DROUGHT PREVALENCE IN THE HORN OF AFRICA AND ITS IMPLICATIONS ON FOREST COVER: A CASE STUDY OF SOMALIA

MUSEI KIPNGENO SYLUS

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF MASTER OF SCIENCE IN PLANT ECOLOGY OF THE UNIVERSITY OF EMBU

NOVEMBER, 2020

DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

Signature…………………………… Date…………………………….................

Musei Kipngeno Sylus

Department of Biological Sciences

B521/1200/2018

This thesis has been submitted for examination with our approval as the University supervisors

Signature…………………………… Date………………………………………

Dr. Justin M. Nyaga

Department of Biological Sciences

University of Embu

Signature…………………………. Date………………………………………

Dr. Abdi Zeila

Department of Land and Water Management

University of Embu

DEDICATION

This thesis is dedicated to my family. My late father Mr. Joel T.T. Sambu, who, unfortunately, didn’t live long to witness my academic accomplishments and my loving mother, Mrs. Robina Sambu, whose prayers and commitments saw me through this journey are worth special mention for their years of dedication and nurturing. I also wish to dedicate this work to my brothers and sisters whose endless love energized me whenever I felt low, particularly my eldest brother, Mr. Kipkoech Cosmas, who tirelessly supported me throughout this process.

ACKNOWLEDGEMENT

First, I thank my supervisors Dr. Abdi Z. Dubow and Dr. Justin M. Nyaga of the Department of Land and Water Management and Biological Sciences respectively at the University of Embu for their unwavering support throughout my thesis journey. Dr. Nyaga was ever willing to help whenever I had an issue concerning my research right from proposal stage to the final stage of thesis writing. He always steered me in the right direction and provided guidance unstintingly. I also thank Dr. Abdi for the sincere support right from formulation of the research idea, for the guidance into ensuring that what I had was researchable. Not forgetting the support in designing the data collection tools besides the vast field work opportunities that endowed me with experience in data handling techniques.

Secondly, I acknowledge the University of Embu for the scholarship that saw me through my master's studies.

Finally, I must thank my family for both moral and financial support throughout the research cycle. Without their hand, this achievement would have been impossible. Thank you.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

ASAL	Arid and Semi-Arid Land
DINA	Drought Impact and Needs Assessment
ECA	Economic Commission for Africa
FRA	Forest Resource Assessment
GDP	Gross Domestic Product
GEE	Google Earth Engine
GWP	Global Water Partnership
IPCC	Intergovernmental Panel on Climate Change
LADA	Land Degradation Assessment in Drylands
MODIS	Moderate resolution imaging spectrometer
NAR	Near Infrared
NASA	National Aeronautics and Space Administration
NIR	Near Infrared
NCA	Natural Capital Accounting
NDVI	Normalized Difference Vegetation Index
PDSI	Palmer Drought Severity Index
SDG	Sustainable Development Goals
SPEI	Standardized Precipitation Evapotranspiration Index
SPI	Standardized Precipitation Index
WMO	World Meteorological Organization
WOCAT	World Overview of Conservation Approaches

ABSTRACT

Somalia is one of the most drought prone countries in Africa. Drought is the country's costliest natural disaster. The impact of drought events on the economy, on people`s livelihoods and on lives has grown. Drought events usually develop gradually unnoticed, causing tremendous effects on both agriculture and environment. This study evaluated the spatio-temporal variations of drought occurrences in Somalia and its implication on forest cover. In this study, precipitation and temperature variables were taken as a proxy to assess and quantify long-term drought in Somalia. The intensities, frequencies and trends of drought occurrences were analyzed using Standardized Precipitation Evapotranspiration Index for the multiple timescales of 1-, 3-, 6-, 12-, and 24-month. Drought maps were done using Normalized Difference Vegetation Index during the period 1982 to 2015. Hansen data was used to account for forest cover change whereas a sample of 20 papers were reviewed in order to determine the best fit land degradation mitigation measures. Temporal variations in drought showed decreasing trends in severity and increasing trends in drought duration as the SPEI timescales increased. The major drought event as identified by SPEI 12 occurred during the period between May 2011 and January 2013, lasting for a period of 12months with an intensity of -0.55. Furthermore, drought count was generally high in the southern parts of Somalia and entire country had suffered droughts ranging from moderately dry to severely dry conditions. An average drought duration of between 2 and 3 months was recorded for most (81%) of the locations. About 23 % of forest cover was lost from 79,294 ha to 67,199ha from 2000 to 2019 representing a loss of 1,058ha per year. The study findings show the need for immediate actions to tackle drought and hence poverty and famine in Somalia. A combination of remote sensing tools conservation practices (such as agroforestry, afforestation, reforestation and conservation agriculture) is ideal for monitoring and mitigating land degradation effects respectively.

CHAPTER ONE

INTRODUCTION

1.1 Background

Globally, natural disasters now occur nearly five times as often as 40 years ago (Ghebrezgabher *et al*., 2016). Consequently, droughts have continued to have increasing substantial social and economic consequences. In most cases, drought is only felt when natural disasters (insect migration, forest fires etc.) happen or when there is inadequate water for human or agricultural needs (Clark et al., 2016). Nonetheless, even moderately severe droughts can lead to damaging effects on the structure and functionality of vegetation resulting in ecosystem changes (Ensham & Airfax, 2012).

Climate change has led to increased frequency of droughts and floods across the globe. Droughts in particular have had devastating effects on populations, causing more human deaths than other natural disasters. An assessment of drought disasters covering the period from 1900 to 2004 associated 50% (out of the 22 million deaths caused by natural disasters) with drought (Parry et al., 2004). Although drought can occur anywhere in the world, drylands are highly prone. Drylands are estimated to cover 41% of the global land. Therefore drought have a highly significant potential to lead to damaging impacts (Johnson & Mayrand, 2007).

Droughts that occurred during the period between 1970 and 2017 resulted in more than 800,000 deaths globally according to Somali Drought Impact Needs Assessment (DINA) report (World Bank, 2018). The report also noted a decline in Gross Domestic Product (GDP) and a rise in conflicts as a result of these droughts. The major huddles to sustainable development in Africa are droughts and forest destruction (Nyong & Adesina, 2007).

About 67% of Africa is categorized as drylands and therefore has a great potential for land degradation according to the United Nations Economic and Social Council (UN Ecosoc) 2007 report (UN Ecosoc, 2007). According to this report, most parts of Africa have undergone some level of degradation that has impacted a minimum of 485 million people in Africa. Desertification in Africa is not only a cause but also a product of high levels of poverty and unsustainable extraction and use of natural resources. This has led to poor economic growth, food insecurity and political instability in the continent. In the Great Horn of Africa, drought occurs frequently causing destruction to both the environment and the natural resources (Wollburg, 2019). This is mainly due to climate changes, high rates of population growth, inadequate institutional frameworks, political instability and elevated poverty levels (Abdulkadir, 2017).

The worst drought was experienced in the Horn of Africa during the 2011 summer (Ghebrezgabher et al., 2016). This drought affected Kenya, Ethiopia, Somalia, Djibouti and Eritrea. This followed very low rainfall during the short (October-December 2010) and long (April-June 2011) rain seasons. This drought caused huge reductions in annual crop production resulting in worst harvests, high death of animals and elevated cost of food (Fredriksen, 2016). UK Meteorological service associated the low levels of rainfall that was experienced during the short rain season to LaNiña conditions (Behera et al., 2005). The effects of the 2011 drought were majorly felt through decline in food production but in Somalia the impacts were more sever and resulted in famine (Anderson et al. 2012). The Drought Impact and Needs Assessment conducted by the World Bank in 2017 showed that the 2016/2017 drought caused damages and losses valued at $3.25 billion out of which 600 million US Dollars was recorded for restoring the impacts on both the environment and natural resources (World Bank, 2018).

The main source of livelihood for millions of Somalia citizens is dependent on environment and natural resources. Their reliance on this sector has had significant impacts such as depletion of vegetation and other natural resources. In 1990 Somalia had 13% forest cover which dropped to 10.7% by 2010. A 27 % rate of tree loss was recorded between 2001 and 2006 in north-eastern Somalia (Ginnetti & Franck, 2014). The drought that occurred between the year 2016 and 2017 in Somalia resulted in detrimental consequences on the environment. As a result, about 68 percent of vegetation was destroyed (an equivalent of 113,282 km^2) which is approximately 18 percent of the total landmass in Somalia. Generally, this drought caused destruction and losses in the environment sector to a tune of 564.8 million and 610.7 million US dollars respectively (World Bank, 2018). It also encouraged over-extraction of natural resources because of the reduced usual sources of livelihoods.

Drought monitoring techniques that depend on satellite data have recently gained global popularity because acquiring such information is cheap, and the data have good spatial and temporal resolutions that are highly reliable. Several drought indices can be used to fulfill the same. These include the Palmer Drought Severity Index (PDSI), Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI). The disadvantages of using PDSI include high interference from the calibration timing and poor spatial resolution. It is also subjective in characterizing drought conditions (Chen et al., 2018). The main setback of PDSI is the fixed time scale of recording indices which do not allow assessment of categories of drought occurring at varying time scales. On the contrary, SPI can be calculated easily and at varied timescales. However, SPI is disadvantaged by the monthly temporal resolution because the mechanisms through which drought develop is not captured. SPEI was developed to circumvent the limitations of SPI. it is an extension of SPI but takes into account both precipitation and potential evapotranspiration (Li et al., 2019). This index is generated from both temperature and precipitation thereby combining the respect of the PDSI to variations in evaporation demand with the ease of computing and the multi-timescale nature of the SPI.

Moderate resolution imaging spectroradiometer (MODIS) NDVI is used to show the response of vegetation to drought impacts in different regions with varying ecological conditions. This is because MODIS data have advanced wide spectral, high distribution in time and is cheap. NDVI can also be used to measure and monitor the conditions of vegetation because it has high correlation with the canopy of vegetation (Khosravi et al., 2017).

Previous drought assessment studies in Somalia made use of (SPI) and (PDSI) which do not fully account for drought severity status as they do not include the role of temperature increase in their computation (Stagge et al., 2014). This study attempted to fill the gap by using SPEI, which takes into consideration both temperature and precipitation plus evapotranspiration in its calculation. SPEI was used to characterize spatiotemporal distribution of meteorological drought from 1990 to 2018. On the other hand, NDVI was used to determine the variation of forest cover with changes in meteorological drought incidences (Li et al., 2015).

This study also attempted to determine the best fit sustainable management methods for mitigating land degradation through systematic review of the available literature. This provides information that can support policy development process, or the designing of programs or projects for adoption of drought mitigation practices.

1.2 Statement of the problem

Drought has detrimental impacts on both the growth and survival of plants. Droughts also affects the structure, composition and function of forests, consequently derailing the ability of the forest to provide ecosystem services. Globally, extreme droughts have already caused significant forest degradation resulting in a decline in forest productivity. The frequency and intensity of drought is expected to rise due to climate change. This is likely to worsen the impacts on the forest structure and function. Droughts have also promoted encroachment of the pastoralists into the forest due to lack of pastures for their livestock. How drought regimes affect forest structure and stability depends on its frequency, intensity and temporal extent. However, it is still difficult to quantify the spatiotemporal distribution, magnitude and intensity of drought. This triggered development of objective drought indices. Nevertheless, there is little, up-to-date scientific literature that is available on the characterization of droughts using these indices in Somalia.

1.3 Justification

The first Sustainable Development Goal aims at eliminating high levels of poverty and hunger by 2030. This is tied to achievement of food security and natural resource conservation which is curtailed by natural hazards like drought. Somalia is the most affected by drought relative to other countries in Africa. However, previous drought assessment studies have focused majorly on smaller regions in the country and failed to capture the countrywide status. Furthermore, these studies made use of PDSI and SPI that are not based on temperature yet drought occurrence is greatly influenced by the rising temperatures. The focus has also been majorly on drought impacts on food production and water availability with little attention on the impacts of these droughts on forest cover.

There is therefore need for a country-wide assessment that can better inform the government and the relevant institutions on the drought patterns and the most applicable mitigation measures that suits Somalia.

1.4 Objectives

1.4.1 General Objective

This research aimed at determining the trends of occurrence of meteorological drought and its impacts on forest cover and also propose recommendations on the best fit sustainable management method for mitigating land degradation in Somalia.

1.4.2 Specific Objectives

1. To characterize meteorological droughts in Somalia between 1990 and 2018.
2. To quantify forest cover loss in Somalia between 1990 and 2018.
3. To determine best-fit sustainable management methods for mitigating land degradation in Somalia.

1.5 Research questions

1. What are the characteristics of meteorological drought in Somalia?
2. What amount of forest cover has been lost in Somalia from 1990 to 2018?
3. What are the best sustainable management methods for mitigating land degradation in Somalia?

1.6 Conceptual Framework

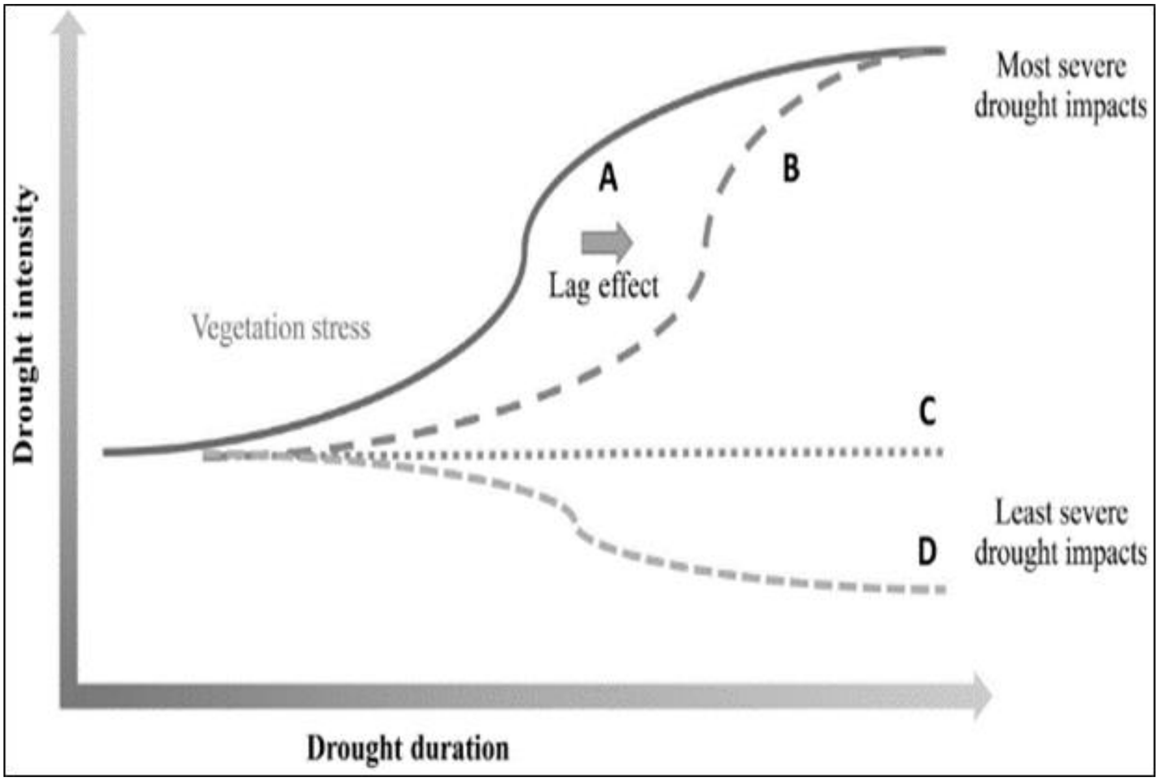

Figure 1: Conceptual framework for drought assessment.

Source: Perret *et al* (2018)

Figure 1 on conceptual framework shows drought impacts on vegetation with time. NDVI can be used to measure the vegetation stress and the drought duration and intensity can be determined using SPEI. In this framework it is assumed that there is insufficient rainfall throughout the covered time. The first scenario (A) depicts a case with an immediately increasing vegetation stress due to insufficient rainfall. Other possibilities include scenario (B) that shows vegetation taking some delay period before experiencing stress, scenario (C) indicating a no change situation or scenario (D) where vegetation stress is on the decline.

CHAPTER TWO

LITERATURE REVIEW

2.1 Drought occurrences

Drought is a hazardous climatic phenomenon denoted by lack of enough rainfall experienced over a long period of time and over a given land (Dai, 2011). American Meteorological Society categorized drought into four major types (meteorological, hydrological, agricultural, and socioeconomic) (Li *et al*., 2015). Meteorological drought refers to a period with below-normal precipitation that lasts for months to years. This type of drought occurs frequently and in most cases lead to occurrence of other types of droughts (Mishra & Singh, 2011). Agricultural drought is indicated by dry soils and occurs due to less frequent rains that retards plant growth resulting in reduced crop yields. Hydrological drought occurs when stored water get depleted and is not replenished (Dai, 2011). It occur when river and water reservoirs, aquifers drop to levels that are lower than the usual average. Socioeconomic drought is denoted by economic effects of meteorological, hydrological and agricultural droughts (Clark *et al*., 2016).

The fifth assessment report of Intergovernmental Panel on Climate Change (IPCC) indicated increasing trends of global warming since 1950s (IPCC, 2014). This is likely to cause an increase in the global temperatures which consequently affect the water cycle, including changes in the rainfall patterns and increased natural phenomena like drought (Sheffield & Wood, 2008). Such temperature increases have resulted in increased rates of occurrence and severity of meteorological disasters. Research has shown that over 45 percent of the global land is susceptible to drought (Li *et al*., 2019).

Historically, approximately 20% of the global land is experiencing drought at any given time. This value has grown to 28% and is predicted to increase to 35% by this year (2020) (Sheffield & Wood, 2008). Compared to other meteorological hazards such as tornados, hurricanes and floods, drought is a unique event which can occur without any signal and can last for a long period of time (Sheffield *et al.*, 2012). Drought is a complex phenomenon that results in several damages to the socioeconomic and environmental sectors (Van Loon, 2015). In the recent past droughts have resulted in high prevalence of famine in many Asian and African countries. It is a global problem whose impacts are felt in large areas and even beyond country borders. For example, in Iraq food insecurity is expected to persist due to extreme weather events that causes drought (Verma *et al*., 2017). Since drought results from decrease of precipitation below its common average, it leads to reduced groundwater recharge and reduction in soil water resources. This consequently leads to declining trends of land and vegetation production levels (Vicente-Serrano *et al*., 2013). For example, the drought severity conditions in northern parts of China have been increasing in recent past and is projected to continue increasing in the coming years. Due to the consequences that droughts can bring to food production, water supply and the environment as a whole, some severe droughts have attracted wide attention in the recent past. These include the Millennium drought in Southern Australia (Kiem *et al*., 2016), the centurial droughts in Southwestern parts of China (Lin *et al*., 2017), East African drought (Lyon, 2014) and the drought that occurred recently in California (Cheng *et al*., 2016)

The main type of natural disaster that hits Africa frequently causing high levels of household insecurity is drought (Calow *et al*., 2010). In most African countries, the local population is threatened by severe drought impacts which in most cases leads to consequences such as loss of both human and animal lives, famine and lack of sufficient food resources. The world food program estimates that about 10 million people are faced with food insecurity while malnutrition claimed lives of tens of thousands in Somalia, a situation brought about by 2011 drought (Nicholson, 2014). This drought also led to severe food insecurity in the almost the entire Horn of Africa with major impacts felt in parts of Djibouti, Ethiopia, northern Kenya and Somalia. It also resulted in increased population displacement and food price increase (Yuan *et al*., 2013).

Agriculture is the main contributor to the East African country`s GDP. It is approximated that agriculture accounts for 25%, 51% and 42% of the GDP for Tanzania, Kenya and Uganda respectively (Mwangi *et al*., 2014). Damages and destruction caused by drought on agriculture therefore leaves the region with a lot of risk of extreme consequences such as famine and deaths. For example the deaths and food shortages that resulted from the droughts which occurred in the last two decades (2008 to 2009 and 2010 to 2011(Mwangi *et al*., 2014).

Climate change will either directly or indirectly affect forest dynamics. For example, it affects the spatial distribution of vegetation types, ecosystem structure and function, and the presences and diversity of flora (Malcolm *et al*., 2006). Extreme climatic conditions is predicted to result in extinction of sub boreal and the montane climate regions in Colombia consequently leading to habitat destruction and fragmentation for the valuable conifer species (Hamann & Wang, 2006). Drought coupled with rising temperatures is destructive to forests globally. Some of the forest mortalities reported in the world includes: the vast death of Eucalyptus in the Northern parts of Australia during the early 1900s which resulted in a severe drought (Fensham & Holman, 1999).

Somalia has a long history of droughts as compared to other countries in East Africa. Droughts were experienced multiple times in the region during the periods; 1974-1975, 1984-1985, 2005, 2008 and 2010-2011 (Alwesabi, 2012). These droughts have resulted in severe effects such as famine, deaths of the people from both famine and malnutrition and even displacement. Drought impacts have been catalyzed by a number of factors in Somalia. These factors include pastoralism as a way of livelihood, civil unrest and the high rates of population growth (Alwesabi, 2012).

The 2003-2007 drought caused 21.6% loss of aboveground biomass in the Mulga Lands bioregion in Queensland (Ensham & Airfax, 2012). During 2012–2015 drought, about 10.6 million hectares of forest harboring up to 800 million trees were affected (Asner *et al*., 2015).

The drought that occurred between 2016 and 2017 in Somalia caused severe damages to the environment. As a result about 68% of vegetation was lost. In general, this drought caused environmental destruction worth around 1175.5 million USD (World Bank, 2018).

2.2 Remote Sensing and Geographic Information System-based Drought Assessment

Drought assessment entails a number of activities. It includes all activities towards drought identification, quantification, characterization, evaluation and monitoring. The purpose of drought assessment influences its characterization and monitoring (Mendicino *et al.*, 2008). However successful analysis of drought characteristics requires vivid assessment of its spatial and temporal properties (Shahid & Behrawan, 2008). Challenges facing comprehensive assessment of drought mainly arise from the scarcity of available data. This calls for the use of remotely sensed data since satellite data is capable of capturing the spatial and temporal properties of drought (Gonzalez-Hidalgo *et al.,* 2018). Drought assessment yields drought properties in terms of intensity, duration, severity frequency and socioeconomic impacts depending on the timescales in which the drought indices are recorded.

Remote sensing and GIS facilitate capturing of up-to-date and timely information on drought. This enables users to evaluate the drought characteristics and trends in a more effective way (Zhou *et al.,* 2017). Remote sensing involves collection of data about an object, place or an event without necessarily touching it or being in that place or attending the event. Various satellites facilitate easy retrieval of climatic parameters such as precipitation and temperature that are useful in calculation of drought indices (Alizadeh & Nikoo, 2018). Satellites give aerial view of land cover, vegetation and hydrological resources thus can facilitate spatial and temporal evaluation of drought distribution (Choubin et al., 2019).

2.4 Natural Capital Accounting

Natural capital accounting can be defined as a procedure of collecting information on the status and flows of natural capital (SEEA UN, 2012). It involves organized recording of information on natural capital such as mineral and biological assets and assessment of the flows from these assets including ecosystem services to human wellbeing in a consistent and comprehensive manner. According to the Natural Capital Coalition, natural capital refers to the vast natural resources that are beneficial to human beings. This is an important capital in developing countries because of its huge input into countries wealth whereby it contributes about (36%) (Coalition & Keynes, 2016).

The Brazilian Amazon Forest ecosystem has a potential to contribute $8.2billion annually to the country`s economy if it is well conserved. This contribution is through services to man for example food production, supply of raw materials for industrial use, greenhouse gas mitigation as well as climate regulation. According to the United Nations Inclusive Wealth Index, natural capital for 140 countries declined between 1992 and 2014. Despite the decline, there has been noticeable growth in GDP among these countries (Managi & Kumar, 2018). This is because GDP have limited representation of natural capital since it takes into account overall income in determining the growth in their economy leaving out the ability of the natural resources to generate wealth (Mardones & del Rio, 2019). Countries that include timber from forests in their accounts often omit other forest functions such as flood control, carbon storage and sequestration and even water and air cleaning and cycling.

Recently, many countries have ratified natural capital accounting into their national accounts However, carrying out natural capital assessment at the national level is not yet adopted by several countries globally. The linkages between the natural assets, services and the final benefit to human beings can be represented in a diagram as shown below:

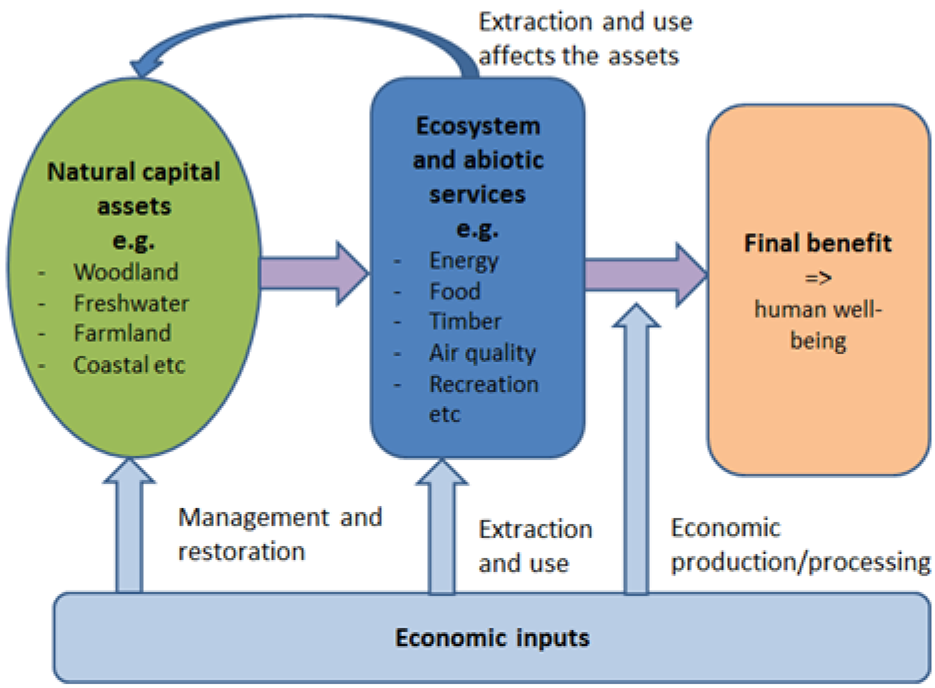

Figure 2: Linkages between the natural assets, services and the final benefit to human beings.

Source: Department for Environment, Food and Rural Affairs (Defra), UK

2.4.1 Natural capital accounting for forest resources.

Forests are beneficial ecosystems capable of generating a wide range of benefits. They have benefits to the economy, environment and society in general (Willis et al., 2003). Various products and services which improves environmental conditions, human well-being and economic status can be obtained from the forests. For many years, there has been no commonly agreed methodology for estimating forests social, economic and environmental benefits. Currently, there exist an internationally accepted methodology for accomplishing systematic forest accounting: the United Nations Statistical Commission's System of Environmental–Economic Accounting 2012 (SEEA) Central Framework and the SEEA Experimental Ecosystem Accounting.

In developing countries, approximately 80% of their citizens rely on forest goods and services for their basic health and nutritional needs (Pearce, 2001). Despite economic contribution, forests are also important in cultural restoration and maintenance and improves the quality of life for millions of people (Dovie, 2003; Shackleton et al., 2007; Harshaw et al., 2009). Sustainable extraction and utilization of forest products can further enhance income and provide alternative to tropical deforestation (Dlamini, 2012). However, the extent to which forests contributes to rural income is poorly captured in literature (Dlamini and Geldenhuys, 2011). This is because most of the services provided by forests (storage of carbon dioxide, maintenance of regional climate and conservation of biodiversity) are indicated by the externalities of the companies investing in large-scale economic operations. Furthermore, a wide range of natural products from forests, woodlands, river and lakes is extracted and used for subsistence purpose or exchanged at a local market by the adjacent communities and therefore do not attract a lot of commercial investments and non-local decision makers (Gram, 2001).

2.4.2 Profile of forests in Somalia

Somalia has a total land area of 63 766 000 ha out of which 9.98% (6, 363, 000) ha is occupied by forests. Table 1 shows the classes of forest in Somalia.

Table 1: Size of various classes of forest in 1980

National Class	Area in 1000 ha
Closed Forest	1 537
Open forest	7 510
Plantations	3
Total forests	9 050
Other land	54 716
Total country area	63 766

Source: Somalia Forest Resource Assessment Report

2.5 Land degradation

Land degradation is a harmful ecological phenomenon, which various researchers have identified and looked at in many aspects. Some have found it to reduce overall soil productivity (agricultural) potential (Foster, 2006) or to decline ecosystem-based functions for the long term (Bai et al., 2008). UNEP (2001) explains it as the process that natural resources have evolved adversely over time due to various human activities on land. It is also described in a broad term as land degradation resulting from varying climatic events in synergy with anthropogenic activities (Blaikie & Brookfield, 2015).

Despite the discrepancies in different meanings, a convergence on characteristics of land degradation exist: it induces deterioration of land capacity to operate normally (for example in provision of food and habitat and water and air cleaning). Degradation of land often begin with minor indicators and gradually develop visible characteristics (Bajocco et al., 2012). Such incremental progress in many parts of the globe renders it insignificant until the deterioration is very advanced. As a result, efforts have been made to control land degradation at advanced stages which have proven to be relatively costly and lenient to handle.

Land degradation effects partially explain why there is a global threat to land productivity (Vogt et al., 2011), further worsened by lack of policies and recommendations to combat the deterioration of soil quality (Bai et al., 2008). Land degradation affects ecological processes and these effects can be worsened by anthropogenic activities. It will take seasons or years for noticeable characteristics of land degradation to be witnessed, often overlooked until when it is at advanced levels because of its progressive nature (Schwilch et al., 2018). It leaves a wake of destruction during its development that may be hard and expensive to eradicate if its control are delayed (Reed et al., 2015). These adverse effects usually affect food safety and economic well-being, as well as the environment, and explain the reasons for the worldwide degradation of land.

Since degradation of land is a process involving anthropogenic activates, its measurement and control will include all aspects of time and space and human activities (Cowie et al., 2018). Inclusion of evaluation and monitoring of human performance is essential because certain human activities intensify destructive ecological processes such that land resources cannot be recovered alone. A meaningful evaluation should, therefore, include land use patterns for human-induced land degradation (Kosmas et al., 2016). Time is also essential for the evaluation of soil degradation. They should be included by properly developing useful baseline data and later measurements.

In Somalia, various works of literature have documented several aspects of advancing land degradation (Omuto et al., 2014). The reports show vegetation loss, gully erosion, topsoil loss, surface dam sealing and irrigation canals, invasive plant species that cannot be palatable, and plant nutrient loss in areas of agriculture potential. All these negatively affect crop production (Oduori et al., 2011). In general, land degradation can be said to potentially affect Somaliland's traditional system of pastoral production (Bolognesi et al., 2015).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study site

Somalia is the area of interest in this study (Figure 3). World Bank estimated its population at 14.74 million in 2017. It covers a total area of 637,660 km² and its capital city is Mogadishu. 50% of the people in Somalia rely on pastoralism which is greatly affected by precipitation timing and amount (Alwesabi, 2012).

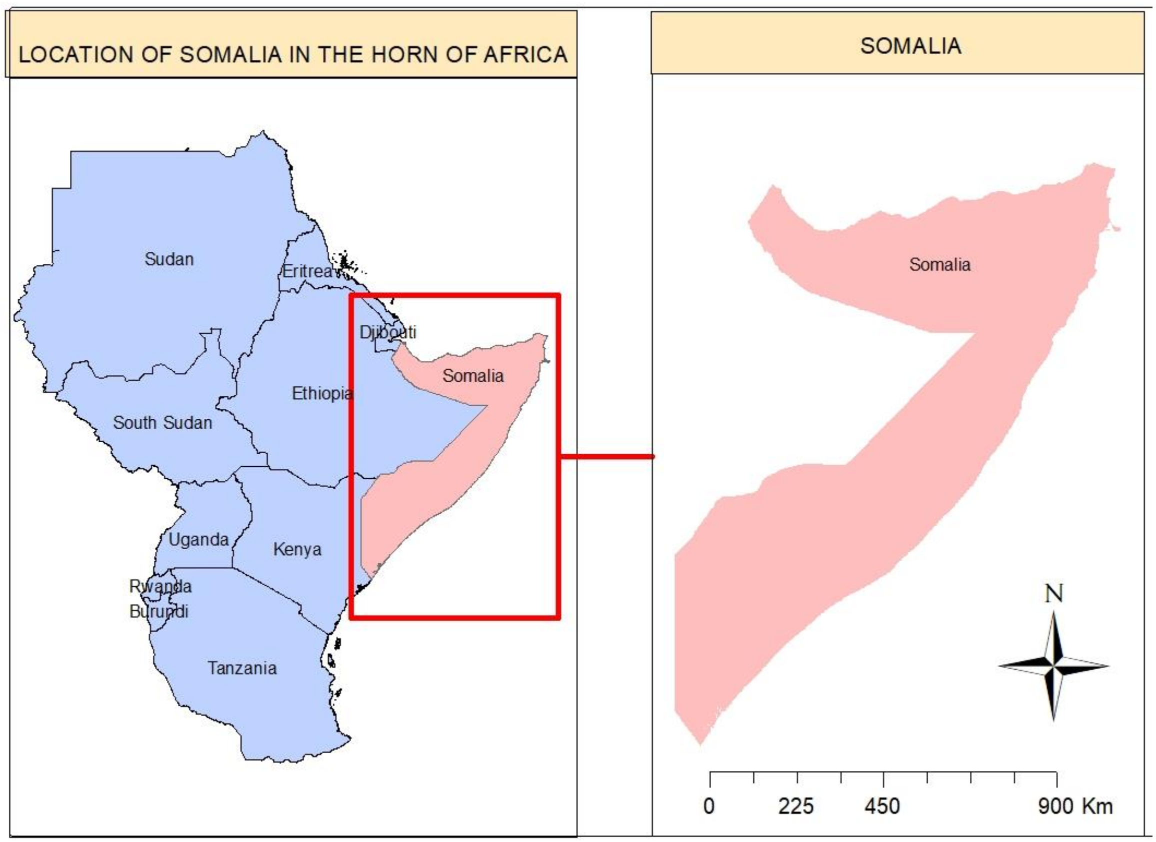

Figure 3: Map of the study area.

Somalia covers large area starting from the equator to the north of Gulf of Aden. It is found in the Horn of Africa and is the easternmost African country. Based on topography, Somalia can be divided into several physiographic zones. The driest zones receive elevated annual average temperature and covers the northern parts of the country (Hadden & Lee, 2007). The central part of the country is covered mostly by plateaus with the southern parts bordering the coastline. There are two perennial rivers in the southern part: Webe Shebele and Jubba. Ethiopian plateau is the source of these two rivers and occasionally flood when high precipitation is received in Ethiopia. There exists a highly productive plain between the two rivers exists. This plain is frequently affected by floods. Somalia`s coastline is the longest in Africa covering 3,025 kilometers in length (Alwesabi, 2012).

Generally, Somalia experience hot weather throughout the year. The country has an average annual daytime temperature of 27°C which is among the world`s highest mean annual temperatures. These high temperatures are due to the fact that Somalia is located close to the equator and receives low precipitation. The northern highland and central parts experience fluctuating temperatures ranging from sub-zero temperature in winter to about 45°C in summer in the Karkaar Mountains and interior plateau respectively. Lower temperature variations are experienced in the southern parts of Somalia. Their temperatures in the coldest months is 20°C and records 30°Cin the hottest months. Due to the cold offshore currents, the coastal region is usually 5°C-10°C cooler than the inland areas (Hadden & Lee, 2007).

There are two climatic zones in Somalia, the semiarid zone which receives moderate rainfall and is suitable for rain fed agriculture and the arid zone which receives low precipitation and is used for pastoralism (Menkhaus, 2014). The semi-arid zone covers the northern mountains, southwest and the northwest areas while the arid zone covers the central and northernmost regions of the country. There are two rainy and two dry seasons in Somalia. The main rainy season occurs from April to June and is followed by a dry season between July and September (Alwesabi, 2012). The short rainy season comes between October and November. This is followed by the second and main dry season, which extends from December to March.

Soil types and properties in Somalia varies with climate and nature of parent rock. The northeastern parts of the country have shallow infertile soils. However the plateaus have limestone parent rock that result in fertile soils which supports the rain fed agriculture. The plains along the plains of Jubba and Shabeelle rivers have the most fertile soils (Hadden & Lee, 2007). The alluvial plains have deep black cotton soils which have a great potential to store water and thus are fit for irrigation farming. To the southern parts, Somalia has vertisols (which cracks during the dry periods) covering large areas. Naturally, vertisols are vegetated with grass and its unstable nature is not conducive for growth of forest. They have shrinking and swelling properties which damages infrastructure and may cause mass wasting. Because they are usually covered by grass or grassy woodlands, vertisols are normally used for grazing livestock. Their impermeability when saturated makes them suitable for rice production. The stickiness when wet and cracks when dry makes vertisols difficult to work on (Hadden & Lee, 2007).

3.2 Datasets and their sources.

The following datasets were used to achieve the research objectives.

Table 2: Datasets, sources and properties.

Category	**Source**	**Bands/Image collection ID**	**Spatial Resolution**	**Temporal Resolution**	**Period**	**Link**
Drought index (SPEI)	Global SPEIbase	N/A	0.5°	Monthly	1980 - 2015	https://spei.csic.es/database.html
Vegetation index (NDVI)	NOAA AVHRR	NOAA/CDR/AVHRR/NDVI/V5	0.05°	daily	1982 - 2001	https://code.earthengine.google.com/65aa2cfb584ecfe98c5fa2d5c340c2ee
	MODIS	MODIS/MCD43A4_006_NDVI	500m	16-day	2001 - 2015	https://code.earthengine.google.com/deec5ea5b0c9cc54e5198015056fe20c
Forest cover	Global Forest Watch	N/A	N/A	Annual	2001 - 2015	www.globalforestwatch.org
Forest loss	Hansen	UMD/hansen/global_forest_change_2019_v1_7	30m	Annual	2000-2019	https://code.earthengine.google.com/2abd4d2bc55e47d36a3dbe54f3afc037
Land degradation	Existing literature	N/A	N/A	N/A	N/A	N/A

3.3 Drought indices

3.3.1 Standardized Precipitation Evapotranspiration Index

For drought assessment purposes, a number of indices have been developed. These include Palmer Drought Severity Index (PDSI), Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI). The Standardized Precipitation Index has gained frequent application in drought characterization in the last few decades. SPI was developed by McKee *et al*.(1993). It can be used to characterize various types of drought depending on the timescale. For example on the 3-months timescale, SPI is used to characterize both agricultural and meteorological drought (WMO, 2012). At longer timescales such as 12 and 24 months, SPI is used to characterize hydrological drought. Despite the widespread acceptance of SPI, atmospheric conditions are not accounted for in its calculation apart from precipitation and this affects the output of drought assessment.

To overcome the deficiencies of SPI, SPEI has been developed (Vicente-Serrano *et al.*, 2010). The SPEI is superior to both PDSI and SPI because of its sensitivity to temperature which greatly affect drought evolution patterns (Li *et al*., 2019). It is standardized the same way as SPI. However, it is calculated differently based on the difference between precipitation and potential evapotranspiration. The Global SPEI database is called the SPEIbase. This database provides historical SPEI values at various timescales ranging from 1 to 48 months with a spatial and temporal resolution of 0.5-degree and one month respectively (Beguería *et al.*, 2010). SPEI is useful in assessment of agriculture, ecology and even water cycles through drought evaluation (Vicente-Serrano *et al*., 2012). It is suitable for assessment of different types of drought depending on the timescale. The 1-, 3-,12- and 24-month SPEI is applicable to meteorological, agricultural, hydrological and socioeconomic drought analysis respectively (Potop *et al.*, 2014).

SPEI enables reasonable estimation of drought severity on multiple temporal scales. Its calculation formula is given as follows (Li *et al*., 2019);

$$PET = 16K\ (10T/I)^m \quad \text{.......} \quad 1$$

Where *PET* is potential evapotranspiration, *K* is the modified latitude based coefficient, *T* is the average temperature per month, *I* is the total heating index per year and *m* is a coefficient that is based on *I*.

To obtain the difference between precipitation and potential evapotranspiration we use the formula;

$$D_i = P_i - PET_i \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . 2$$

Pi is precipitation while *PETi* stands for potential evapotranspiration.

The log-logistic distribution formula for the Di is as follows:

$$f(x) = \frac{\beta}{\alpha}((x-r)/\alpha)^{\beta-1}[1 + \llbracket((x-r)/\alpha)\rrbracket \;\hat{}\beta\,]^{-2} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . 3$$

$$F(x) = \int_0^x f(t)\,dt = [1 + (\alpha/(x-r))\beta]^{-1} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . 4$$

α represent the scale, βrepresent the shape, γ is the origin, *f(x)* stands for probability density function, and *F(x)* stands for probability distribution function.

However SPEI is normalized using the formula:

$$SPEI = W - \frac{C_0 \; + C_1 + C_2W^2}{1 + d_1w + d_2w^2 + d_3w^3} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \; 5$$

$$W = \sqrt{-2ln(P)} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . 6$$

When $P \geq 0.5$. *P* is the probability of superseding a determined D value and $P=1-F(x)$. If $P > 0.5$, then *P* changes to 1-*P* and the resulting SPEI will have its sign reversed. *C* and *d* represent constants that are derived based on the *P* value.

Based on SPEI, drought is categorized as shown in table 3 below(Bae *et al*., 2018)

Table 3: Drought categories based on Standardized Precipitation Evapotranspiration Index

SPEI VALUE	CLASS
More than 2.00	Extremely wet (humid)
1.50 to 1.99	Severely wet
1.00 to 1.49	Moderately wet
0.50 to 0.99	Slightly wet
−0.49 to 0.49	Near normal
−0.99 to −0.50	Mild dry
−1.49 to −1.00	Moderately dry
−1.99 to −1.50	Severely dry
Less than −2.00	Extremely dry (drought)

SPEI values from Golbal SPEIbase were adopted for this study and use without any modification. Table 3 categories were used for classifying drought.

3.3.2 The Normalized Difference Vegetation Index (NDVI)

NDVI is a measure of how green the vegetation is. NASA`s Aqua and Terra satellites carries Moderate Resolution Imaging Spectroradiometer (MODIS) instrument. This instrument takes images of the land surface in 36 spectral bands at a temporal and spatial resolution of 1 to 2 days and 1000 m respectively. It was launched in March 5 2000 and has up to date data. MODIS calculates NDVI values based on the near-infrared (NIR) and red bands at an interval of 16 days.

NDVI is a ratio of near infrared (NIR) and red (R) reflectance (Parry *et al*., 2004). It is computed as follows:

$$NDVI = \left(\frac{NIR - RED}{NIR + RED}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7$$

Where NIR is the near-infrared band whereas RED represent the red bands respectively. NDVI runs from negative 1 to positive 1. Negative indices indicate clouds, water or snow. The values near zero indicates bare rock or soil without any green vegetation while indices close to +1 indicates dense vegetation (Ozyavuz *et al*., 2015).

3.4Analysis of drought frequencies and conditions

Drought conditions varies from one drought event to another. Drought conditions can be worsened by water scarcity that results from global climatic changes (Dubrovsky et al., 2009). A drought event can be defined as a prolonged period with a SPEI value of -1 or less which starts when the SPEI drops to a value below 0 and is said to end when the SPEI gets to a positive value preceded by a value of -1.0 or less (McKee et al., 1993). Drought characterization is done in three dimensions; drought duration, severity and intensity (Lee et al., 2017).

Runs theory, proposed by Yevjevich (1967) can be used to characterize drought events in the three dimensions. A run refers to the part of time series with all values above or below a chosen threshold (Mishra & Singh, 2010). The portion below the truncation level is called negative run while the portion above the truncation level is called positive run. This theory adapts a probabilistic methodology in characterizing drought by estimating the return periods for extreme events (Gonza & Valde, 2006). This theory was applied to analyze drought characteristics based on SPEI whereby the drought characterization was based on the statistical parameters of drought duration and severity at different truncation levels. Based on this theory, drought duration, severity and intensity can be defined in reference to the truncation level. Drought severity refers to the sum of drought parameter below the truncation level while drought duration refers to the number of months or years during which the drought parameter is continuously below the truncation level. Drought intensity refers to drought severity divided by respective drought duration. Thus, drought duration is expressed in years or any other time period during which a drought parameter is continuously below the critical level, that is the number of months between the commencement of drought and the end month (Spinoni et al., 2014). An illustration of drought characteristics for a given threshold level is shown in figure 2.

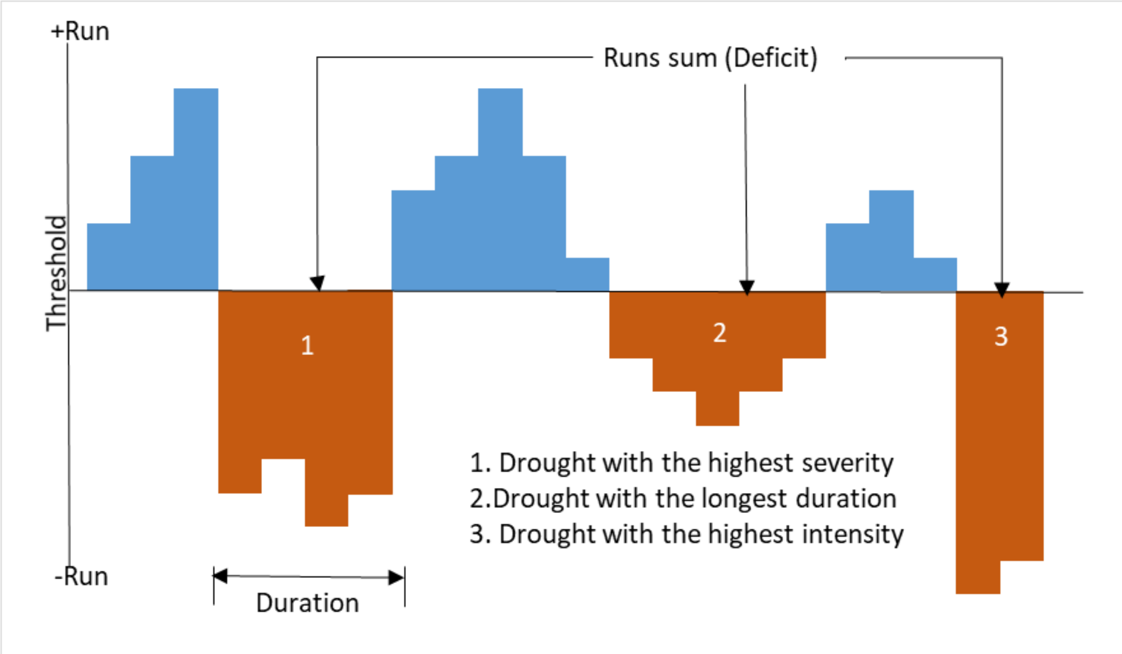

Figure 4: Drought characteristics using run theory based on selected threshold level.

Source: Lee et al. (2017).

3.5 Interpolation and trend analysis methods

Trend analysis was performed using the Man-Kendall test (Mann, 1945). This is a nonparametric method that is used to determine whether a given set of time series data have trend. It evaluates the significance of trend in time series of hydrology and meteorology datasets (Sicard et al., 2010) and is therefore applicable in drought trend evaluation based on given drought indices (Damberg & AghaKouchak, 2014). This study adopted the Mann Kendall trend test to determine trends of annual and seasonal SPEI series, during years 1980–2015.

Interpolation methods are useful in analyzing both short-term and long-term distribution of NDVI and SPEI. Interpolation have been used in the recent past in a number of studies (Suparta & Rahman, 2016; Kilibarda et al., 2015) to assess climate change time series. In this study, time series of annual and seasonal SPEI and NDVI were subjected to interpolation. Spatial interpolation can be defined as a procedure of estimating weather or climatic condition of an unobserved area from points spread over an observed area (Ghebrezgabher et al., 2016). However, the accuracy of spatial interpolation depends on the quality of the data available for the observed area. Other factors that determines the accuracy of spatial interpolation includes the distance from the sea, atmospheric haze and circulation and the topography of the area under study (Irmak et al., 2010). Therefore, underestimation or overestimation is a limitation to spatial interpolation (Gottschalk e al., 2015; Plouffe et al., 2015). A number of interpolation techniques are available in ArcGIS including the Inverse Distance Weighting (IDW), Kriging, Spline and Natural Neighbor. In this study Inverse Distance Weighting (IDW) was selected over other interpolation methods for its suitability to evenly distributed data (Azpurua & dos Ramos, 2010). This method is deterministic whereby values of unmeasured points are estimated by linear combination of values at nearby measured points. IDW has been used previously in similar studies such as (Vu et al., 2018).

3.6 Accounting for forest cover loss

The Global Forest Watch`s data (tree cover loss) compounded with the use of Natural Capital Accounting methodology was used in quantification of forest cover loss. Due to its effectiveness in description of observed data, change detection analysis was adopted for forest cover loss assessment (Gandhi *et al*., 2015). Country specific tree cover data for Somalia were retrieved from the Global Forest Watch website[1]. A 30% threshold as recommended by International Geosphere Biosphere Program was used to discriminate forest from non-forest (Kim *et al*., 2014). Tree cover loss data from the Global Forest Watch website is calculated based on remotely sensed images and have been used in forest cover loss assessment for the period between 2001 and 2018, the period for which data is available.

3.7 Determining best-fit sustainable management for mitigating land degradation

There exist a number of published papers on land degradation. As such, a systematic review of journal papers from between the years 2008 and 2020 was conducted. This was done stepwise as follows; first, search words were defined whereby 'land degradation' and 'mitigation measures' were the keywords for the search process. The search string was therefore defined as “Land degradation” and “Mitigation Measures”. Secondly, different

[1]www.globalforestwatch.org

databases were used to source journal papers. These included Science Direct, Taylor and Francis, Research gate, World Bank and FAO reports on land degradation.

The inclusion criteria was: (i) Peer reviewed journals and (ii) Articles published in English. The exclusion criteria was (i) Articles from symposia; (ii) Theses at master`s level; (iii) Lecture notes; (iv) Book sections and (v) Book summaries to determine their suitability. Articles were grouped under several topics on land degradation, on top of mitigation measures, land degradation forms, management practices and generation of knowledge. If one of those screening requirements was not met the papers were omitted. Further screening of the selected articles was carried out to ensure that no other related articles were omitted from the search.

CHAPTER FOUR

RESULTS

4.1 Drought characterization

4.1.1 Temporal characteristics of drought

4.1.1.1 Observed drought occurrence

This study made use of 34 years monthly SPEI values for multiple time scales of 1-, 3-, 6-, 12- and 24-month derived from the SPEIbase. For each of the drought category (Table 2), frequencies of drought occurrences were computed as a percentage of the total number of observed drought events in the time series. Table 2 presents frequencies of drought occurrences at different time scales for various drought categories. Wet conditions are less persistent for the 1-month SPEI compared to the other timescales. However wet periods are more persistent in a 3- and 12-month timescale, while drought periods were observed more than wet periods for the remaining timescales. The results further indicate a decreasing trend in the frequency of moderately severe droughts except for 1-month SPEI.

Table 4: Observed drought frequencies in Somalia for multiple time scales

Time scale	Drought frequencies (%)					
	Wet	**Mild**	**Moderate**	**Severe**	**Extreme**	**χ^2 test *P* value**
SPEI 1	47.8	46.6	5.4	0.2	0	<0.001
SPEI 3	51.7	42.2	6.1	0.0	0	<0.001
SPEI 6	48.5	47.5	3.7	0.2	0	<0.001
SPEI 12	51.7	45.3	2.9	0	0	<0.001
SPEI 24	49.0	49.3	1.7	0	0	<0.001
χ^2 test *P* value	0.892^{ns}	0.643^{ns}	0.189^{ns}	1.000^{ns}	*	

χ^2 test, Chi-square (two-tailed test); significant at probability level $p \leq 0.001$; ns, not significant at $p \leq 0.001$; ***p*** value for extreme drought was not determined.

4.1.1.2 Long-term annual drought variations

SPEI values enable users to analyses distribution of drought both in time and space. In this study, 1-Month, 3-Month, 6-Month and 12-Month timescales were chosen for drought evaluation. Figure 5 shows annual variations of SPEI at various time series in Somalia during 1982–2015. The drought occurred with increased frequency throughout the study period with various magnitudes. It was evident that drought had increased, especially after 2003 (Figure 5) both in frequency and magnitude. Drought events were more frequent with shorter durations for 1-month SPEI compared to the 3-, 6-, and 12-month SPEI. Generally, as the record time increases, drought duration increases while the drought frequency and intensity declines.

Results shows that the most intense drought (SPEI= -1.09) for SPEI 6 occurred between May to December 2003. For the 12-month SPEI, the most intense drought (SPEI= -0.72) occurred between July to December 2015. In contrast, the maximum drought duration (D) for the 6-month and 12-month SPEI were found to be D=26 months and D=41 months respectively.

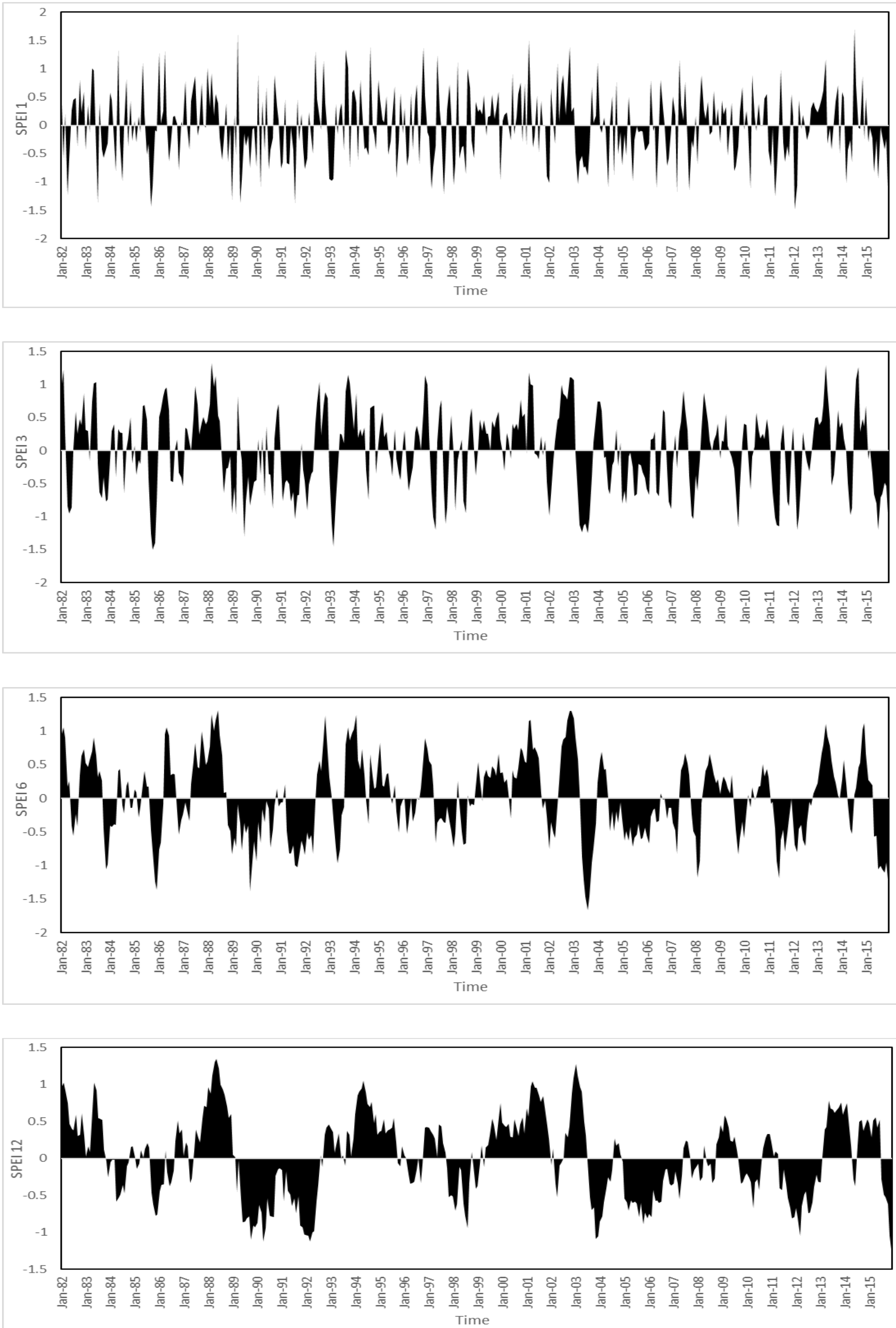

Figure 5: Long-term annual drought variations at 1-month, 3-month, 6-month and 12-month timescales.

4.1.1.3 Long-term monthly distribution of drought

Figure 6 shows the monthly distribution of SPEI at each timescale during the 1982-2015. Although there is a similarity in trends of drought in all the four timescales, the severity and intensity increased with timescales. Figure 5 shows a decreasing trend among all the SPEI timescales during 1982-2015 beside the inconsistent patterns. Almost all months were wet 1988, a water deficit was recorded for all months in 1991 and 2005. Wetting trends were record in 1988while drying trends were captured in 1991 and 2005. During the months of October-December, few droughts were recorded as shown in figure 6.

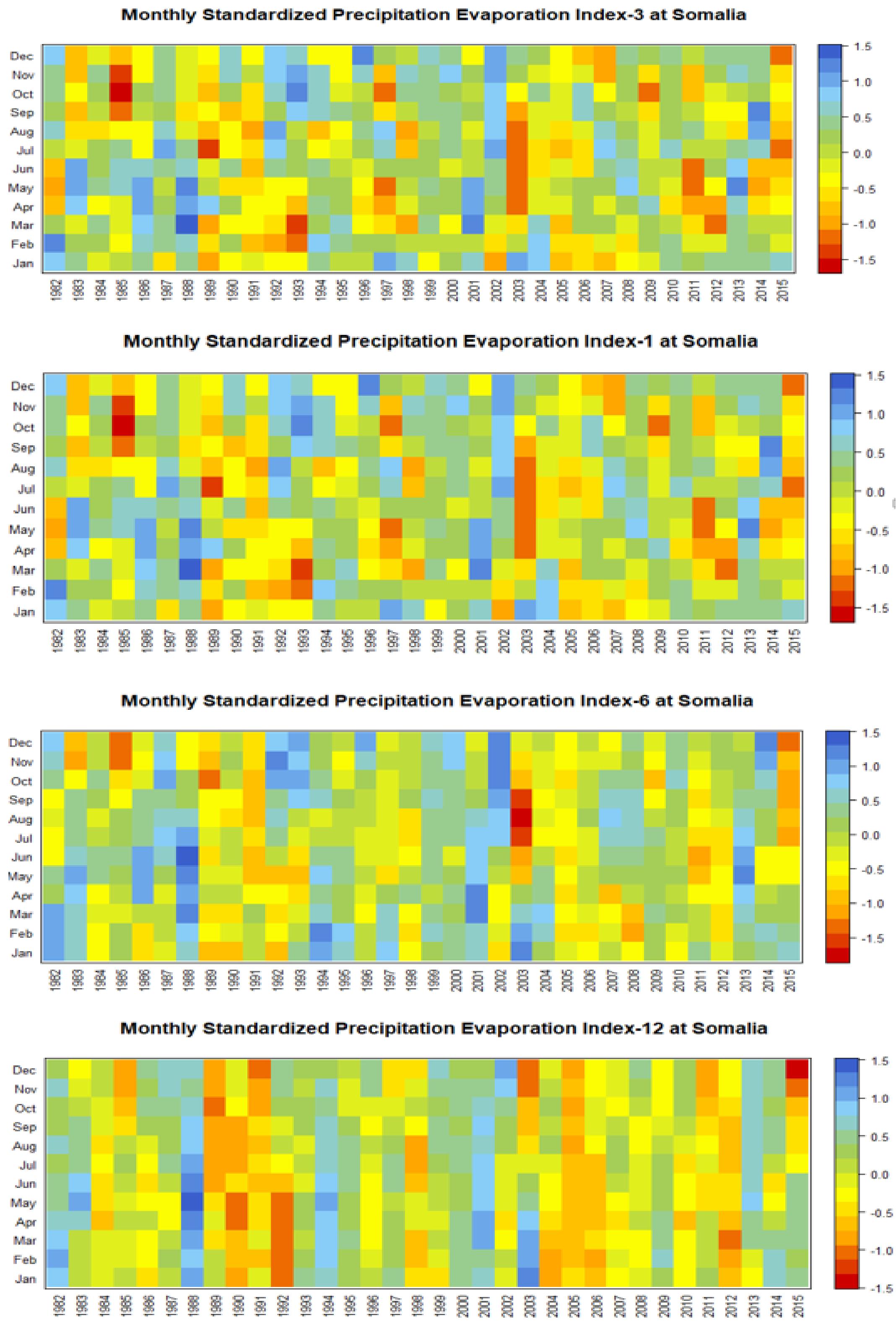

Figure 6: Monthly drought patterns at various timescales

4.1.1.4 Annual patterns of drought

Figure 7 shows drought trends based on Mann Kendall test and slope for each timescale. The results showed an increasing trend of drought over the past 34 from 1982 to 2015. The P values for the 1-, 3-, 6-, and 12 month SPEI were - 0.0000042, -0.00001, -0.000013, and -0.000014, respectively. The fluctuating downward trend in Figure 7 indicates that the drought trends increased in the country, but non-statistically significant.

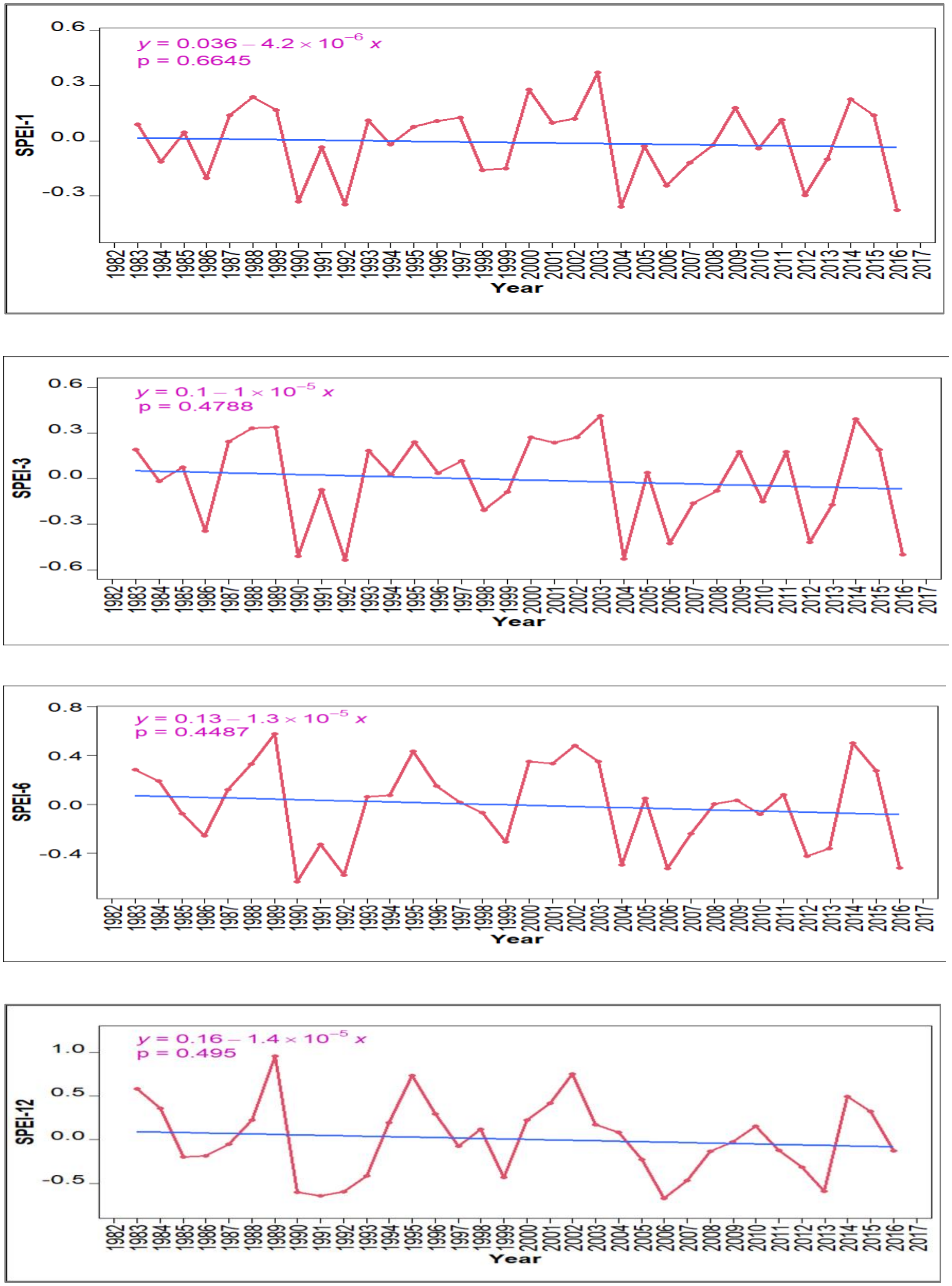

Figure 7: Annual variations of SPEI at each of the four timescales during 1982–2015

To check for multi-year drought fluctuations, the study period was divided into two, 1982-1999 and 2000-2015 as shown in figure 8. Although the latter period (2000-2015) showed increased downward trend compared to the 1982-1999 period (Figure 8), the two periods showed non-statistically significant downward trends for all the SPEI timescales.

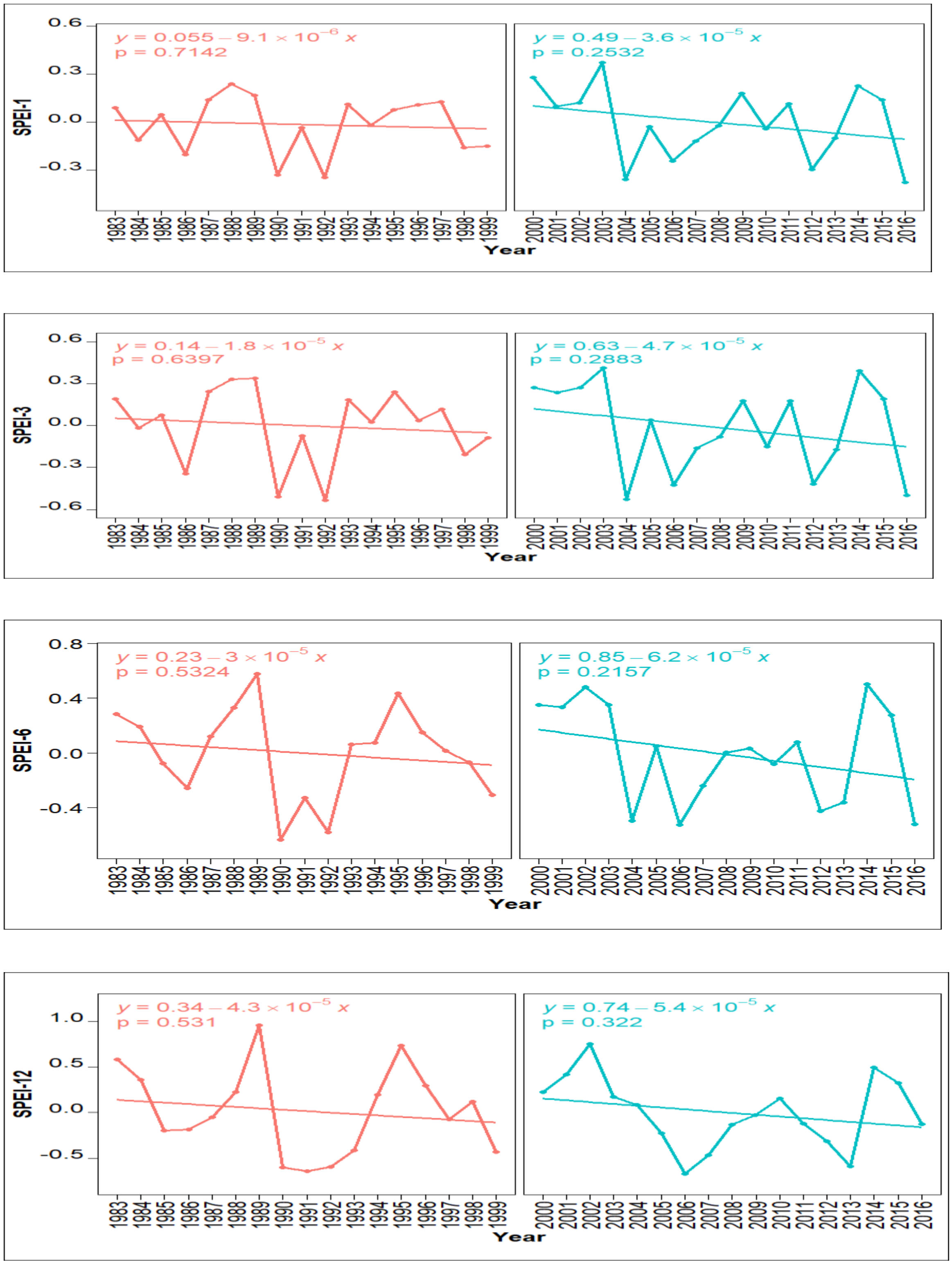

Figure 8: Temporal variation of the annual SPEI over Somalia in each timescale from 1982-2015. The red and blue lines indicate the time series data of the SPEI during 1982-1999 and 2000-2015, respectively.

4.1.2 Spatial evaluation of drought

4.1.2.1 Spatial distribution of drought characteristics.

Drought identification was done for all locations using the runs theory. For each station drought characteristics including count and severity were determined. A total of 14820 drought occurrences were extracted. On average there were about 76 drought occurrences for each location with a mean duration of 2.53 months and a mean severity of -1.42.

Figure 4 (a) shows the spatial distribution of SPEI locations in Somalia. Figure 4(b), 4(c) and 4 (d) shows spatial distribution of drought characteristics in terms of drought count, mean duration and mean severity respectively. There was remarkable variations of drought count in space (Figure 4b). The northern parts of Somalia experienced high (76-100) drought occurrences. The central parts have counts ranging from low (51-75) and extremely low (39-50). However, the southern parts of Somalia presented between high (76-100) and extremely high (101-125) drought counts. As shown in figure 4 (c), almost the entire Somalia is hit by drought of equal severity. Drought ranges between severely dry (-1.53 to -1.43) and moderately dry (-1.42 to -1.33) conditions. Figure 4 (d) shows spatial variation of mean duration. A small section of the central parts of Somalia experienced extremely short drought duration (1.3 to 1.6 months). North West and south west parts experienced between long (2.5 to 3.2 months) and extremely long droughts (3.3 and 4.0 months). However, the larger part of central Somalia experienced short (1.7 to 2.4 months) drought durations. A negative relationship between drought count and drought duration can be deduced from these results.

It is evident that there are a lot of differences in drought characteristics regionally within the country. The North West and South West parts are highly prone to have high frequencies of droughts with short duration. Drought prevention and management teams in these areas should therefore focus efforts on short and moderate droughts to reduce the impacts of these droughts on crops. In the central parts prone to low frequencies of droughts which last between short and long duration, drought prevention and management should focus on longer droughts in order to minimize the impacts of these droughts on water availability within the country.

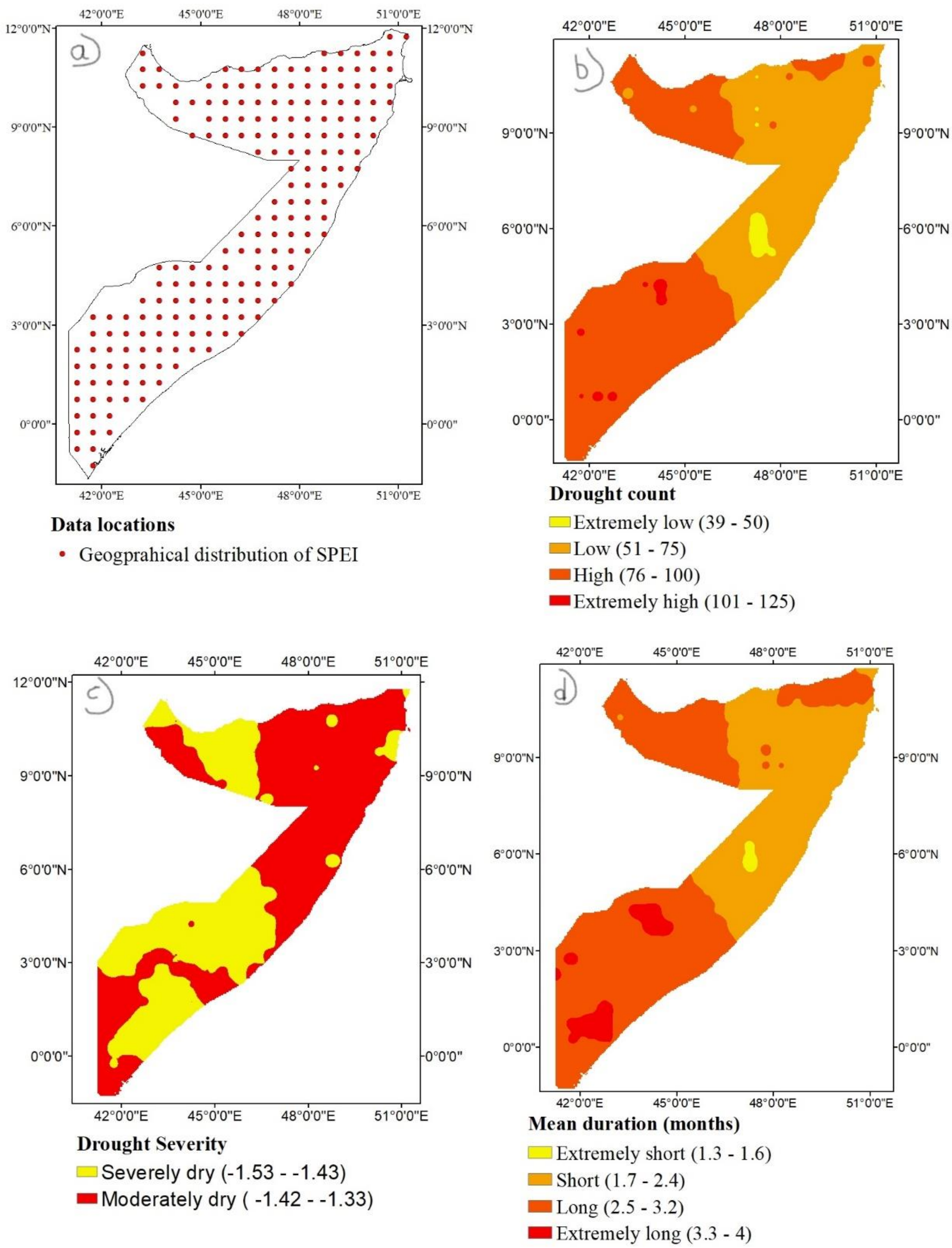

Figure 9: Spatial distribution of drought characteristics over Somalia: (a) SPEI locations, (b) drought count, (c) drought severity and (d) drought duration.

4.2 Accounting for forest cover loss

4.2.1 Physical forest accounts

This section presents the physical accounts of forest cover in Somalia. The main components of physical accounts are opening and closing stocks. Table 5 shows tree cover extend in Somalia for various periods between 2000 and 2018 at various tree cover thresholds ranging from 10% to 75%.

Table 5: Tree cover loss summary

Tree cover threshold (%)	Total area (ha)	Tree cover (ha)				% tree cover loss since 2000	Tree cover loss/year 2001-2018 (ha)	Average loss/year 2001-2010 (ha)
		Extent in 2000	Extent in 2010	Extent in 2018	Loss 2001- 2018			
10	63426842	3890753	3122190	3114000	14743	0.40%	819	655
15	63426842	1333029	1390822	1385363	11041	0.80%	613	558
20	63426842	174770	325046	322832	5374	3.10%	299	316
25	63426842	135035	262067	260299	4710	3.50%	262	294
30	**63426842**	**87294**	**146785**	**145462**	**3598**	**4.10%**	**200**	**228**
50	63426842	15692	27913	27454	1332	8.50%	74	87
75	63426842	1095	4142	4122	127	11.60%	7	11

Table 6 shows the physical accounts of forest cover in hectares and the respective volume in cubic meters. A 30% threshold recommended by International Geosphere Biosphere Program (IGBP) was adopted in selecting forest from non-forest trees (bolded in table 5) (Kim *et al.*, 2014).

The overall forest cover declined for the opening stocks from around 87, 294 hectares in 2000 to around 67, 199 hectares in 2019. This translates to 23.01% forest cover loss. On the other hand, volume account was done at a rate of 25m^3/ha suggested by FAO for use in converting the area in hectares to volume in cubic meters (FAO, 1981). Forest stock has been decreasing over the study period to 1.63 million m^3in 2019.

Table 6: Area and volume account for forest cover loss

Year	Opening Stock (ha)	**Opening stock volume (M^3)**	Forest cover loss (ha)	Closing Stock (ha)	**Closing stock volume (M^3)**
2000	87294.00	2182350.00	200.00	87094.00	2177350.00
2001	87094.00	2177350.00	1068.38	86025.62	2150640.44
2002	86025.62	2150640.44	952.99	85072.63	2126815.73
2003	85072.63	2126815.73	492.50	84580.13	2114503.32
2004	84580.13	2114503.32	667.86	83912.27	2097806.76
2005	83912.27	2097806.76	941.71	82970.56	2074264.12
2006	82970.56	2074264.12	336.72	82633.85	2065846.22
2007	82633.85	2065846.22	896.67	81737.18	2043429.39
2008	81737.18	2043429.39	705.58	81031.59	2025789.83
2009	81031.59	2025789.83	674.27	80357.32	2008933.07
2010	80357.32	2008933.07	370.11	79987.21	1999680.26
2011	79987.21	1999680.26	519.89	79467.32	1986682.90
2012	79467.32	1986682.90	2006.75	77460.57	1936514.27
2013	77460.57	1936514.27	4116.75	73343.82	1833595.53
2014	73343.82	1833595.53	2429.88	70913.94	1772848.49
2015	70913.94	1772848.49	468.48	70445.46	1761136.55
2016	70445.46	1761136.55	577.16	69868.31	1746707.63
2017	69868.31	1746707.63	2121.31	67746.99	1693674.80
2018	67746.99	1693674.80	547.35	67199.65	1679991.13
2019	67199.65	1679991.13	1613.90	65585.75	1639643.66

Table 7 compares extend of forest cover determined based on Hansen data with the forest cover determined by Forest Resource Assessment of 2015. The Hansen based estimates are higher than FRA estimates by 14.58%.

Table 7: Comparison of Forest Resource Assessment (FRA) -and Hansen-based forest cover

Year	**FRA-Based FC (ha)**	**Hansen-based FC (ha)**	**Range (ha)**	**% difference**
2000	7515000.00	8729400.00	1214400.00	13.91
2001	7438200.20	8709400.00	1271199.81	14.60
2002	7361399.90	8602562.00	1241162.10	14.43
2003	7284600.10	8507263.00	1222662.90	14.37
2004	7207799.81	8458013.00	1250213.20	14.78
2005	7131000.00	8391227.00	1260227.00	15.02
2006	7054200.20	8297056.00	1242855.81	14.98
2007	6977399.90	8263385.00	1285985.10	15.56
2008	6900600.10	8173718.00	1273117.90	15.58
2009	6823799.81	8103159.00	1279359.20	15.79
2010	6747000.00	8035732.00	1288732.00	16.04
2011	6670200.20	7998721.00	1328520.81	16.61
2012	6593399.90	7946732.00	1353332.10	17.03
2013	6516600.10	7746057.00	1229456.90	15.87
2014	6439799.81	7334382.00	894582.20	12.20
2015	6363000.00	7091394.00	728394.00	10.27
2016	6286200.20	7044546.00	758345.81	10.77
Average			**1214400.00**	**14.58**

Forest cover was lost at fluctuating rates throughout the study period. Figure 10 shows the variation of forest cover as determined by the Hansen data and the FRA. Both estimates shows decreasing trends of forest cover throughout study period.

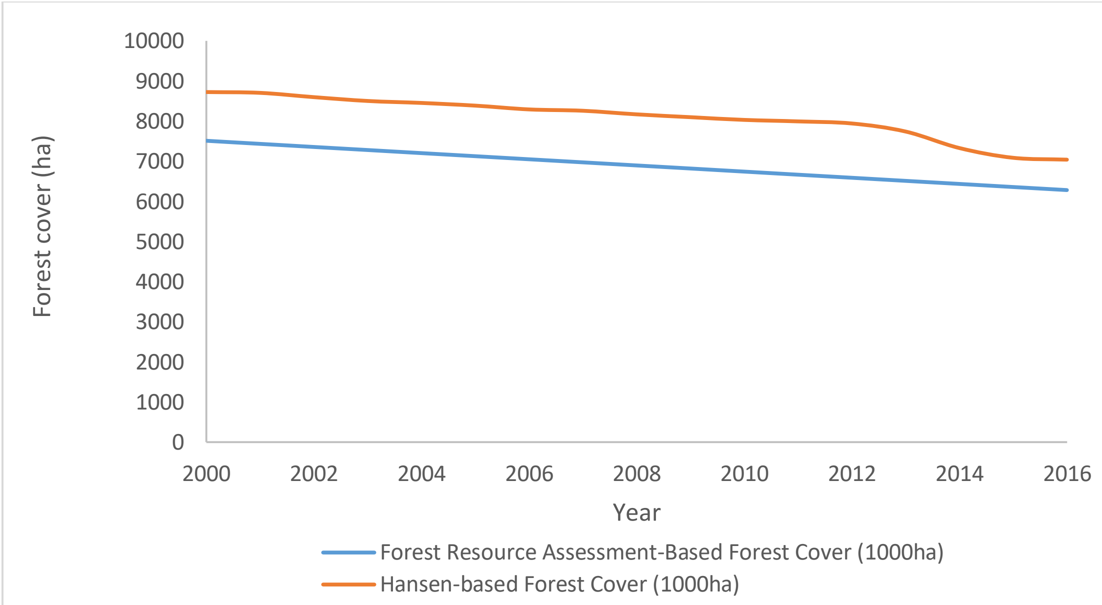

Figure 10: Variation of forest cover with time.

Besides the high correlation (r = 0.95) between the 2015 FRA- and Hansen-based forest cover, FRA underestimated the forest cover by an average of 14.58% for the period between 2000 and 2016.

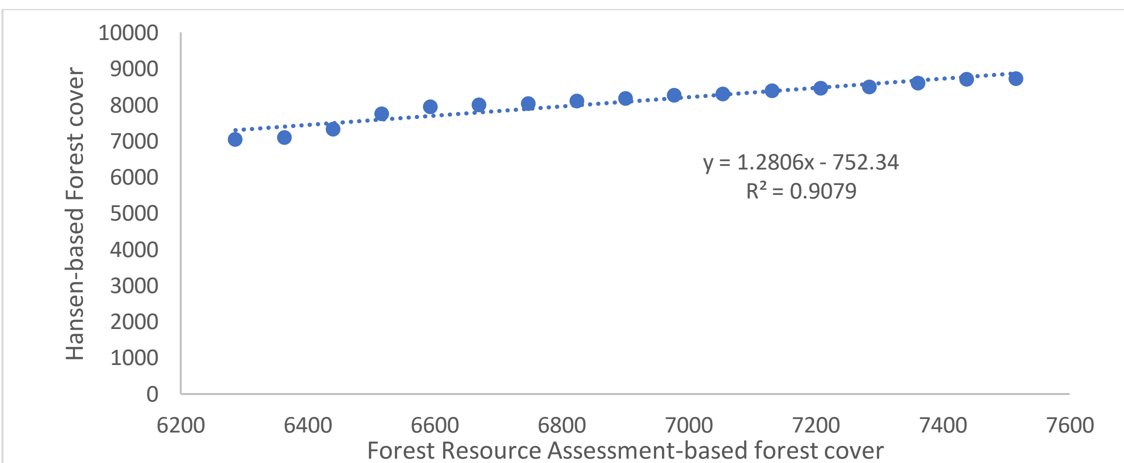

Figure 11: Correlation of Hansen based- and Forest Resource Assessment based forest cover estimates

4.4 Best-fit sustainable management methods for mitigating land degradation

From 100 papers that were screened only 20 met the criteria. From the 20 reviewed papers, land degradation was defined in various forms and entailed various aspects (Beier &

Stephansson, 2012; Maystadt & Ecker, 2014; Meeking, 2013; Shiferaw et al., 2013; Jama et al., 2020). Some articles(de Jong et al., 2011; Le et al., 2012; Nachtergaele & Licona-Manzur, 2008; Vargas et al., 2008; Adami et al., 2012)applied GIS and remote sensing methods in identification and mapping of areas experiencing land degradation. Furthermore, most articles recommended a remote sensing based monitoring of land degradation for selection of best mitigation measures. Other studies provided mitigation measures (Galati et al., 2015; Kosmas et al., 2013) while others assessed various land degradation types(Nkonya et al., 2012; Rizk & Rashed, 2015). 43% of the reviewed articles found soil erosion to be the major form of land degradation while 57% found loss of vegetation cover as the dominant land degradation type in Somalia.

The study was divided into three thematic areas; land degradation types, land degradation assessment methods and land degradation mitigation measures (Table 8).

Table 8: Thematic analysis

Thematic area	**Research studies**	**Findings**
Land degradation types/forms	Beier & Stephansson (2012) Maystadt & Ecker (2014) Meekin (2013) Shiferaw et al. (2013) Jama et al. (2020) Nkonya et al. (2012) Rizk & Rashed (2015)	Soil erosion Loss of vegetation cover
Land degradation assessment methods	de Jong et al. (2011) Le et al. (2012) Nachtergaele & Licona-Manzur (2008) Vargas et al. (2008) Adami et al. (2012) Eckert et al. (2015) Onchere (2000)	Remote sensing techniques

Land degradation mitigation measures	Galati et al. (2015) Kosmas et al. (2013) Zegeye (2018) El Shabrawy et al. (2014) Magembe et al. (2015) Keestra et al. (2016)	Soil bundling Water harvesting Afforestation Reforestation Inorganic farming Conservation tillage Managed grazing Ridging Terracing

Table 9 shows the major land degradation mitigation measures recommended by the reviewed articles and their respective percentages.

Table 9 Land degradation mitigation measures

Land degradation mitigation measure	**Percentage articles recommending it.**
Soil bundling and water harvesting	30%
Afforestation and reforestation	20%
Agricultural practices such as combined use of organic and inorganic farming techniques, conservation tillage, managed grazing, ridging, terracing etc.	50%

CHAPTER FIVE

DISCUSSIONS

5.1 Drought characteristics

Drought characterization was done with respect to severity, duration, intensity and trends. These characteristics explained the historical distribution of drought in time and space in Somalia as captured at various timescales. As determined by SPEI values, the trends of drought occurrence have increased at fluctuating downward trends which is in agreement with the findings of Mpelasoka (2018). This is because drought duration increases with timescale which is also in line with previous findings (Potopová et al., 2019; Vicente-Serrano et al., 2012). These variations in drought as determined by SPEI at various timescales can be useful in multi-dimensional drought evaluation. For instance, SPEI 1 represent meteorological drought, SPEI 3 can be used for agricultural drought evaluation and SPEI 6 and SPEI 12 can be used for hydrological drought assessment (Asong et al., 2018). Previously drought have been found to mutate gradually beginning with meteorological drought to agricultural and eventually to hydrological (Van Loon, 2015). At hydrological level, its recovery normally takes longer period of time compared to the other two.

Wet conditions are less persistent for the 1-month SPEI compared to the other timescales. However wet periods are more persistent in a 3- and 12-month timescale while drought periods are observed more than wet periods for the remaining timescales. The results further indicate a decreasing trend in the frequency of moderately severe droughts except for 1-month SPEI. This implies that the 1-month SPEI could not be useful in evaluating drought trends in the region. This is further explained by the ever-drying conditions in Somalia (being a semi-arid country) that results in frequent precipitation deficits. Generally, as the record time increases, drought duration increases while the drought frequency and intensity declines. This implies that the increase in timescale have a smoothing effect on individual drought severity and an increasing effect on drought duration.

Based on SPEI, drought events were successfully identified. For example, SPEI 12 successfully identified the May 2011 to January 2013 (duration of 21 months and intensity of -0.55) drought that have been featured in other studies (Anderson et al., 2012; Dutra et al., 2013). Droughts with high severity occurred during 1973–1974, 1984–1985, 1989-1993 and 2010–2011. These drought events were found to have large scale impacts in the Horn of Africa (Haile et al., 2020) which resulted in destructive effects on the environment and society (Haile et al., 2019). The 1984–1985 and 1989-1993 drought events were previously found to have affected the entire African continent (Masih et al., 2014). The 1984 drought was previously found to affect the entire Horn of Africa presenting serious environmental problems (Ghebrezgabher et al., 2016).

The monthly SPEI also captured the wetting trend in 1988 and the drying trend in 1991 and 2005. However, during the months of October-December, few droughts were recorded. This can be attributed to the short rains that comes during these months (Lyon & Vigaud, 2017). There were also decadal variations besides the generally increasing drought trends. These variations could be associated with the changes in climatic and environmental conditions in the past few decades. Other sources of differences might include the seasonality, patterns of precipitation and oceanic influence. Generally there is an increasing trend of drought occurrence showing rising drought count and the associated consequences on agriculture and water resources (Haile et al., 2020). The most severe drought years were 1984-1985, 1989-1993, 2005-2007, and 2010–2011. These droughts caused huge damages to both the environment and livelihoods (Haile et al., 2019).

Drought showed significantly drying trends with increased frequency. Spatiotemporal evaluation of drought can improve knowledge and understand of mechanisms and factors influencing drought occurrences and distribution (Zhou et al., 2017). In general, high drought counts with long durations and high intensities are distributed in various parts of Somalia, Spinoni et al. (2014) also found similar trends. Somalia is characterized by arid and semi-arid climatic conditions and is therefore frequently hit by drought of high severity (Zhou et al., 2017).

5.2 Account for forest cover loss

An increasing trend in forest cover loss resulting in decreasing forest cover was witnessed throughout the study period as shown in Figure 10. A 23.01% decrease in forest cover has been recorded in the period between 2000 and 2019. The Forest Resource Assessment does forest cover change analysis based on assumed uniform annual change of 76800 ha. Besides the different approaches adopted by FRA and Hansen in estimating forest cover change, there is a strong correlation of 0.95 between their forests cover estimates (figure 11). However, FRA underestimated forest cover by 14.58% for the period 2000 to 2016 (table 7).

5.3 Sustainable management for mitigating land degradation

5.3.1 Land degradation types

Various forms of land degradation were assessed by the reviewed articles. The prevalent forms of land degradation in Somalia are vegetation loss (57%) and soil erosion (43%) as shown in table 8. According to Nachtergaele & Licona-Manzur (2008) assessment, the main areas experiencing loss of vegetation cover were the central and the North-Eastern parts of Somalia. The loss was estimated at 1.4% per annum (Zerga et al. 2018). The findings were attributed to overgrazing and extreme drought events. Additionally, the increase in population which results in clearing of vegetation for human settlement, urbanization and agriculture accelerated the situation.

Soil erosion in Somalia is mainly accelerated by wind and water agents. The Northern parts were mainly affected by water erosion (Omuto et al., 2014) while wind erosion was experienced in the North Eastern coast of the Aden Gulf. Wind erosion was attributed to the presence of high wind storms (Bolognesi et al., 2015). The occurrence of water erosion was mainly due to the loss of vegetation and the flash floods which carry the topsoil. Vegetation cover checks the rate of erosion by either wind or water. However, since the loss of vegetation is the primary type of land degradation, it exposes the land, making it more prone to both wind and water erosion.

The decrease in soil moisture was attributed to climate variability (Beier & Stephansson, 2012). The increased temperatures result in high water losses through evapotranspiration leading to a decline in moisture. Additionally, prolonged droughts and reduced rainfall patterns results in low moisture.

5.3.2 Land degradation assessment

Remote sensing

This technique of assessing land degradation was used in 60% of the reviewed papers. It involved the NDVI-based analysis in identifying the main areas affected by land degradation. According to Maystadt & Eckert (2014), the steps followed during the assessment process were described in figure 12 below.

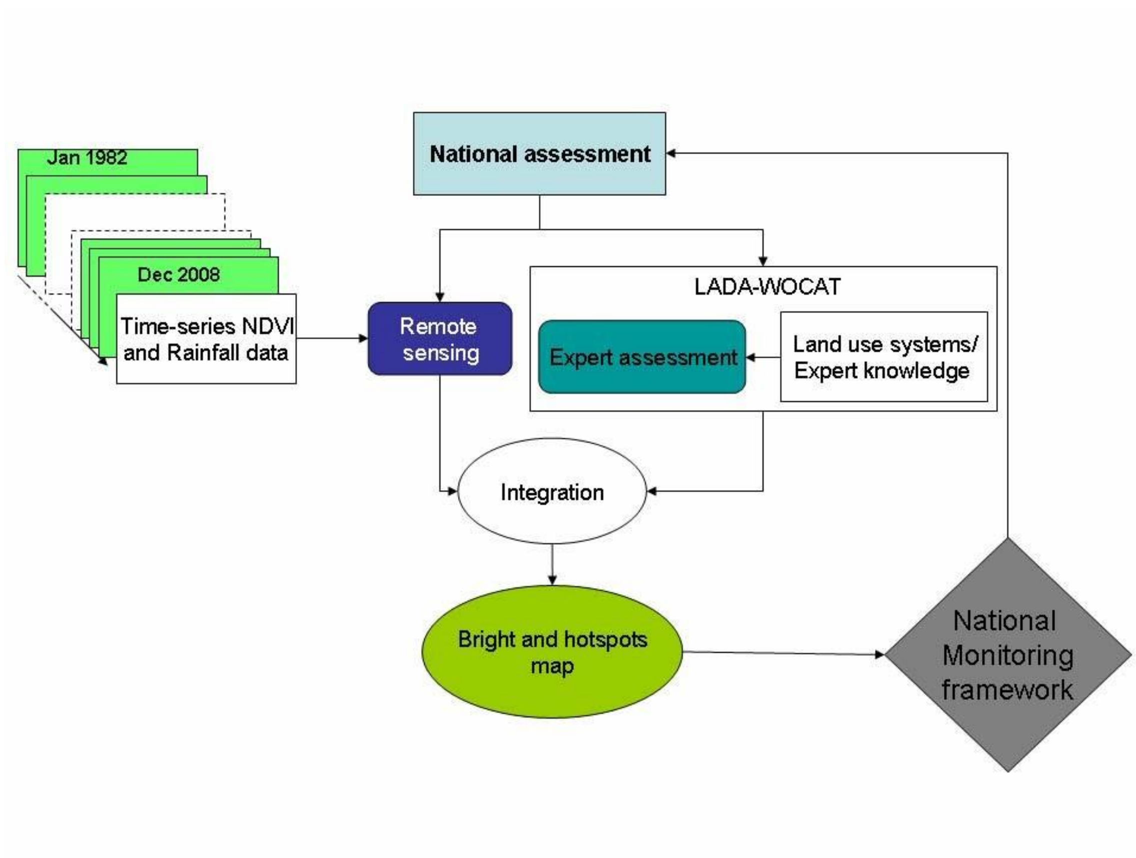

Figure 12 Steps followed in remote sensing based assessment and monitoring of land degradation

The steps were carried out to develop land-use system maps which were used to monitor land degradation. Land use involves a series of activities aimed at offering goods and services. A land use map entails all the anthropogenic activities and all the resources available. According to Nachtergaele & Licona-Manzur (2008), this measure was advocated to evaluate land degradation. Vegetation loss has been identified as the primary type of land degradation in Somalia (Enenkel et al., 2013). Therefore, proper mapping of the areas with high vegetation cover loss is vital for the selection of proper mitigation measures.

Additionally, the use of NDVI as a rainfall sensor can be applied to forecast rainfall to avert climate change effects (Nachtergaele & Licona-Manzur, 2008). This was attributed to the fact that - NDVI can be used to assess the increase or decline in the trends and the disparities between the remotely sensed -and predicted-rainfall - with time (Enenkel et al., 2013). This approach was identified to be effective due to its better ability to model NDVI-rainfall relation compared to the common traditional single model approach used for land cover dynamics analysis (Nachtergaele &Licona-Manzur, 2008).It is an application of regression that simultaneously establish environmental relations at the landscape level and also the relationship between the various same units in the landscape (Omuto et al., 2006). Furthermore, this approach is realistic since various vegetation responds differently to rainfall patterns which cannot be captured with single model.

Table 10: Criteria for vegetation cover loss

Vegetation status	Indictor of anthropogenic vegetation loss
Lost vegetation	Stumps or cut tree branches
	Evidence of charcoal burning
	Overgrazed land
	Less than 10% vegetation cover
	Report of decreasing vegetation cover in the last five to ten years
No vegetation loss	More than 10% vegetation cover
	No evidence of charcoal production
	No evidence of livestock overgrazing
	No reports of declining vegetation in the last five to ten years

There were two major causes of direct land degradation found by experts in Somaliland: overuse of vegetation and expansion of agriculture (Omuto et al., 2014). Vegetation overutilization was primarily for the collection of fuelwood, fencing and building materials, livestock grazing and the processing of coal. This is an unregulated operation that removes trees selectively (particularly the *Acacia busei*) (Rembold et al., 2013). Another clear cause of land erosion was also an agricultural extension (i.e. rise in rain fed/ irrigated farms) to rangelands. First, rangelands were marginally suitable for agriculture and primarily when it was not properly managed.

In regions where agriculture has been practised, lack of good agricultural practice worsened the deterioration of soil. Second, farming influenced typical animal pasture patterns in rangeland areas. As a result, the concentration of animal pasture in individual sections was said to be rising. This caused significant levels of overgrazing. The overgrazed fields can regenerate vegetation and therefore invasive plants start colonizing the area.

About 53% of the reviewed papers assessed the drivers of land degradation. Indirect factors driving land degradation in Somaliland include: an increase in population of humans and livestock, deprivation and poor policies and ineffective enforcement of the existing policies (Nachtergaele & Licona-Manzur, 2008). The population in Somalia is increasing, as in many places in the world. While there is no official public domain figure, in different works of literature, there is an annual population growth rate of around 3% in Somalia (Omuto et al., 2014). This increase undoubtedly puts the limited land resources under pressure (Table 11).

Table 11: Extent of various types of land degradation

Type of land degradation	**Area (sq. km)**	**Area affected (%)**
Water driven Soil erosion	76661.09	45.21
Biological degradation	51673.45	30.48
Water degradation	16055.44	9.47
Soil erosion by wind	13520.54	7.97
Chemical soil deterioration	1365.61	0.80
Urban	47.44	0.03
Non-degraded areas	10235.75	6.04
Total	169559.32	100

Source: Nachtergaele & Licona-Manzur (2008)

Poverty also induces land loss indirectly. With a limited resources base, people require better benefits derived from significant assets including crop and livestock farming (Beier & Stephansson, 2012). As household income is small, land users are unable to make investments in developing land management and thus degrading property (Nachtergaele & Licona-Manzur, 2008*)*. Another indirect driver of land degradation is the absence of effective policies and the government's deficient compliance (Venema et al., 2009). While the government of Somaliland is trying to monitor the use of land resources, more effort and support are still needed.

5.3.3 Land degradation mitigation measures

The articles reviewed reported that land degradation affected both flora and fauna as well as food security and livelihoods, and vegetation cover. To mitigate the impacts, soil bundling and water harvesting were recommended by 30% of the articles. Most of these reactions are in the agribusiness processes, with the primary forms of land degradation being depletion of fertile top soil, nutritive degeneration and water scarcity.

While several organizations in Somalia (such as United Nations Environment Program, Food and Agriculture Organisation and National Action Program among others) are implementing the above responses, documentation or assessment of the practices implemented is lacking (Onchere, 2000). 75% of the places with human induced vegetation loss were correctly defined in the NDVI-based study (Baumann, 2014). It correctly defined areas of vegetation cover loss with a precision of 76% and the affected areas with a precision of 72%. Seven impacted areas were nevertheless misclassified as uninfluenced (Enenkel et al., 2013).

After 2002, however, the majority of these lands were recolonized with grass or trees, and thus the loss of vegetation cover was not easily detected by 8 km NDVI images (Eckert et al., 2015). Similarly, on the boundary between the densely and the sparsely vegetated areas, 8 of the 11 misclassified areas with no evidence of vegetation cover loss were captured. A misclassification was also likely due to inadequate description of the newly established tree species and the coarse resolution of NDVI (Sergio M. Vicente-Serrano et al., 2015). The findings from the NDVI-based study indicate that vegetation coverage was high at the point where the photographs were taken, and vegetation coverage was not significantly decreasing in the region surrounding the lower photographs (Nachtergaele & Licona-Manzur, 2008). The images revealed that the change of land use from natural vegetation to agricultural use decreased vegetation cover as expressed by NDVI signals that decreased (Eckert et al., 2015). The findings suggest that NDVI-based research can detect human-induced vegetation loss. The vegetation can be correlated with a loss of vegetation that protects certain soil degradation (Omuto et al., 2014).

5.3.3.1 Afforestation and Reforestation

This strategy is a curative and defensive aspect of vegetation. This approach was found to be useful by 20% of the articles reviewed in this study. With a carefully planned and efficiently controlled forestation system, the land otherwise abandoned will regain value. Jama et al. (2020) notes that restoration and reforestation is the critical step to restoring troubling land on a broad enough scale to fix the soil problems.

Successful implementation of afforestation and reforestation schemes calls for the opportunity to form neighborhood advocacy groups or include local organizations in the neighborhood(Zegeye, 2018). Activities such as the development of children's schools in villages, plant and protect multifunctional trees along roads, farms and homes, etc., for example, call for the opportunity to obtain know-how, resources and energy from people living in rural areas.

About 50% of the reviewed papers recommended a number farming practices to mitigating land degradation. Farmers' use of some new soil enhancement inputs like combined use of organic and inorganic fertilizers can also bring short-term economic benefits (Magembe et al., 2015). The soil enhancement inputs augmenting the soil reducing the erodibility rate (Keesstra et al., 2016). The principles behind the process of conservation are part and parcel of farming work cycles. This technique proved to integrate the three main strategies referred to by Tegene (1992) to regulate soil erosion: agronomic methods which improve vegetative cover to control erosion, and soil management methods, which seek to control erosion through the improvement in soil aggregation; and structural methods of soil conservation that mitigate erosion by length shortening and reduces soil slope gradient. These methods include building linked ridges, sheets, *Fanya juu* terraces, bench terraces, hillside terraces, waterways and individual water processing facilities(El Shabrawy et al., 2014). Several agricultural activities are thought to preserve the natural resource base and at the same time, increasing productivity. Cultivation of crops; incorporation of the animal farming with arable crops; cutting and transportation system of the use of degraded pasturing, managed grazing and tethering.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

6.1.1 Drought characteristics

Somalia has always been the unfortunate recipient of detrimental consequences of droughts that often develop gradually and unnoticed. This therefore made it necessary to evaluate the patterns of drought occurrence at monthly, annual and inter-annual based on SPEI captured at four different timescales (1-, 3-, 6- and 12-month). The 3-month SPEI was selected for the assessment of spatial patterns of drought. Based on the results of this study, a number of conclusions can be made:

1. The duration and severity of drought increased as the SPEI timescale increased. Based on all timescales, the SPEI showed decreasing trends implying that drought count increased throughout the study period. Based on MK-trend test, the annual average trends of changes in the SPEI for Somalia were -0.00000142, - 0.000013, -0.00001, and -0.000014 for the 1-, 3-, 6-, and 12-month respectively revealing increasing trends of drought.
2. An increasing trend of drought was found in the last 34 years with fluctuating spatial and temporal patterns. Drought increased intermittently for the period 1982 to 1999 and increased persistently for the period 2000 to 2015 with considerable regional variations. Somalia experienced the most severe droughts during 1984-1985, 1989-1993, 2005-2007, and 2010–2011.

These results being the first for the country are expected to be useful for the policy and decision makers in understanding drought patterns for enhanced preparedness.

6.1.2 Account for forest cover loss

This analysis shows the temporal patterns of forest cover loss in Somalia and proposes a remote sensing-based accounting for forest cover loss. Generally the following conclusions were made from this analysis;

1. Forest cover has been decreasing in Somalia at an average rate of 1.67% per year from 2000 to 2019.

2. This study show higher forest cover than that of Forest Resource Assessment report of 2015 for the period 2000 to 2016. . The Hansen based forest cover is higher by 14.58%.

6.1.3 Best-fit sustainable management methods for mitigating land degradation

A total of 20 papers on land degradation in Somalia were reviewed. From the review, the following conclusions can be made;

1. Somalia is a highly degraded country with the main type of land degradation being soil erosion that result from wind and water erosion and loss of vegetation cover.
2. From the reviewed articles a combination of remote sensing technique together with other land degradation measures is a promising tool for the better results in land degradation management. Mapping and identifying areas prone to degradation enable proper monitoring and management of land degradation.
3. The most commonly used land degradation mitigation measure is the use of soil bands. Other practices, such as agroforestry, afforestation and reforestation, can also be adopted to mitigate land degradation.

6.2 Recommendations

From this study the following recommendations can be made;

1. These results can be used to design drought monitoring and management systems at national level, since Somalia is frequently hit by widespread drought and does not have enough ground meteorological stations, such a system is necessary.
2. The following practices can be adopted in order to minimize land degradation; conservation agriculture and mulching, minimum tillage, cover cropping, agroforestry, integrated nutrient management and any other practices that minimize soil disturbance and increase soil organic carbon.
3. There is need to develop institutional framework for enhanced and sustainable management and restoration of degraded lands. This can be done through creation of awareness among people/farmers living in areas that are prone to degradation.

REFERENCES

Abdulkadir, G. (2017). *Assessment of Drought Recurrence in Somaliland : Causes , Impacts and Climatology & Weather Forecasting*. *5*(2), 1–12.

Adami, M., Rudorff, B. F. T., Freitas, R. M., Aguiar, D. A., Sugawara, L. M., & Mello, M. P. (2012). Remote sensing time series to evaluate direct land use change of recent expanded sugarcane crop in Brazil. *Sustainability*, *4*(4), 574-585.

Alizadeh, M. R., & Nikoo, M. R. (2018). A fusion-based methodology for meteorological drought estimation using remote sensing data. *Remote sensing of environment*, *211*, 229-247.

Alwesabi, M. S. (2012). *MODIS NDVI satellite data for assessing drought in Somalia during the period 2000-2011*. *257*.

Anderson, W. B., Zaitchik, B. F., Hain, C. R., Anderson, M. C., Yilmaz, M. T., Mecikalski, J., & Schultz, L. (2012). Towards an integrated soil moisture drought monitor for East Africa. *Hydrology and Earth System Sciences, 16*(8), 2893–2913.

Asong, Z. E., Wheater, H. S., Bonsal, B., Razavi, S., & Kurkute, S. (2018). Historical drought patterns over Canada and their teleconnections with large-scale climate signals. *Hydrology & Earth System Sciences*, *22*(6).

Asner, G. P., Brodrick, P. G., Anderson, C. B., Vaughn, N., Knapp, D. E., & Martin, R. E. (2015). *Progressive forest canopy water loss during the 2012 – 2015 California drought*. *2015*, 249–255.

Azpurua, M., & dos Ramos, K. (2010). A comparison of spatial interpolation methods for estimation of average electromagnetic field magnitude. *Progress In Electromagnetics Research M*, *14*(September), 135–145.

Bae, S., Lee, S. H., Yoo, S. H., & Kim, T. (2018). Analysis of drought intensity and trends using the modified SPEI in South Korea from 1981 to 2010. *Water (Switzerland)*, *10*(3).

Behera, S. K., Luo, J. J., Masson, S., Delecluse, P., Gualdi, S., Navarra, A., & Yamagata, T. (2005). Paramount impact of the Indian Ocean dipole on the East African short rains: A CGCM study. *Journal of Climate*, *18*(21), 4514-4530.

Bai, Z. G., D, D. L., O, L., & S, M. E. (2008). *Proxy global assessment of land degradation*. *3*(September), 223–234.

Bajocco, S., De Angelis, A., Perini, L., Ferrara, A., & Salvati, L. (2012). The impact of Land Use/Land Cover Changes on land degradation dynamics: A Mediterranean case study. *Environmental Management*, *49*(5), 980–989.

Baumann, M. (2014). *Pastoral production systems in Central Somalia*. *June 1993*.

Beguería, S., Vicente-Serrano, S. M., & Angulo-Martínez, M. (2010). A multiscalar global drought dataset: The SPEI base: A new gridded product for the analysis of drought variability and impacts. *Bulletin of the American Meteorological Society*, *91*(10), 1351–1356.

Beier, A.-C., & Stephansson, E. (2012). *Environmental and Climate Change Policy Brief: Somalia*. 1–30.

Blaikie, P., & Brookfield, H. (Eds.). (2015). *Land degradation and society*. Routledge.

Bolognesi, M., Vrieling, A., Rembold, F., & Gadain, H. (2015). Energy for Sustainable Development Rapid mapping and impact estimation of illegal charcoal production in southern Somalia based on WorldView-1 imagery. *Energy for Sustainable Development*, *25*, 40–49.

Calow, R. C., MacDonald, A. M., Nicol, A. L., & Robins, N. S. (2010). Ground water security and drought in Africa: Linking availability, access, and demand. *Ground Water*, *48*(2), 246–256.

Chen, S., Zhang, L., Liu, X., Guo, M., & She, D. (2018). The Use of SPEI and TVDI to Assess Temporal-Spatial Variations in Drought Conditions in the Middle and Lower Reaches of the Yangtze River Basin, China. *Advances in Meteorology*, *2018*.

Cheng, L., Hoerling, M., Aghakouchak, A., Livneh, B., Quan, X. W., & Eischeid, J. (2016). How has human-induced climate change affected California drought risk? *Journal of Climate*, *29*(1), 111–120.

Choubin, B., Soleimani, F., Pirnia, A., Sajedi-Hosseini, F., Alilou, H., Rahmati, O., ... & Shahabi, H. (2019). Effects of drought on vegetative cover changes: Investigating spatiotemporal patterns. In *Extreme Hydrology and Climate Variability* (pp. 213-222). Elsevier.

Clark, J. S., Iverson, L., Woodall, C. W., Allen, C. D., Bell, D. M., Bragg, D. O. N. C., Amato, A. W. D., Davis, F. W., Hersh, M. H., Ibanez, I., & Jackson, S. T. (2016). *The impacts of increasing drought on forest dynamics , structure , and biodiversity in the United States*. 2329–2352.

Coalition, N. C.,& Keynes, M. (2016). Natural Capital Coalition. *Natural Capital Protocol*.

Cowie, A. L., Orr, B. J., Castillo, V. M., Chasek, P., Crossman, N. D., Erlewein, A., Louwagie, G., Maron, M., Metternicht, G. I., Minelli, S., Tengberg, A. E., Walter, S., & Welton, S. (2018). *Land in balance : The scienti fi c conceptual framework for Land Degradation Neutrality*. *79*(August 2017), 25–35.

Dai, A. (2011). Drought under global warming: A review. *Wiley Interdisciplinary Reviews: Climate Change*, *2*(1), 45–65.

Damberg, L., & AghaKouchak, A. (2014). Global trends and patterns of drought from space. *Theoretical and Applied Climatology*, *117*(3–4), 441–448.

de Jong, R., de Bruin, S., Schaepman, M., & Dent, D. (2011). Quantitative mapping of global land degradation using earth observations. *International Journal of Remote Sensing*, *32*(21), 6823–6853.

Dlamini, C. S., & Geldenhuys, C. J. (2011). Towards a theoretical framework for the management of non-timber forest products (NTFPs) in Swaziland: A review. *Journal of Geography and Regional Planning*, *4*(15), 715-730.

Dlamini, C. S. (2012). Types of values and valuation methods for environmental resources: Highlights of key aspects, concepts and approaches in the economic valuation of forest goods and services. *Journal of Horticulture and Forestry*, *4*(12), 181-189.

Dovie, D. B. (2003). Rural economy and livelihoods from the non-timber forest products trade. Compromising sustainability in southern Africa?. *The International Journal of Sustainable Development & World Ecology*, *10*(3), 247-262.

Dubrovsky, M., Svoboda, M. D., Trnka, M., Hayes, M. J., Wilhite, D. A., Zalud, Z., & Hlavinka, P. (2009). Application of relative drought indices in assessing climate-change impacts on drought conditions in Czechia. Theoretical and Applied Climatology, 96(1-2), 155-171.

Dutra, E., Magnusson, L., Wetterhall, F., Cloke, H. L., Balsamo, G., Boussetta, S., & Pappenberger, F. (2013). The 2010-2011 drought in the Horn of Africa in ECMWF reanalysis and seasonal forecast products. *International Journal of Climatology*, *33*(7), 1720–1729.

Eckert, S., Hüsler, F., Liniger, H., & Hodel, E. (2015). Trend analysis of MODIS NDVI time series for detecting land degradation and regeneration in Mongolia. *Journal of Arid Environments*, *113*, 16–28.

El Shabrawy, M. O. A., Hosni, H. A., El Garf, I. A., Marzouk, M. M., Kawashty, S. A., & Saleh, N. A. M. (2014). Flavonoids from allium myrianthum boiss. *Biochemical Systematics and Ecology*, *56*, 125–128.

Enenkel, M., Rojas, O., & Balint, Z. (2013). *Use of satellite-derived soil moisture to improve drought monitoring*. *15*(Cci), 2013.

Ensham, R. J. F., & Airfax, R. J. F. (2012). *Potential aboveground biomass in drought-prone forest used for rangeland pastoralism*. *22*(3), 894–908.

FAO, UN. (1981). Tropical forest resources assessment project. *Forest resources of tropical Africa. Part II: Country Briefs. FAO, UNEP.*

Fensham, R. J., & Holman, J. E. (1999). Temporal and spatial patterns in drought-related tree dieback in Australian savanna - 2001 - Journal of Applied Ecology - Wiley Online Library. *Journal of Applied Ecology*, 1035–1050.

Foster, R. H. (2006). Methods for assessing land degradation in Botswana. *Earth & E-Nvironment*, *1*, 238–276.

Framework, C. (2012). *SEEA 2012 Central Framework*.

Fredriksen, A. (2016). *Crisis in ' a normal bad year ': Spaces of humanitarian emergency , the Integrated Food Security Phase Classification scale and the Somali famine of 2011*.

Galati, A., Gristina, L., Crescimanno, M., Barone, E., & Novara, A. (2015). Towards More Efficient Incentives for Agri-environment Measures in Degraded and Eroded Vineyards. *Land Degradation and Development*, *26*(6), 557–564.

Gandhi, G. M., Parthiban, S., Thummalu, N., & Christy, A. (2015). Ndvi : Vegetation change detection using remote sensing and gis – A case study of Vellore District. *Procedia - Procedia Computer Science*, *57*, 1199–1210.

Ghebrezgabher, M. G., Yang, T., & Yang, X. (2016). Long-term trend of climate change and drought assessment in the Horn of Africa. *Advances in Meteorology*, *2016*.

Ginnetti, J., & Franck, T. (2014). *ASSESSING DROUGHT DISPLACEMENT RISK FOR KENYAN, ETHIOPIAN AND SOMALI PASTORALISTS Norwegian Refugee Council (NRC) Internal Displacement Monitoring Centre (IDMC) DISASTERS CLIMATE CHANGE AND DISPLACEMENT EVIDENCE FOR ACTION*.

Gonza, J., & Valde, J. B. (2006). *New drought frequency index : Definition and comparative performance analysis*. *42*, 1–13.

González-Hidalgo, J. C., Vicente-Serrano, S. M., Peña-Angulo, D., Salinas, C., Tomas-Burguera, M., & Beguería, S. (2018). High-resolution spatio-temporal analyses of drought episodes in the western Mediterranean basin (Spanish mainland, Iberian

Peninsula). *Acta Geophysica*, *66*(3), 381-392.

Gottschalk, L., Krasovskaia, I., Dominguez, E., Caicedo, F., & Velasco, A. (2015). Interpolation of monthly runoff along rivers applying empirical orthogonal functions: Application to the Upper Magdalena River, Colombia. *Journal of Hydrology*, *528*, 177–191.

Gram, S. (2001). Economic valuation of special forest products: an assessment of methodological shortcomings. *Ecological economics*, *36*(1), 109-117.

Hadden, B. R. L., & Lee, R. (2007). *The Geology of Somalia : a Selected Bibliography of Somalian Geology , Geography and Earth Science . 7701 Telegraph Road UNCLASSIFIED / UNLIMITED Bibliography of Liberian Earth Science*. *February*.

Haile, G. G., Tang, Q., Sun, S., Huang, Z., Zhang, X., & Liu, X. (2019). Droughts in East Africa: Causes, impacts and resilience. *Earth-science reviews*, *193*, 146-161.

Haile, G.G, Tang, Q., Leng, G., Jia, G., Wang, J., Cai, D., Sun, S., Baniya, B., & Zhang, Q. (2020). Long-term spatiotemporal variation of drought patterns over the Greater Horn of Africa. *Science of the Total Environment*, *704*, 135299.

Hamann, A., & Wang, T. (2006). Potential effects of climate change on ecosystem and tree species distribution in British Columbia. *Ecology*, *87*(11), 2773–2786.

Harshaw, H. W., Sheppard, S., & Jeakins, P. (2009). Public attitudes toward sustainable forest management: Opinions from forest-dependent communities in British Columbia. *Journal of Ecosystems and Management*, *10*(2).

Irmak, A., Ranade, P. K., Marx, D., Irmak, S., Hubbard, K. G., Meyer, G. E., & Martin, D. L. (2010). *S i c v n*. *53*(6), 1759–1771.

Jama, O. M., Liu, G., Diriye, A. W., Yousaf, B., Basiru, I., & Abdi, A. M. (2020). Participation of civil society in decisions to mitigate environmental degradation in post-conflict societies: evidence from Somalia. *Journal of Environmental Planning and Management*, 1-21.

Johnson, P. M., & Mayrand, K. (2007). *Governing Global Desertification*. *31*, 93–95.

Keesstra, S., Pereira, P., Novara, A., Brevik, E. C., Azorin-Molina, C., Parras-Alcántara, L., ... & Cerdà, A. (2016). Effects of soil management techniques on soil water erosion in apricot orchards. *Science of the Total Environment*, *551*, 357-366.

Khosravi, H., Haydari, E., Shekoohizadegan, S., & Zareie, S. (2017). Assessment the Effect of Drought on Vegetation in Desert Area using Landsat Data. *Egyptian Journal of Remote Sensing and Space Science*, *20*, S3–S12.

Kiem, A. S., Johnson, F., Westra, S., van Dijk, A., Evans, J. P., O'Donnell, A., Rouillard, A., Barr, C., Tyler, J., Thyer, M., Jakob, D., Woldemeskel, F., Sivakumar, B., & Mehrotra, R. (2016). Natural hazards in Australia: droughts. *Climatic Change*, *139*(1), 37–54.

Kilibarda, M., Tadić, M. P., Hengl, T., Luković, J., & Bajat, B. (2015). Global geographic and feature space coverage of temperature data in the context of spatio-temporal interpolation. Spatial Statistics, 14, 22-38.

Kim, D., Sexton, J. O., Noojipady, P., Huang, C., Anand, A., Channan, S., Feng, M., & Townshend, J. R. (2014). Remote Sensing of Environment Global , Landsat-based forest-cover change from 1990 to 2000. *Remote Sensing of Environment*, *155*, 178–193.

Kosmas, C., Kairis, O., Karavitis, C., Ritsema, C., Salvati, L., Acikalin, S., Alcalá, M., Alfama, P., Atlhopheng, J., Barrera, J., Belgacem, A., Solé-Benet, A., Brito, J., Chaker, M., Chanda, R., Coelho, C., Darkoh, M., Diamantis, I., Ermolaeva, O., … Ziogas, A. (2013). Evaluation and Selection of Indicators for Land Degradation and Desertification Monitoring: Methodological Approach. *Environmental Management*, *54*(5), 951–970.

Kosmas, C., Karamesouti, M., Kounalaki, K., Detsis, V., Vassiliou, P., & Salvati, L. (2016). Land degradation and long-term changes in agro-pastoral systems: An empirical analysis of ecological resilience in Asteroussia-Crete (Greece). *Catena*, *147*, 196-204.

Le, Q. B., Tamene, L., & Vlek, P. L. G. (2012). Multi-pronged assessment of land degradation in West Africa to assess the importance of atmospheric fertilization in masking the processes involved. *Global and Planetary Change*, *92–93*, 71–81.

Lee, S. H., Yoo, S. H., Choi, J. Y., & Bae, S. (2017). Assessment of the impact of climate change on drought characteristics in the Hwanghae Plain, North Korea using time series SPI and SPEI: 1981–2100. *Water (Switzerland)*, *9*(8).

Li, X., He, B., Quan, X., Liao, Z., Bai, X., Ave, X., Zone, W. H., Yang, W., Huete, A. R., & Thenkabail, P. S. (2015). *remote sensing*. *Vci*, 10917–10937.

Li, Y., Xie, Z., Qin, Y., Xia, H., Zheng, Z., & Zhang, L. (2019). *Drought Under Global Warming and Climate Change : An Empirical Study of the Loess Plateau*. 1–15.

Li, Z., Zhou, T., Zhao, X., Huang, K., Gao, S., & Wu, H. (2015). *Assessments of Drought Impacts on Vegetation in China with the Optimal Time Scales of the Climatic Drought Index*. 7615–7634.

Lin, W., Wen, C., Wen, Z., Gang, H., Lin, W., Wen, C., Wen, Z., & Gang, H. (2017). *Drought in Southwest China : A Review Drought in Southwest China : A Review*. *2834*(August).

Lyon, B. (2014). Seasonal drought in the Greater Horn of Africa and its recent increase during the March-May long rains. *Journal of Climate*, *27*(21), 7953–7975.

Lyon, B., & Vigaud, N. (2017). Unraveling East Africa's climate paradox. *Climate extremes: Patterns and mechanisms*, *265*, 281.

Magembe, K. S., Makonda, F. B. S., & Masanja, M. M. (2015). Fuelwood consumption in brick making: A case of Morogoro Municipality, Tanzania.

Malcolm, J. R., Liu, C., Neilson, R. P., Hansen, L., & Hannah, L. (2006). Global warming and extinctions of endemic species from biodiversity hotspots. *Conservation Biology*, *20*(2), 538–548.

Managi, S., & Kumar, P. (2018). *Inclusive wealth report 2018*. Taylor & Francis.

Mann, H. B. (1945). Nonparametric tests against trend. Econometrica: Journal of the econometric society, 245-259.

Mardones, C., & del Rio, R. (2019). Correction of Chilean GDP for natural capital depreciation and environmental degradation caused by copper mining. *Resources Policy*, *60*, 143-152.

Masih, I., Maskey, S., Mussá, F. E. F., & Trambauer, P. (2014). A review of droughts on the African continent: a geospatial and long-term perspective. *Hydrology and Earth System Sciences*, *18*(9), 3635.

Maystadt, J. F., & Ecker, O. (2014). Extreme weather and civil war: Does drought fuel conflict in Somalia through livestock price shocks? *American Journal of Agricultural Economics*, *96*(4), 1157–1182.

McKee, T. B., Doesken, N. J., & Kleist, J. (1993). The relationship of drought frequency and duration to time scales. *Proceedings of the 8th Conference on Applied Climatology*, *17*(22), 179–183.

Meeking, E. J. (2013). A Study of Climate Change Induced Migration in Somalia. *E International Students*.

Mendicino, G., Senatore, A., & Versace, P. (2008). A Groundwater Resource Index (GRI) for drought monitoring and forecasting in a Mediterranean climate. *Journal of Hydrology*, *357*(3-4), 282-302.

Menkhaus, K. (2014). Calm between the storms? Patterns of political violence in Somalia, 1950–1980. *Journal of Eastern African Studies*, *8*(4), 558–572.

Mishra, A. K., & Singh, V. P. (2010). Review paper A review of drought concepts. *Journal of Hydrology*, *391*(1–2), 202–216.

Mishra, A. K., & Singh, V. P. (2011). Drought modeling - A review. *Journal of Hydrology*, *403*(1–2), 157–175.

Mpelasoka, F., Awange, J. L., & Zerihun, A. (2018). Influence of coupled ocean-atmosphere phenomena on the Greater Horn of Africa droughts and their implications. *Science of the Total Environment*, *610*, 691-702.

Mwangi, E., Wetterhall, F., Dutra, E., Di Giuseppe, F., & Pappenberger, F. (2014). Forecasting droughts in East Africa. *Hydrology and Earth System Sciences*, *18*(2), 611–620.

Nachtergaele, F. O., & Licona-Manzur, C. (2008). The Land Degradation Assessment in Drylands (LADA) Project: reflections on indicators for land degradation assessment. In *The future of drylands* (pp. 327-348). Springer, Dordrecht.

Nicholson, S. E. (2014). A detailed look at the recent drought situation in the Greater Horn of Africa. *Journal of Arid Environments*, *103*, 71–79.

Nkonya, E., Gerber, N., von Braun, J., De Pinto, A., & Braun, J. Von. (2012). Economics Of Land Degradation: The Costs of Action versus Inaction. *IFRI Issue Briefs*, *68*(September), 1–7.

Nyong, A., Development, A., Group, B., & Adesina, F. (2007). *The Value of Indigenous Knowledge in Climate Change Mitigation and Adaptation Strategies in the African Sahel*. *June*.

Oduori, S. M., Rembold, F., Abdulle, O. H., & Vargas, R. (2011). Assessment of charcoal driven deforestation rates in a fragile rangeland environment in North Eastern Somalia using very high resolution imagery. *Journal of Arid Environments*, *75*(11), 1173–1181.

Omuto, T. C., Minasny, B., McBratney, A. B., & Biamah, E. K. (2006). Nonlinear mixed effect modelling for improved estimation of water retention and infiltration parameters. *Journal of Hydrology*, *330*(3-4), 748-758.

Omuto, C. T., Balint, Z., & Alim, M. S. (2014). *A FRAMEWORK FOR NATIONAL ASSESSMENT OF LAND DEGRADATION IN THE DRYLANDS : A CASE STUDY OF SOMALIA*. *119*(October 2011), 105–119.

Onchere, N. M. (2000). The United Nations Convention to Combat Desertification: constraints to implementation in Eastern Africa. In *Rangeland Desertification* (pp. 197-209). Springer, Dordrecht.

Ozyavuz, M., Bilgili, B. C., & Salici, A. (2015). Determination of vegetation changes with NDVI method. *Journal of Environmental Protection and Ecology*, *16*(1), 264–273.

Parry, M. L., Rosenzweig, C., Iglesias, A., Livermore, M., & Fischer, G. (2004). *Effects of climate change on global food production under SRES emissions and socio-economic scenarios*. *14*, 53–67.

Pearce, D. W. (2001). The economic value of forest ecosystems. *Ecosystem health*, *7*(4), 284-296.

Perret, J., Williams, C. A., Halverson, G. H., Lee, C. M., Fisher, J. B., & Cooley, S. S. (2018). Assessing regional drought impacts on vegetation and evapotranspiration: a case study in Guanacaste, Costa Rica. *Ecological Applications*, *0*(0), 1–21.

Plouffe, C. C., Robertson, C., & Chandrapala, L. (2015). Comparing interpolation techniques for monthly rainfall mapping using multiple evaluation criteria and auxiliary data sources: A case study of Sri Lanka. Environmental Modelling & Software, 67, 57-71.

Potopová, V., Cazac, V., Boincean, B., Soukup, J., & Trnka, M. (2019). Application of hydroclimatic drought indicators in the transboundary Prut River basin. *Theoretical and Applied Climatology*, *137*(3-4), 3103-3121.

Potop, V., Boroneanţ, C., Možný, M., Štěpánek, P., & Skalák, P. (2014). Observed spatiotemporal characteristics of drought on various time scales over the Czech Republic. *Theoretical and Applied Climatology*, *115*(3–4), 563–581.

Reed, M. S., Stringer, L. C., Dougill, A. J., Perkins, J. S., Atlhopheng, J. R., Mulale, K., & Favretto, N. (2015). Reorienting land degradation towards sustainable land management: Linking sustainable livelihoods with ecosystem services in rangeland systems. *Journal of environmental management*, *151*, 472-485.

Rembold, F., Commission, E., Bolognesi, M., Leonardi, U., & Vrieling, A. (2013). *MAPPING FOREST DEGRADATION CAUSED BY THE RECENT INCREASE OF*. *May 2014*.

Rizk, I., & Rashed, M. (2015). Monitoring urban growth and land use change detection with GIS and remote sensing techniques in Daqahlia governorate Egypt. *International Journal of Sustainable Built Environment*, *4*(1), 117–124.

Schwilch, G., Lemann, T., Berglund, Ö., Camarotto, C., Cerdà, A., Daliakopoulos, I. N., ... & Siebielec, G. (2018). Assessing impacts of soil management measures on ecosystem services. *Sustainability*, *10*(12), 4416.

SEEA, U. (2012). The System of Environmental-Economic Accounts (SEEA): measurement framework in support of sustainable development and green economy policy, Briefing Paper. *Briefing Paper*.

Shackleton, C. M., Shackleton, S. E., Buiten, E., & Bird, N. (2007). The importance of dry woodlands and forests in rural livelihoods and poverty alleviation in South Africa. *Forest policy and economics*, *9*(5), 558-577.

Shahid, S., & Behrawan, H. (2008). Drought risk assessment in the western part of Bangladesh. *Natural hazards*, *46*(3), 391-413.

Sheffield, J., & Wood, E. F. (2008). Projected changes in drought occurrence under future global warming from multi-model, multi-scenario, IPCC AR4 simulations. *Climate Dynamics*, *31*(1), 79–105.

Sheffield, J., Wood, E. F., & Roderick, M. L. (2012). Little change in global drought over the past 60 years. *Nature*, *491*(7424), 435–438.

Shiferaw, A., Hurni, H., & Zeleke, G. (2013). A review on soil carbon sequestration in Ethiopia to mitigate land degradation and climate change. *Journal of Environment and Earth Science*, *3*(12), 187-200.

Sicard, P., Mangin, A., Hebel, P., & Malléa, P. (2010). Detection and estimation trends linked to air quality and mortality on French Riviera over the 1990-2005 period. *Science of the Total Environment*, *408*(8), 1943–1950.

Spinoni, J., Naumann, G., Carrao, H., Barbosa, P., & Vogt, J. (2014). World drought frequency, duration, and severity for 1951-2010. *International Journal of Climatology*, *34*(8), 2792–2804.

Stagge, J. H., Tallaksen, L. M., Xu, C.-Y., & Van Lanen, H. A. J. (2014). Standardized precipitation-evapotranspiration index (SPEI): Sensitivity to potential evapotranspiration model and parameters. *Hydrology in a Changing World: Environmental and Human Dimensions Proceedings of FRIEND-Water*, *363*(January 2015), 1–8.

Suparta, W., & Rahman, R. (2016). Spatial interpolation of GPS PWV and meteorological variables over the west coast of Peninsular Malaysia during 2013 Klang Valley Flash Flood. *Atmospheric Research*, *168*, 205–219.

Tegene, B. (1992). *Erosion: its effects on properties and productivity of Eutric Nitosols in Gununo area, southern Ethiopia, and some techniques of its control*.

UN Ecosoc. (2007). Africa Review Report on Drought and Desertification. *Fifth Meeting of the Africa Committee on Sustainable Development (ACSD-5). Addis Ababa 22-25 October 2007*, *November*, 71.

UNEP (2001). An Assessment of the Status of the World‘s Remaining Closed Forests. Division of Early Warning and Assessment (DEWA).

Van Loon, A. F. (2015). Hydrological drought explained. *Wiley Interdisciplinary Reviews: Water*, *2*(4), 359–392.

Vargas, R. R., Omuto, C. T., & Lewis, N. (2008). Land Degradation Assessment Of A Selected Study Area In Somaliland: Application Of The LADA/WOCAT Approach At Local Level. National Land Degradation Workshop, 16-18 September, Pretoria, South Africa.

Venema, J. H., Alim, M., Vargas, R. R., Oduori, S., & Ismail, A. (2009). Land use planning guidelines for Somaliland. *Technical Project Report L-13. FAO-SWALIM, Nairobi, Kenya*.

Verma, A., Ivanov, A., & Gergely, J. (2017). *Global Report Food Crisis 2017*.

Vicente-Serrano, S. M., Gouveia, C., Camarero, J. J., Begueria, S., Trigo, R., Lopez-Moreno, J. I., Azorin-Molina, C., Pasho, E., Lorenzo-Lacruz, J., Revuelto, J., Moran-Tejeda, E., & Sanchez-Lorenzo, A. (2013). Response of vegetation to drought time-scales across global land biomes. *Proceedings of the National Academy of Sciences*, *110*(1), 52–57.

Vicente-Serrano, Sergio M., Beguería, S., & López-Moreno, J. I. (2010). A multiscalar drought index sensitive to global warming: The standardized precipitation evapotranspiration index. *Journal of Climate*, *23*(7), 1696–1718.

Vicente-Serrano, Sergio M., Beguería, S., Lorenzo-Lacruz, J., Camarero, J. J., López-Moreno, J. I., Azorin-Molina, C., Revuelto, J., Morán-Tejeda, E., & Sanchez-Lorenzo, A. (2012). Performance of drought indices for ecological, agricultural, and hydrological applications. *Earth Interactions*, *16*(10).

Vicente-Serrano, Sergio M., Cabello, D., Tomás-Burguera, M., Martín-Hernández, N., Beguería, S., Azorin-Molina, C., & Kenawy, A. El. (2015). Drought variability and land degradation in semiarid regions: Assessment using remote sensing data and drought indices (1982-2011). *Remote Sensing*, *7*(4), 4391–4423.

Vogt, J. V., Safriel, U., Von Maltitz, G., Sokona, Y., Zougmore, R., Bastin, G., & Hill, J. (2011). Monitoring and assessment of land degradation and desertification: towards new conceptual and integrated approaches. *Land Degradation & Development*, *22*(2), 150-165.

Vu, T. M., Raghavan, S. V, Liong, S., & Mishra, A. K. (2018). *Uncertainties of gridded precipitation observations in characterizing spatio-temporal drought and wetness over*. *2081*(October 2017), 2067–2081.

Willis, K. G., Garrod, G., Scarpa, R., Powe, N., Lovett, A., Bateman, I. J., ... & Macmillan, D. C. (2003). *The social and environmental benefits of forests in Great Britain*. Edinburgh: Forestry Commission.

WMO. (2012). *Standardized Precipitation Index User Guide. Technical Report 1090.1090*.

WMO, & GWP. (2016). *Integrated Drought Management Programme Handbook of Drought Indicators and Indices* (Issue 1173).

World Bank, (2018). Somalia Drought Impact and Needs Assessment. United Nations Development Programme, I, 18.

Yevjevich, V. M. (1967). Objective approach to definitions and investigations of continental hydrologic droughts, An. *Hydrology papers (Colorado State University); no. 23*.

Yu, M., Li, Q., Hayes, M. J., Svoboda, M. D., & Heim, R. R. (2014). Are droughts becoming more frequent or severe in China based on the standardized precipitation evapotranspiration index: 1951–2010?. *International Journal of Climatology*, *34*(3), 545-558.

Yuan, X., Wood, E. F., Chaney, N. W., Sheffield, J., Kam, J., Liang, M., & Guan, K. (2013). Probabilistic Seasonal Forecasting of African Drought by Dynamical Models. *Journal of Hydrometeorology*, *14*(6), 1706–1720.

Zegeye, H. (2018). Climate change in Ethiopia: impacts, mitigation and adaptation. *International Journal of Researh in Environmental Studies*, *2*(4), 66–84.

Zerga, B., Workineh, B., Teketay, D., & Woldetsadik, M. (2018). Rangeland Degradation and Rehabilitation Efforts in the Somali National Regional State, Eastern Ethiopia: A Review. *International Journal of Innovative Research and Development, 7*(5).

Zhou, L., Wu, J., Mo, X., Zhou, H., Diao, C., Wang, Q., ... & Zhang, F. (2017). Quantitative and detailed spatiotemporal patterns of drought in China during 2001–2013. *Science of the Total Environment*, *589,* 136-145.