisture is mostly attributed to climatic conditions. The result is that there is an increased evapotranspiration that leads to less infiltration of water in the soil and reducing the run-off potentiality leading to increased drought conditions. Wajir County is a pastoral dominated area therefore the mobility, administration and implementation of land policies to support drought risk management tend to be difficult. Soil moisture content contribute to climatic sensitivity of the area. Deterioration of favourable conditions in support of agricultural, grazing and pastoral lands has resulted to conflicts of resources by the different communities that stay in the area. Conflict is due to limited pastoral lands and inadequate water sources.

4.1.4. Evapotranspiration

Evapotranspiration is an important factor in drought monitoring as it will be used to produce standard precipitation evapotranspiration Index (SPEI). In this case, both the precipitation and the evapotranspiration capacities were considered for drought monitoring. SPEI was calculated in different time scales so as to come up with drought indices for monitoring the dryness or wetness of the studied area.

Different time scales were used in the calculation of SPEI. Time scales can vary between 1-48 months and even over 18 months. Thorn Waite method was used in the calculation of SPEI where the climatic variables, i.e., precipitation, temperature and evapotranspiration were used for drought monitoring. SPEI combines different indices, that being Standard Precipitation Index (SPI) that involves rainfall capacities, Actual Evapotranspiration (AET).

Of all the years under study, 2000, had the lowest rainfall capacity, hence the results shown Figure 13: Evapotranspiration Values Wajir County (1990, 2000, 2010 and 2021). The highest value was recorded at 228mm while the lowest value recorded at 111mm.The highest value was recorded at 345mm while the lowest value was recorded ta 156mm. There was an increased value of the AET from the year 2010 to the year 2021. The highest value was recorded at 417mm while the lowest value was recorded at 191mm. The increased values were as a result of the increased rainfall capacities.

Evapotranspiration involves the evaporation or the losing of water content from the soil to the atmosphere due to high temperatures. In Wajir County, evapotranspiration is high due to the high levels of temperature in the region. This section seeks to complete the first goal of analyzing trends in climatic variables. The trends in evapotranspiration were investigated in order to determine the characteristics of evapotranspiration and how they affect drought in the area.

Wajir County has high evapotranspiration levels, which leads to food insecurity, according to the findings. This was due to unsustainable plant growth and crop productivity due to limited energy and water content absorbed by plants in the region. The decline in food productivity in the country as a whole has harmed the economy. Wajir County contributes a small portion of the country's crop productivity. According to the FAO report, economic growth has slowed from 6.4 percent in 2018 to 5.1 percent in 2019.

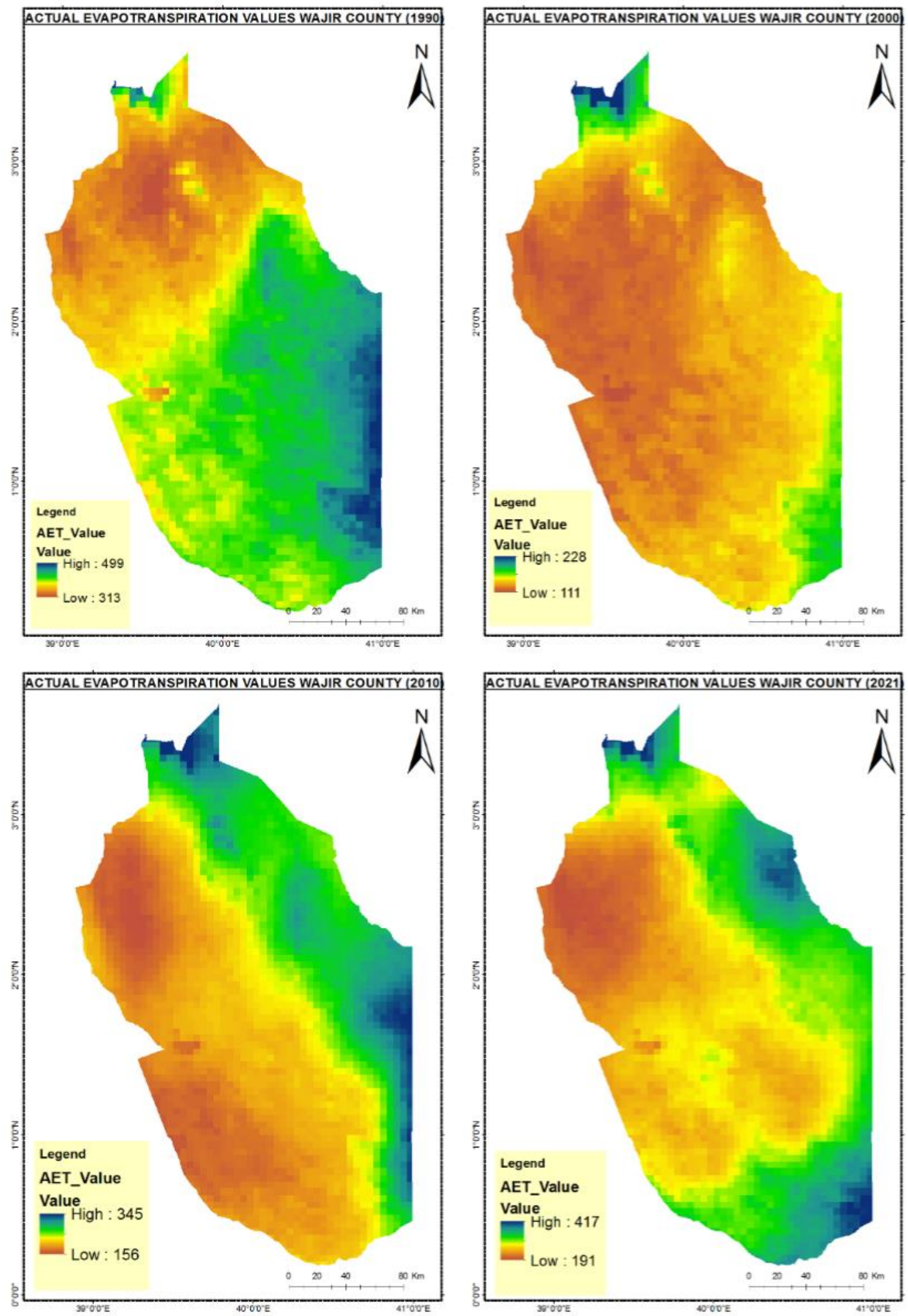


Figure 12: Evapotranspiration Values Wajir County (1990, 2000, 2010 and 2021)

The highest value was recorded at 499mm and the lowest value recorded at 313mm. Evapotranspiration involves both evaporation and transpiration. This indicated that it is a combination of water from the ground surface to the atmosphere, while transpiration involves the emission of water from plants to the atmosphere. Therefore, East of Wajir County was seen to have a higher value of evapotranspiration as compared to the other parts of the county.

4.1.5. SPEI

Standard Precipitation Evaporation Index (SPEI) is characterized in a multi-scalar method making it an important index in drought monitoring. It potentially stands as the index with a wide range of time scales thus quite effective in drought monitoring. It encompasses the evapotranspiration and precipitation values. Soil moisture values are also a factor to SPEI. SPEI is important for drought monitoring as it represents the climatic water balance effectively. Water balance is the deriving of SPEI using temperature, moisture precipitation and evapotranspiration values.

SPEI has a threshold of values that represent different levels of drought. The threshold is shown in Table 6.

Table 6: SPEI Classification Values

SPEI Values	Dryness/Wetness Classes
2.0 or more	Extremely Wet
1.6 to 1.99	Very wet
1.3 to 1.59	Moderately Wet
0.8 to 1.29	Slightly Wet
0.5 to 0.79	Incipient Wet
-.49 to 0.49	Near Normal
-0.79 to -0.5	Incipient Dry
-1.29 to -0.8	Mid Drought
-1.59 to 1.3	Moderate Drought
-1.99 to -1.6	Severe Drought
-2.0 or less	

Distribution of the SPEI values are represented in Figure 13.

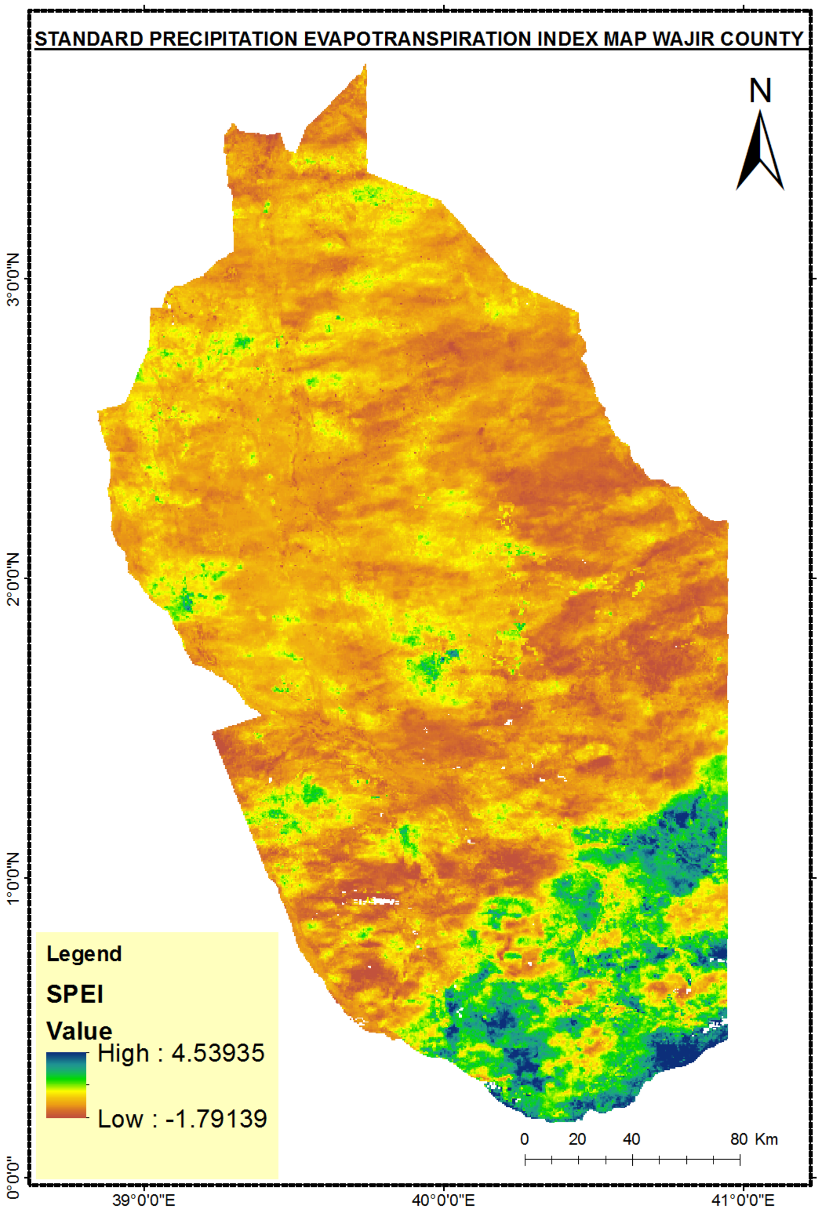


Figure 13: SPEI Map Wajir County

In this study, the standard precipitation and evapotranspiration index was used to monitor drought conditions using the variables precipitation and evapotranspiration. Wajir County experienced low precipitation while experiencing high evapotranspiration. Because of the high temperatures in the area, evapotranspiration was high. This also corresponds to the area's agricultural productivity and food security in general. This does not meet the Standard Development Goals (SDGs) of eradicating poverty and hunger.

Hunger-stricken areas and increased poverty result from a lack of food security.The Standard Precipitation and Evapotranspiration Index is a drought monitoring indicator. According to the National Drought Management Authority's short rains assessment, the southern side of the county is used for pastoral activities, with cattle and goats being the main animal species raised. This explains the high evapotranspiration and low precipitation values in the county's south. Inadequate rainfall has been experienced in the area, affecting pastoral lands, browse regeneration, and the recharge of water sources. As a result, the residents' livelihoods are impacted. The cattle bearers had to trek long distances due to a lack of water due to dried lagers and insufficient rainfall. This has an additional impact on the productivity of domestic animals, which provide milk, meat, and other essential produce to the inhabitants. This increases hunger and food inadequacy, thereby increasing poverty and food insecurity in general.

4.2. Vegetative Variables

4.2.1. NDVI

Normalized Differential Vegetation Index is usually used to depict the greenness, or the amount of vegetation cover in a certain area. The data used in this project was Landsat where Band 4 and 5 are used.

The vegetation index is normally a reflection of the climatic variables. Increase in rainfall capacities, and soil moisture results to increased vegetation as the required nutrients by the atmosphere are met.

Wajir County is an ASAL region with little vegetation cover. The vegetation is sparse and mostly represents pastoral/grazing lands. Due to decreased rainfall capacity, increased temperature levels, increased evapotranspiration, and decreased soil moisture, subsistence farmers are the only ones who cultivate and farm for food production. The area is unsuitable for crop production, according to the results of the climatic variables. As a result, poverty and food insecurity increased in the region.

As a result, the humanitarian response to the risk will improve. Responses could include the introduction of drought-resistant food crops, emergency responses to severely impacted areas, and the production of relief food for those affected. NDVI, in conjunction with climatic variables, had primarily aid in the identification of areas with the potential to sustain agricultural practices. Areas with high NDVI values has been highlighted on the map as potential crop lands.

Wajir County's NDVI levels were low during the brief rains. This explains the increased food insecurity in the region, as agricultural areas were limited. Wajir County, on the other hand, had some areas that could support crop production during long rains.

The vegetation indices were computed in this study to depict the spread of vegetation cover and aid in the analysis of the effects of the climatic variables in the study area. The results are represented in Figure 14

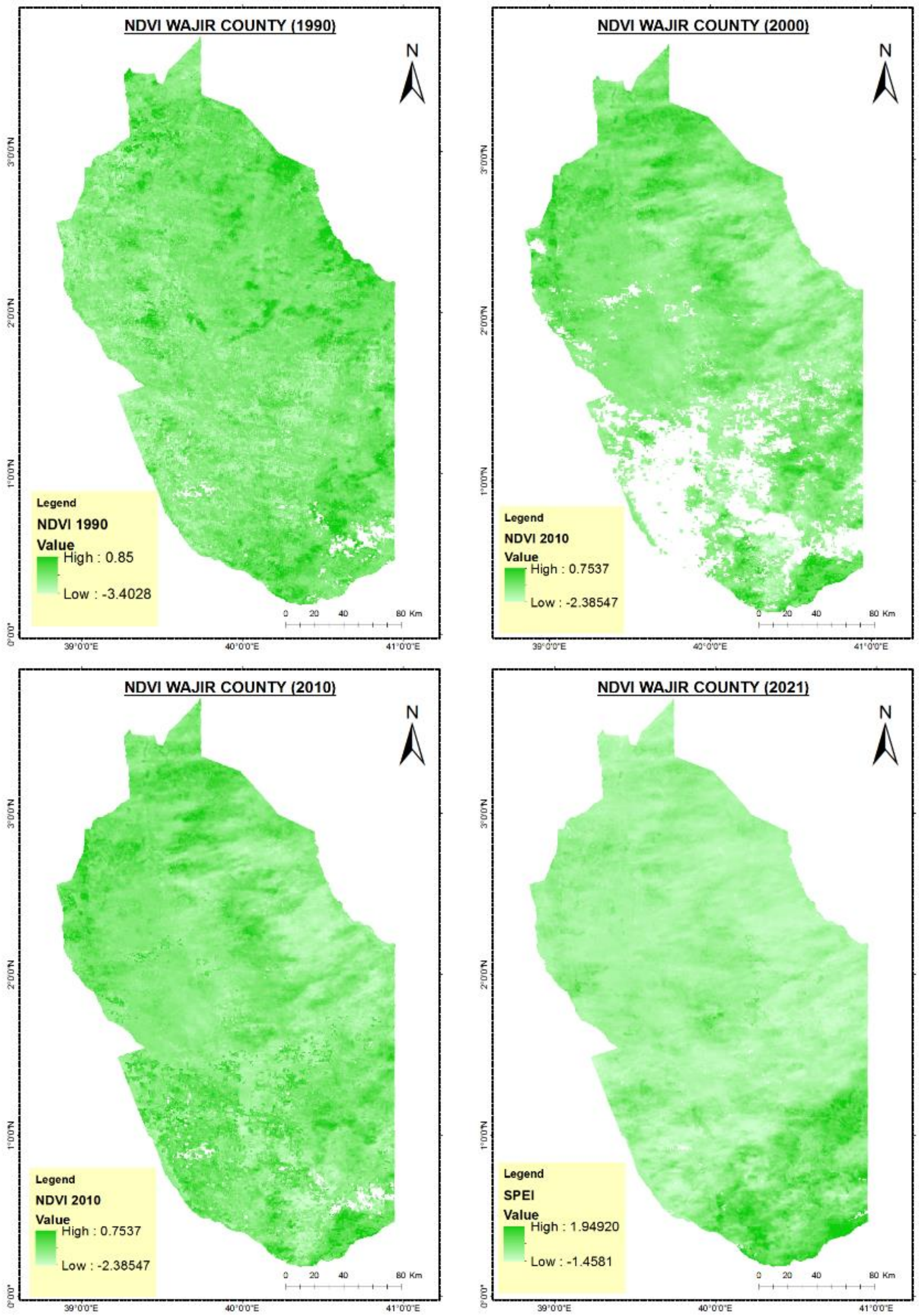


Figure 14:NDVI Wajir County (1990, 2000, 2010 and 2021)

4.2.2. SVI

In terms of vegetation condition, the Standard Vegetation Index is used in drought monitoring. Precipitation, temperature, and soil moisture are all necessary for plant growth in the ecosystem. The variation in the climatic variables mentioned resulted in differences in the area's green or vegetation condition. SVI is calculated using a timeline series and MODIS data with a resolution of 250m.

For SVI processing, different values were assigned to raw data pixels for proper masking. Table 8 displays the values and classes assigned.

Table 7: SVI Raw Data Processing Masking Threshold

Value	Class of Pixel
-1	Fill/No Data
0	Good Data
1	Marginal Data
2	Snow Ice
3	Cloudy

From the results, the index recorded for April 22, 2000 was -1.00 which indicated moderate drought. In the year 2010, the value recorded for the same date was 0.86. The difference in the index values was minimal due to the variation of the climatic variables including temperature and soil moisture. The higher the soil moisture, the lesser the drought index or rather the higher the standard vegetation index. For the year 2021, the value of the vegetation index recorded at -1.04.

Standard Vegetation Index is a drought monitoring index that encompasses the NDVI and determines the condition of drought in a certain area. For Wajir County, the results depicted that the county falls on an average of moderate to extreme drought conditions. Food production in a region should be equally proportional to a certain age threshold. According to National Drought Management Authority, the threshold should be an age of 29 years. Therefore, Wajir County's population is mostly characterized by people below 29 years. This will require more resources in terms of food production, health facilities and even education. Limited production of food crops results to poverty, hunger and food insecurity hence characterizing drought in the region.

There is a high dependency ration in Wajir County, indicating that the population is mainly dominated by young and an age bracket of above 65 years. Therefore, crop farming, agriculture and productivity is left for the middle-aged, who the minority are resulting to increased food insecurity, poverty and drought at large. Standard Vegetation Index is an agricultural indicator of drought. This index has been used to identify potential pastoral lands, hence be a guidance system for assessing potential grazing lands and resources. Standard Vegetation Index indicate severe drought in the county as only few areas are suitable for crop farming and pastoral lands.

The data was then pre-processed, and the standard vegetation calculated which is represented in Figure 15

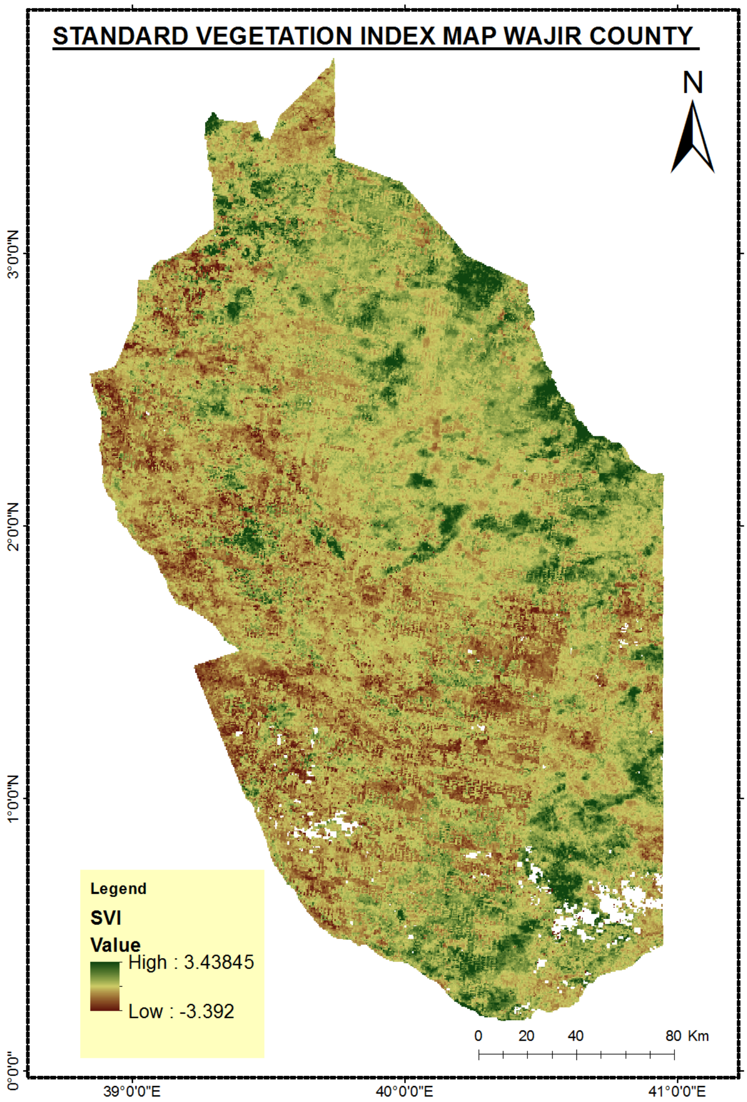


Figure 15: SVI Wajir County

4.2.3. PDSI

The Palmer Drought Severity Index is a tool for determining the level of wetness or dryness of a situation based on a variety of factors. The precipitation and temperature values were the main factors considered in this index. It includes several indices, including the Standard Precipitation Index (SPI), the Standard Precipitation Evapotranspiration Index (SPEI), and the Cumulative Vegetation Index, which corresponds to the Standard Vegetation Index (SVI). It considers the concept of water balancing in crop-producing areas in the area of interest. Moisture levels were also taken into account. This includes soil moisture, which is the amount of water emitted from the ground, as well as moisture in the air, which is derived from precipitation values. This index was created primarily to highlight drought indices based on vegetation growth potentiality in the areas. The value ranges are classified to show the level of drought, i.e., the wetness or dryness of a particular area.

Table 8 shows the value ranges.

Table 8: PDSI Classification Values

PDSI Value	Wetness/Dryness Level
4.0 or more	Extremely Wet
3.0 to 3.99	Very Wet
2.0 to 2.99	Moderately Wet
1.0 to 1.99	Slightly Wet
0.5 to 0.99	Incipient Wet
0.49 to -0.49	Near Normal
-0.5 to -0.99	Incipient Dry
-1 to -1.99	Mild Drought
-2.0 to -2.99	Moderate Drought
-3.0 to -3.99	Severe Drought
-4 or less	Extreme Drought

The data analysed was then represented on a map for the specific years of study; 1990, 2000, 2010 and 2021. The results are as shown in Figure 16.

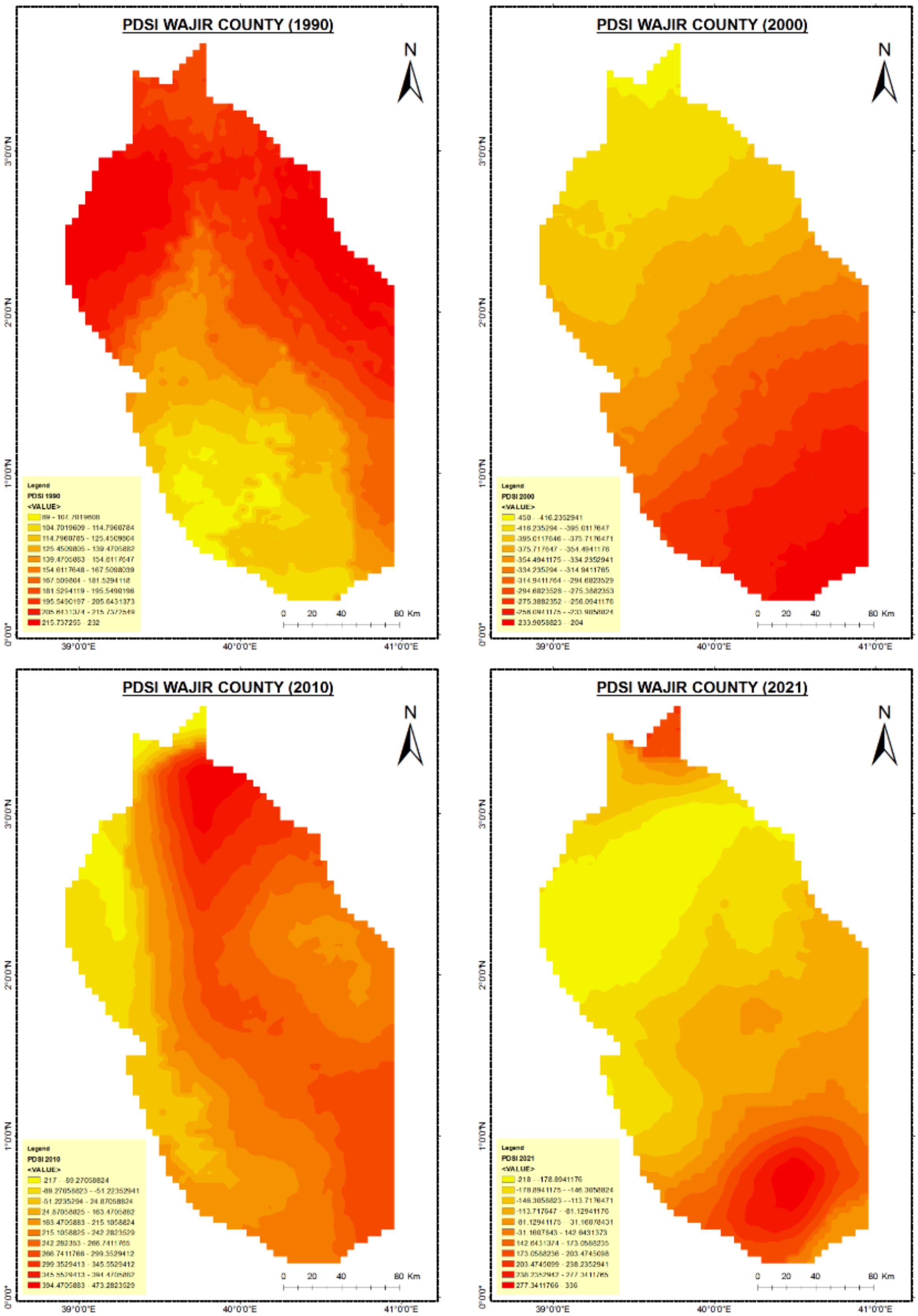


Figure 16:PDSI Classification images (1990, 2000, 2010, 2021)

In 1990, the highest value was recorded at 1.19 and the lowest value recorded at -1.73. This indicated that in 1990, the drought levels of Wajir County were ranging between slightly wet and mild drought. In the year 2000, the indices recorded were -4.31for the highest value and 1.83 for the lowest severity index. This indicated that in 2000, Wajir County was lying between extreme drought levels and slightly wet. In the year 2000, the drought levels were recorded at -4.87 for the highest value and 2.52 for the lowest severity index. This sows that in the year 2010, Wajir County was falling under extreme drought and moderately wet levels of the severity index. The moderate wet level was contributed by the increased rainfall capacities from the year 2000. In the year 2021, the following values were recorded for drought severity indices in Wajir County: -3.56 for the highest level and 2.16 for the lowest severity index. This indicates that in the year 2021, Wajir County was classified to fall under severe drought and moderately wet. These results were attributed by all the climatic variables, i.e precipitation, temperature, soil moisture and evapotranspiration.

Palmer's Drought Severity Index was used to determine the severity of the drought conditions or, more accurately, the extent of the drought in the area. The index values show that Wajir county was classified as being in severe drought, indicating the need for mitigation measures to avoid the effects of extreme drought conditions on the inhabitants. According to the findings, drought conditions in 2021 will be more severe than in 1990. The variation in the results is influenced by the area's weather and climatic conditions.

The study of drought severity trends aids in the monitoring and planning of mitigation measures to prevent adverse effects. Early warning bulletins can be issued to firms, organizations, and parastatals that are involved in the situation in order to formulate policies and mitigate the effects of drought in the region.

4.3. Hydrological Variables

This is a factor used to determine the level of ground water storage by prioritizing stream flow and flow accumulation. With flow accumulation knowledge, a correlation analysis between climatic variables and hydrological indices is possible, yielding results that show the drought severity index. Flow accumulation statistics were done for the area of study and the results produced in Figure 17.

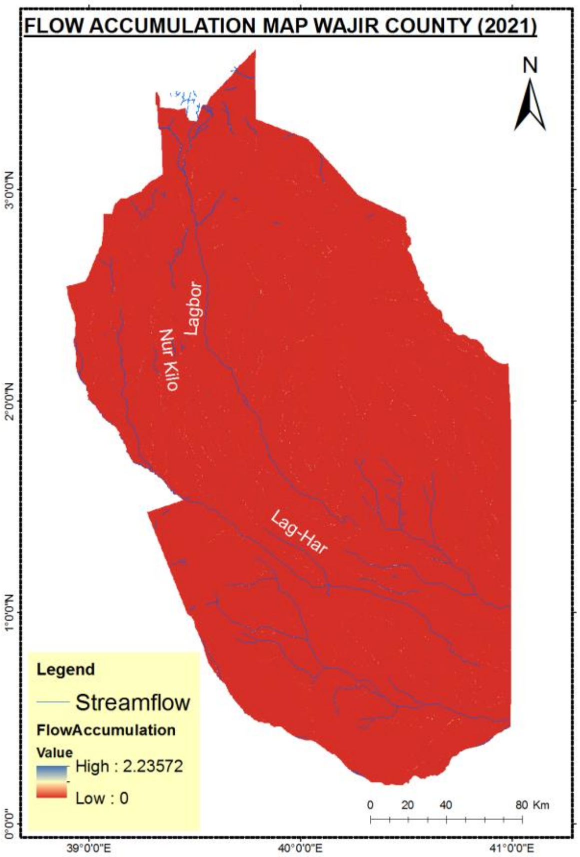


Figure 17: Flow Accumulation Wajir County

Flow accumulation is an important factor when it comes to drought monitoring as the results can be used to identify areas that are potential water sources. Areas that show streams attract more trekking and human movement as people are dependent on the available water sources for domestic use. From the above result, it is evident that the southern side of the county had more water sources than the other parts of the county. The main economic activity in the southern part of the county is pastoral keeping and limited agricultural practise due to the availability of water sources.

Hydrological indicators are on a seasonal basis, hence the study of the patterns of water sources can be an important factor in the planning of providence of alternative water sources to the inhabitants of Wajir County. Monitoring can be done on dried lagers and the existing ones to develop a water collection system for the inhabitants. Introduction of water pans and boreholes can be efficient when the points and places of ground water sources have successfully been identified.

4.4. Effects of the Climate Variables on Land Use Land Cover

Land Use Land Cover refers to the usage of land, either human-influenced or naturally. This was assessed using Landsat images and the results were represented on maps and bar graphs for the area changes of different classes for different years. Land Use Land Cover Classes were affected by all the climatic variables. The results are shown in Figure 18

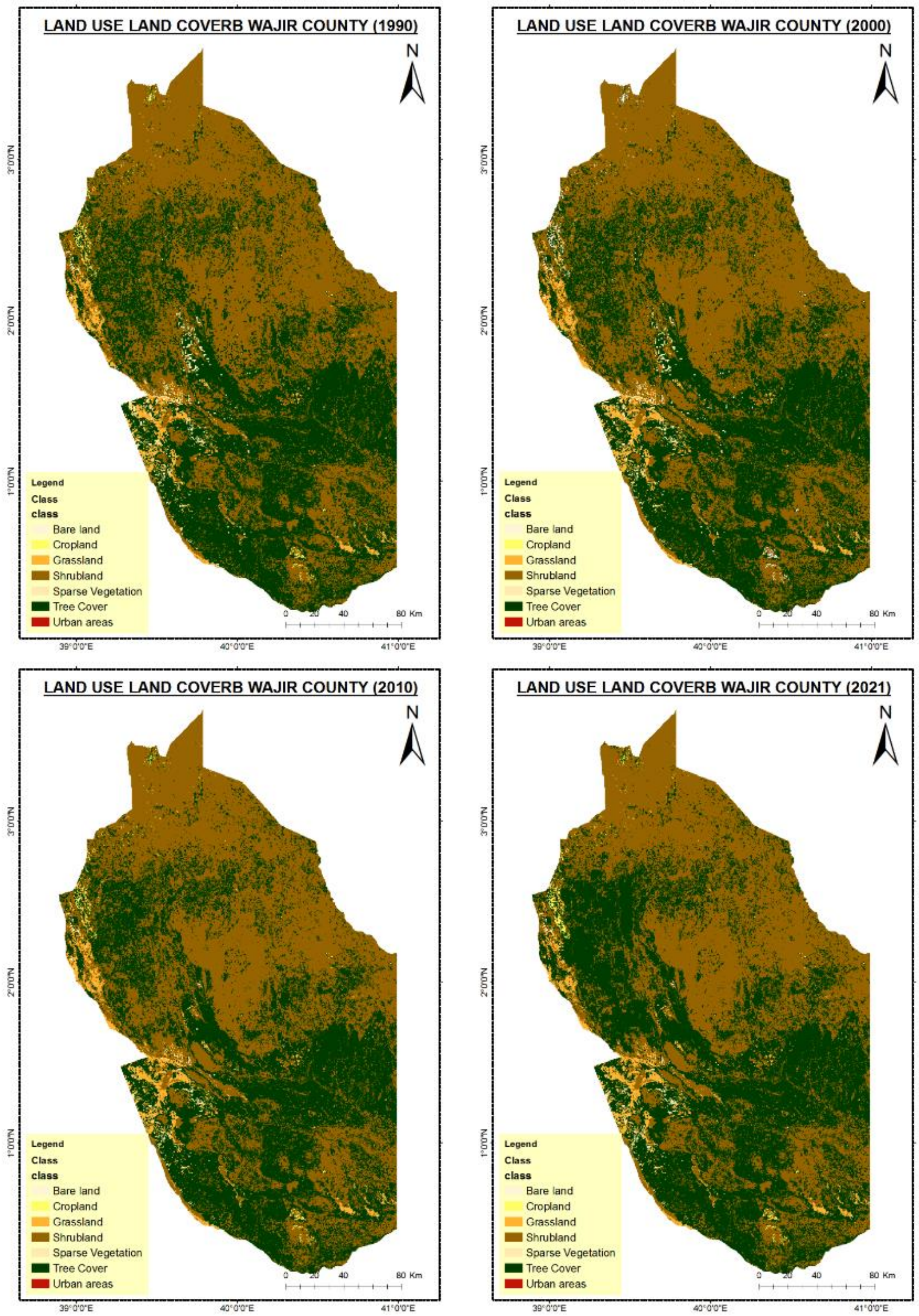


Figure 18: Land Use Land Cover Wajir County (1990, 2000, 2010, 2021)

Different classes were increasing and reducing depending on the variability on the climatic indicators. Total areas of different classes were calculated in square kilometres and the results represented in the following bar graphs:

1990

Table 9: LULC Area distribution 1990

Class	Area in km²
Croplands	149
Tree Cover	25875
Shrubland	28766
Grassland	1459
Sparse vegetation	395
Urban Areas	3
Bare Land	26

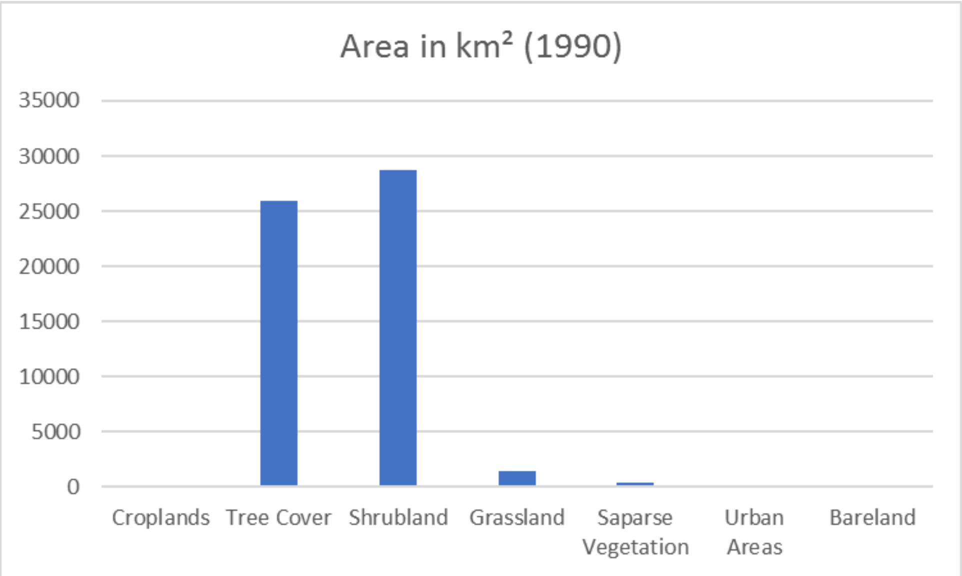


Figure 19: LULC Bar Graph (1990)

2000

Table 10: LULC Area Distribution 2000

Class	Area in km²
Croplands	149
Tree Cover	24 883
Shrubland	29713
Grassland	1533
Sparse vegetation	354
Urban Areas	3
Bare Land	30

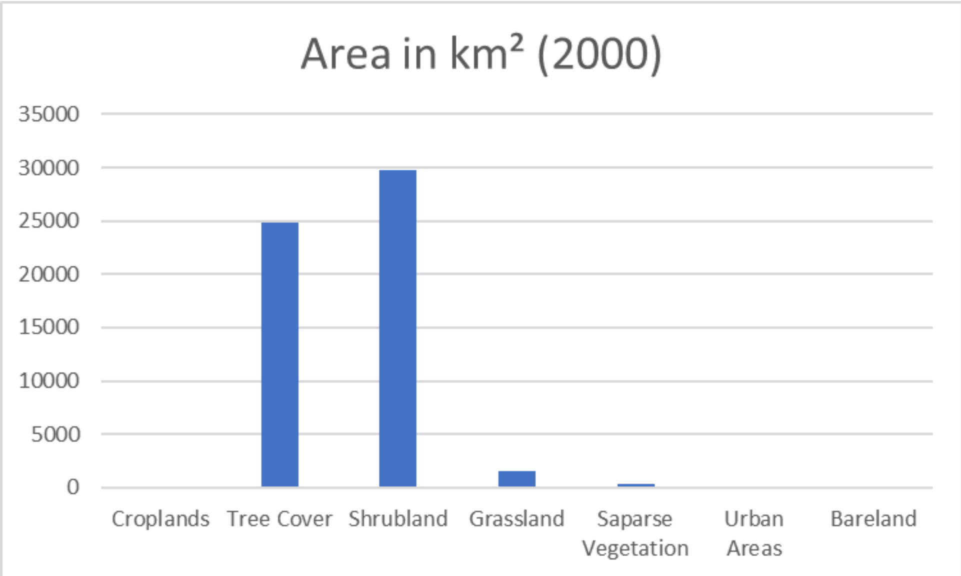


Figure 20: LULC Bar Graph 2000

2010

Table 11: LULC Area Distribution 2010

Class	Area km²
Croplands	155
Tree Cover	25321
Shrubland	28139
Grassland	1459
Sparse Vegetation	361
Urban Areas	3
Built Up	29

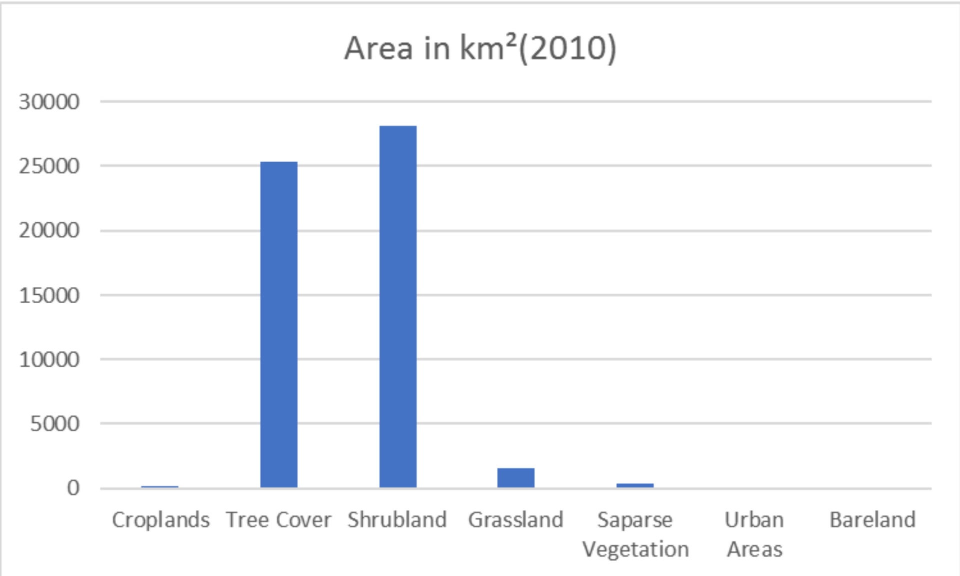


Figure 21: LULC Bar Graph 2010

2021

Table 12: LULC Area Distribution 2021

Class	Area km²
Cropland	153
Tree Cover	24391
Shrubland	27671
Grassland	1493
Sparse Vegetation	372
Urban areas	4
Bare land	27

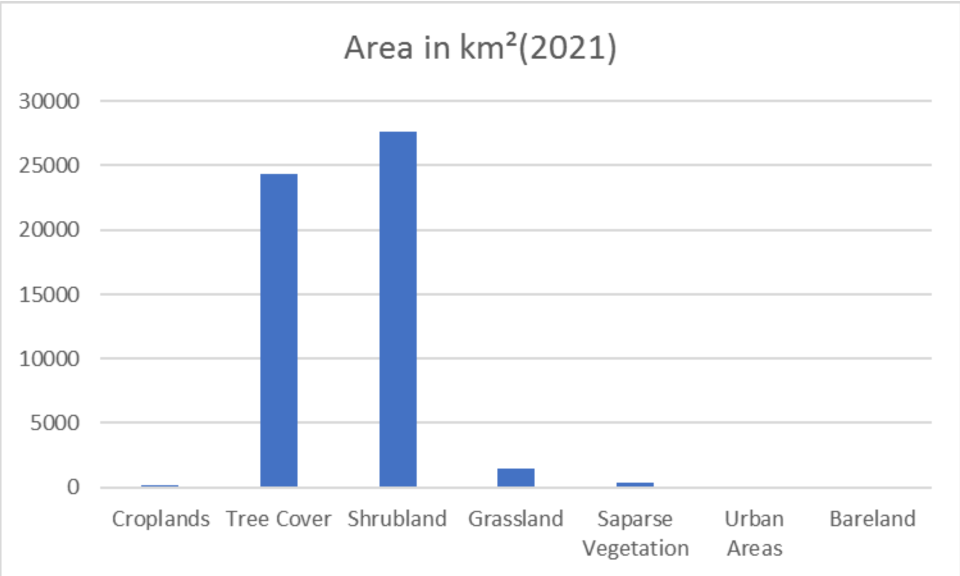


Figure 22: LULC Bar Graph 2021

As presented above, there have been relative, notable differences in the LULC classes from 1990 to 2021. For analysis, the paper has focused on the most recent presentation, that is, LULC distribution of 2010 and 2021. The area under crop cover in 2021 reduced by 1.2%, from 155km^2 in 2010 to 153km^2 in 2021. As Wajir is an ASAL region, there was positive correlation between the amount of rainfall received and the quantity of area under crop cover. The 2021 report by the National Drought Management Authority (NDMA) substantiate the aforementioned hypothesis. As reported by NDMA, short rains provide around 30% of the total annual food production in the county, which is a significant amount. However, the rainfall was insufficient in most sections of the county during the 2020 short rains season, with the exception of Wajir North sub-county, which is located along the highlands bordering Ethiopia.

The same could be said about the long rains experienced in the county. As reported by NDMA, the long rains began late in the second dekad of March 2021, as opposed to the usual first dekad of March. The county received between 51 and 75% of average rainfall, with certain unusual areas in Wajir South, Wajir West, Tarbaj, and Wajir East receiving between 5% and 25% of normal rainfall. Rains were not evenly distributed in space or time. The entire area planted in maize, sorghum, and pulses, the county's three primary crops, declined by 44%, 16%, and 34%, respectively, owing to a delayed commencement of rainfall that resulted in near-complete crop failure. Actual yields of the three major food crops fell by a whopping 58 percent.

The county saw little rainfall that was unevenly distributed in both time and location, resulting in a significant reduction in the area planted for different rain-fed crops and, as a result, a reduction in their performance, with crops drying prematurely. Apart from the low rainfall performance, the COVID-19 Pandemic weakened the community's purchasing power by reducing non-agricultural wage income, which in turn restricted access to agriculture supplies. The study closes by indicating that the present drought has had a substantial impact on over 450 hectares of food crops.

Other classes constituting the LULC such as shrubland, tree cover and grassland also reduced. Shrubland reduced by 1.7%, from 28138 km^2 in 2010 to 27671 km^2 in 2010. The area under tree cover reduced by 3.7% from 25321km^2 to 24391km^2. All these can be attributed to the significant reduction of both short and long rains experienced in the county. As reported by NDMA, the little, unevenly distributed rainfall resulted in reduced cropland cover. However, the percentage of area under grassland increased by %, from 1459km^2 to 1493$km^{2.}$ This can be attributed by a reduction in economic and activity, particularly livestock farming brought about by the COVID pandemic. NDMA reports that the COVID-19 Pandemic partially slowed down all economic activities in the county, particularly livestock and crop production.

4.5. Discussion

The purpose of this study was to evaluate climate variation in drought assessment monitoring. Drought in Wajir county was monitored using remote sensing and geographic information in this study. Different types of data were used to create indices for drought monitoring. The indices are as follows: Standard Precipitation Index (SPI), Standard Precipitation Evapotranspiration Index (SPEI), Standard Vegetation Index (SVI), Normalized Vegetation Index (NDVI), and Palmer's Drought Severity Index (PDSI), which is a weighted overlay of the other indices. The input factors for the development of the indices are climatic variables, hydrological variables, and vegetative variables.

Climatic Variables

Rainfall, temperature, evapotranspiration, and soil moisture data were used to calculate climatic variables. Their trends and analyses were completed and represented on maps from 1990 to 2021. When it comes to drought monitoring, climate is a critical factor. Variations in rainfall, temperature, evapotranspiration, and soil moisture impact aspects of the ecology and environment, resulting in effects on drought levels. Rainfall affects ground water content, which includes the wetness or dryness of the ground depending on the ground's ability to hold water. Ground water serves as a water source in the county, particularly for acquirers and dug wells. This therefore showed that areas with the lowest soil moisture content are prone to be affected by drought as compared to the other parts of the county. According to guidelines by FAO, drought monitoring results to the assessment and monitoring of food security in the area.

Hydrological Variables

These variables are in cooperated with the climatic variables using weighted overlay approach to determine the standard precipitation index of the county. Standard precipitation index is one of the indices used in drought monitoring. A threshold was given with different classes identifying the levels of drought in the area. According to the results, under the precipitation index, Wajir county falls under the class severely dry while other parts are extremely dry.

In cooperation of evapotranspiration results to the index Standard Precipitation Evapotranspiration Index which is also an index that is used in the monitoring of drought. The index has a threshold for drought monitoring and according to the results, Wajir county falls under moderate to severe drought. In wet seasons, the area falls under Incipient dry where the area has high humidity levels but low hydrological levels in terms of high temperatures and low rainfall capacities.

Vegetation Indices/Variables

These are variables that determine the greenness or the capabilities of crop yield in the county. These indices are used in drought monitoring as the vegetation condition, or the vegetative nature of the area directly applies to the condition of drought in the area. In this study, Normalized Vegetation Index (NDVI) was used and later on used to produce the Standard Vegetation Index (SVI) that has a threshold for drought monitoring. According to the results, the standard vegetation indices, Wajir County falls under severe to extreme droughts as most parts were characterized to experience extreme drought in terms of the vegetation cover of the county.

Palmer's Drought Severity Index

This is an index that is used in drought monitoring by combining the other indices using either weighted overlay or Analytical Hierarchical Process in determining the most and least drought-stricken areas. The threshold provided for this index involves all the factors that were used in generating the input indices for the model.

According to the results from Palmer's drought severity index, Wajir county falls under severe to extreme drought.

CHAPTER 5.0. Conclusions and Recommendations

5.1 Conclusions

The main objective of this study was to assess climate variability and its effects on drought in Wajir County. From the results depicted, Wajir County receives low rainfall and high temperature values that attribute to the level of dryness in the region. According to National Drought Management Authority, there are different indicators that can be used to monitor drought. One of the indicators are production indicators, these are the indicators that encompass livestock migration, milk production, livestock body condition, livestock deaths, actual planting date, area planted and actual harvest. All these indicators are directly affected by the climatic conditions of the area. The presence of water sources forms the hydrological variables affect livestock body condition, migration, milk production and even area of planting.

Climate variability affects the land use and land cover of the region. From the results above, there is a variation between tree cover, grassland, cropland and bare land. There was a gradual increase of croplands in the region up to the year 2010, but due to the locust invasion in 2020, there was a slight reduction of the croplands due to infestation by the flying pests. Cases of out-migration of livestock resulted due to the conditions of grasslands in the area where there was fluctuation for the year 1990 to 2021. According to a report from NDMA, the migration was mainly towards Wajir South, where from our results, seems to have favourable conditions for agro-pastoral activities as compared to the other parts of the county.

Wajir County is an ASAL area therefore it is characterized by arid and semi-arid regions. Wajir receives inadequate rainfall of approximately 400.98mm per year. The low moisture levels in most parts of the county indicated that the drought severity indices are high in most of the parts of the county.

The SPI values of Wajir County indicated that the frequency in which rainfall is received in the county is minimal with very high temperatures thus contributing to the increased drought severity indices all over the county. SPEI on the other hand being an aggregate of the different climatic variables, indicates that Wajir County mostly falls under the moderately wet and severe drought indices of the palmer's drought severity indices.

SVI determines the greenness or the vegetation indices of the area. From the LULC results, Wajir county is filled with sparse vegetation, scattered trees, shrubland and grassland. The health of the vegetation was below the threshold values required hence interpreting drought indices and making the county in study under the classes near normal and extreme droughts.

5.2 Recommendations

1. Development of policies and regulations for understanding the disaster risk that need to be followed in matters regarding to drought. Understanding of the disaster risk will allow formulation of relevant policies by bodies responsible for the catastrophe.
2. Strengthening of the disaster risk governance for better management of the risk. This fosters collaboration and partnership as mitigation measures, response, recovery and rehabilitation will encompass different governing bodies.
3. Proposition of usage of remote sensing and GIS maps in planning and development of policies that govern the situation on the ground. Future predictions using these maps will enable development of working frameworks for the situation.

   Others
4. Investing and prioritization of disaster risk management for resilience. This will strengthen the socio-economic, health and cultural resilience of the affected parties.
5. Sensitization of the local community on the drought levels of the region. This can be done by passing information to the ground on the on the methods of water conservation that need to be taken to avoid future adverse effects.
6. Prioritization of the most affected areas, to manage to come up with preventive measures and solutions on the most affected areas, as well as bright a hotspot.
7. Developing measures and interventions that will protect already affected areas. In that case of exploitation of natural resources, exercises like tree planting and building of gabions may be practiced to avoid adverse effects in the future.
8. Sensitization and training of policymakers on the effects of drought for awareness creation on the importance of water conservation measures.
9. Growing of thorny bushes is advised to stabilize dunes. This generally protects the area from wind erosion.
10. Adopt the conservation measures that were put in place in short-term recommendations for sustainable living and prevention of drought effects.

References

Articles in Journals

1. Liu, L., & Basso, B. (2020). Impacts of climate variability and adaptation strategies on crop yields and soil organic carbon in the US Midwest. *Plos One*. doi:https://doi.org/10.1371/journal.pone.0225433

2. Ocheng, J., Karimi, L., & Mathenge, M. (2016). Effects of climate variability and change on agricultural production: The case of small scale farmers in Kenya. *NJAS-Wageningen Journal of Life Sciences*, 71-78.

3. Traore, B., Corbees, M., Wjik, T., Rufino, M., & Giller, K. (2013). Effects of climate variability and climate change on crop production in southern Mali. *European Journal of Agronomy*, 115-125.

4. Bardsley, D., & Wiseman, N. (2012). Climate change vulnerability and social development for remote indigenous communities of South Australia. *Global Environmental Change*, *22*(3), 713-723. doi: 10.1016/j.gloenvcha.2012.04.003
5. Qutbudin, I., Shiru, M., Sharafati, A., Ahmed, K., Al-Ansari, N., & Yaseen, Z. et al. (2019). Seasonal Drought Pattern Changes Due to Climate Variability: Case Study in Afghanistan. *Water*, *11*(5), 1096. doi: 10.3390/w11051096

Web-based Articles

6. FAO. (2022). *Desert Locust Crisis* . Retrieved from Food and Agricultural Organization: https://www.fao.org/emergencies/crisis/desertlocust/en/

7. FAO. (2022, February 5). *Drought in the Horn of Africa – Rapid response and mitigation plan to avert a humanitarian catastrophe*. Retrieved from Food and Agricultural Organization: https://www.fao.org/emergencies/resources/documents/resources-detail/en/c/1469293/

8. NASA. (2014, April 9). *MODIS Vegetation Index Products (NDVI and EVI)*. Retrieved from National Aeronautics and Space Administration: https://modis.gsfc.nasa.gov/data/dataprod/mod13.php

9. UCAR-Center for Science Education. (2022). *Climate Variability*. Retrieved from UCAR: https://scied.ucar.edu/learning-zone/how-climate-works/climate-variability

10. Wheeler, R. (2022, January 5). *Development of Kenya Food Security Coordination System (KFSCS)*. Retrieved from Enn-Online: https://www.ennonline.net/fex/12/development#:~:text=This%20steering%20group%20first%20called,monitoring%20and%20assessment%20system%20for