ASSESSING THE IMPACTS OF DROUGHT ON WATER SUPPLY AVAILABILITY IN WEST HARARGHE ZONE, EASTERN ETHIOPIA

MEZGEBU SOLOMON TAYE

A THESIS SUBMITTED TO THE DEPARTMENT OF WATER RESOURCE ENGINEERING

SCHOOL OF CIVIL ENGINEERING AND ARCHITECTURE

PRESENTED IN PARTIAL FULFILLMENT FOR THE REQUIREMENT OF THE DEGREE OF MASTER IN WATER SUPPLY AND ENVIRONMENTAL ENGINEERING

OFFICE OF GRADUATE STUDIES

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

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ADAMA, ETHIOPIA

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APPROVAL SHEET

I, the advisors of the thesis entitled **"Assessing the impacts of drought on water supply availability in west Hararghe zone, Eastern Ethiopia"** and developed by **Mezgebu Solomon Taye,** hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Mezgebu Solomon Taye	________________	________________
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We, the undersigned, members of the Board of Examiners of the thesis by **Mezgebu Solomon Taye** have read and evaluated the thesis entitled **"Assessing the impacts of drought on water supply availability in west Hararghe zone, Eastern Ethiopia"** and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in water supply and environmental engineering.

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Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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School Dean	Signature	Date
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Office of Postgraduate Studies, Dean	Signature	Date

DECLARATION

I hereby declare that this Master Thesis entitled **“Assessing the impacts of drought on water supply availability in west Hararghe zone, Eastern Ethiopia”** is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Mezgebu Solomon Taye ______________________ ______________

Name of the student Signature Date

RECOMMENDATION

I the advisor of this thesis, hereby certify that I/we have read the revised version of the thesis entitled **“Assessing the impacts of drought on water supply availability in west Hararghe zone, Eastern Ethiopia”** prepared under my/our guidance by **Mezgebu Solomon Taye** submitted in partial fulfillment of the requirements for the degree of Mater’s of Science in water supply and environmental Engineering. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

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ACRONYMS

CBD:	Convention of Biological Diversity
DPPA:	Disaster Preparedness and Prevention Agency
DPPC:	Disaster Prevention and Preparedness Commission
DRMC:	Disaster Risk Management Commission
FAO:	Food and Agricultural Organization
FSCB:	Food Security Coordination Bureau
GWP:	Global Water Partnership
HMNDP:	High-Level Meeting on National Drought Policy
IDPM:	Integrated Drought Management Program
IDW:	Inverse Distance Weighted
LST:	Land Surface Temperature
MOA:	Ministry of Agriculture
MoE:	Ministry of Education
MoH:	Ministry of Health
MoWIE:	Ministry of Water, Irrigation and Electricity
NDVI:	Normalized Difference Vegetation Index
NDWI:	Normalized Difference Water Index
NMSA:	National Meteorological Services Agency
PSNP:	Productive Safety Net Program
RRC:	Relief and Rehabilitation Commission
SPI:	Standardized Precipitation Index
TCI:	Temperature Condition Index
VCI:	Vegetation Condition Index
WMO:	World Meteorological Organization

ABSTRACT

Drought arises from insufficiency of rain for an extended period of time that causes a considerable hydrologic imbalance and, consequently leads to surface and subsurface water loss which directly resulted in water supply shortages that occurs in many regions of Ethiopia like the case of this study, West Hararghe Zone. This study aims to identify drought severity, and mapping drought risk prone areas and investigate drought impacts on water supply availability in West Hararghe Zone, Eastern Ethiopia. The study uses Geographic Information System (GIS) based drought indicators include; normalized difference water index (NDWI), Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), Vegetation Condition Index (VCI), vegetation health index (VHI), and Standardized Precipitation Index (SPI) to analyze quantitative research parts and field observation and survey data analysis for qualitative research parts. The practical field observations, Questionnaires and discussions played great roles in enhancing the acquisitions of commendable information and experiences on the objective reality of the situation. The result maps shows that about 1,137.18 km^2 (8.05%), 4,171.48 km^2 (22.52%), 6,136.19 km^2 (35.13%) and 6,009.69 km^2 (37.98%) of all the total geographical area of the Zone were no drought, slight drought, moderate drought and severe drought risk average areas from results of all indices in 2021, respectively. Furthermore, severity of the drought increased from 2,803.13 km^2 (18.59%) in 2000 to 6,009.69 km^2 (37.98%) in 2021, which shows above 3,206.56 km2 average areas were additionally occupied by severe drought. This clearly reveals that there is a dramatic increase of drought coverage in west Hararghe Zone. This results is congruent with the results from survey analysis which indicates that above 60% average percentages of water supply as a whole and about 50% of water supply wells in the study areas were affected by drought in the past two decades. Drought severity generated maps of the study area indicates that: Hawi Gudina, Burka Dintu, Gumbi Bordode, Boke, Oda Bultum, Mi'eso, Ancar, Shenen Dugo and Guba Qorica were attacked by severe drought in 2021 among districts of the zone. Findings of this study could be used as a guide for concerned decision makers; government and non-government organizations for drought monitoring, preparedness, and its impacts mitigation activities.

Keywords: *West Hararghe; Droughts; Water Supply; GIS; Drought Indices.*

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the Study

Globally, drought as a natural phenomenon creates numerous multidimensional effects on water resource, agricultural activities, human health, and environmental crisis (Tsegay Wolde-Georgis, 2022). Drought is dryness due to shortage of water, which lasts for several months or years, and considerably endangers food and water security (Nguyen *et al.,* 2019). Drought events involve complex interactions between numerous climatological and hydrological processes, which gradually evolve with time (Kona Pala & Mishra, 2020).

As a complex natural event, drought stems from a lack of precipitation or meteorological drought over a prolonged period of time, and its effect can be only witnessed slowly over a period of time and propagated to hydrological drought which directly endanger water resources (Nguyen *et al.,* 2019). When drought impacts affect the water supply; the water levels in streams, reservoirs, and groundwater are reduced and this leads to inadequate water supply, threatening the health, safety, and welfare of communities (Mohammad *et al*., 2018). Water resources are the core medium of the environment through which we feel the direct impacts of climate change, whereby abnormal weather can lead to water scarcity (Zhang *et al.,* 2014). Extreme inter-annual variability of seasonal rainfall and prolonged dry seasons due to climate change pose water shortage challenges, which challenges local communities in terms of meeting their water demands.

Droughts exacerbate water scarcity and cause negative impacts to people's health and inter-related loss of productivity (Mohammad *et al*., 2018). Abnormally dry weather due to extreme drought can cause a serious imbalance in water cycles that changes the precipitation and evaporation processes, atmospheric water vapor circulation, and soil moisture availability (Mohammad, et., al 2018), resulting in low water volumes in streams, rivers, and reservoirs. At the same time, the current demand for water exceeds supply, exacerbating the problem even more.

Ethiopia is located in Africa's Horn where drought is the leading causes of water shortage and the country is predominantly rural with a large population depending on agriculture and pastoral activities, but there has been limited development of surface water and groundwater resources (Sida *et al.,* (2019). The country is one of the drought affected countries every eight–ten years. The country has been facing drought at a growing incidence throughout the past many decades (Edessa, 2010). The impact of drought in Ethiopia is not only leads to the shortage of water and food but also have an environmental, socio-economic and health impact on the population (Sheffield *et al*., 2009). In Ethiopia (Tsegay Wolde Giorgis, 2022) Showed that the characteristics of water resources during droughts vary significantly across different regions of the country due to differences in climate and watershed properties. Ethiopia is one of the largest humanitarian aid beneficiaries in the world and experiences significant climate change induced drought and water-related stresses on crop and livestock productivity (Sida *et al.,* (2019).

Water supply coverage of West Hararghe zone as Oromia Regional government announce on 10 October 2017, above 650 drinkable water projects had been completed in the Zone, which combined with other ongoing projects would bring drinkable water to 72,300 inhabitants and raise the percentage of access from 37% to 47% (Oromia Regional Government State website, accessed on 10 October 2017). Drought creates numerous effects on water resources in this zone (Sida *et al.,* (2019) and Levine *et al*., (2019). Given the projected worsening of drought impacts on water supply due to increasing climatic variability and human water demands as stated by (Yang *et al*., 2018), there is an urgent need for drought risk management strategies, in order to mitigate future drought risk (Cai *et al*., 2015 and Wilhite *et al*., 2000).

In order to address these research questions, the following six widely used and applicable drought indexes were used: Standardized Precipitation Index (SPI), normalized difference vegetation index (NDVI), Normalized Difference Water Index (NDWI), Vegetation Condition Index (VCI), Land Surface Temperature (LST) and Vegetation Health Index (VHI) (Gebrehiwot, *et al*., 2016). These GIS based indices have been widely used for assessing drought, as they are among the best in detecting the onset of drought and measuring the intensity, duration, and impact of drought globally (Cheng *et al.*, 2015).

In this context, evaluation of the impacts of droughts on water supply can assist water resources managers in identifying vulnerabilities in water resources and framing future management strategies. The researcher is motivated to assess the impacts of drought on water supply and to explore different drought indicators, which can be used for effective identification of drought severity and drought prone areas and to map its intensity in order to easily mitigate drought induced water supply deficits in the study area by the help of Geographical information system and meteorological data's and provide insights regarding how the knowledge of drought propagation mechanisms can be applied for more effective drought management.

1.2. Statement of the Problem

Much of the Ethiopian highlands and the east of the country were hit by a severe drought in 2015–16, associated with the El Niño event of 2015, and this drought received a huge relief response both from the Government of Ethiopia and the international community (Simon *et al*., 2019). Drought is inarguably one of the most challenging and complex natural disasters (Wilhite *et al*., 2005).

Among many regions of Ethiopia West Hararghe Zone was one of the major regions were seriously affected by drought crisis. Drought as an environmental phenomenon is an integral part of climatic variability that puts its direct impacts on water resources in this zone. It becomes more frequent, more intense, more spatially extensive, and of longer duration in west Hararghe (Niguyen *et al*., 2019).

Drought impacts on water supply availability are determined by water availability for different water user sectors and the environmental loss during a droughts (Bachmair *et al*., 2016). By considering the two increasing per year scenarios which are: the drought impacts on water resources due to changing climatic variability and the human water demands (Schewe *et al.*, 2014), there is a need to urgently carry out different findings on drought for long-term drought risk management strategies and its mitigation (Cai *et al*., 2015 and Wilhite *et al.*, 2000).

In this context, evaluation of the impacts of droughts on water supply availability can assist water resources managers in identifying drought vulnerabilities in existing water systems and framing future management strategies, solutions and methods to cope up drought risks (Yang *et al*., 2018).

Though a number of studies as stated in the literature have been conducted on the impacts of drought on physical environment in Ethiopia, an issue of the effects of drought on water supply is still uncertain which needs investigation in the study area. Different researches as stated in the literature assess drought by using one or two indices which cannot be enough to characterize the drought characteristics as a whole and its impacts on water resources. For instance, (Wondwosan, 2017) studied the agricultural drought risk area assessment in West Hararghe zone by using NDVI and SPI only without touching an issue of drought impacts on water supply. Although there were many effects of drought in west Hararghe zone different study was unable incorporate those effects, which were assessed in this research.

Therefore, this study intend to fill the existing research gap through field survey analysis and incorporating various drought indices like Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), Standardized Precipitation Index (SPI), Vegetation Health Index (VHI), Vegetation Condition Index (VCI), Temperature Condition Index (TCI) and Normalized Difference Water Index (NDWI).

1.3. Objective of the study

1.3.1. General objective

The main objective of this study is to assess the impacts of drought on water supply availability in the west Hararghe zone, Oromia regional state, Ethiopia.

1.3.2. Specific Objectives

In order to effectively achieve the intended general objective, attempts have been made to:

- ☞ Identify drought risk prone areas in West Hararghe Zone
- ☞ Examine the level of drought risks and prepare drought severity maps of the zone using GIS based indices of 20 years.
- ☞ Investigate effects of drought on water supply availability in the study area

1.4. Research Questions

1. Where are the places that are seriously in danger by drought in west Hararghe zone?
2. What is drought risk level exist in the study area?
3. What is the extent of drought impact on water supply in the study area?

1.5. Significance of the study

This is a firm conviction that assessing the drought risks by the use of different indices with the help of Geographic Information System (GIS) can effectively facilitate the detection, identification and mapping of drought risk prone areas. Reliable drought risk area mapping is expected to enhance decision making process for drought monitoring and mitigation actions. Thus it is hoped that drought risk map of the zone which was produced from this study, can be helpful for policy makers, to prioritize their action plans based on the identified risk level and highly vulnerable areas of the zone. Moreover, it is helpful for government, development agents, aid agents, and or non-governmental organizations to scale up their aids.

Apparently this research has an in-depth significance in providing an information of drought effects on water supply through field survey analysis for water resource managers to monitor and manage drought risks on water supply. Hopefully this study is the first in the study area and so it may serve as the reference for the similar findings and for the communities and environments as well.

1.6. Scope of the Study

This study was geographically carried out in West Hararghe Zone, Oromia Regional state, Ethiopia. The study conceptually emphasizes on generating information about drought and identifying drought risk areas and its impacts on water supply availability. The study has opted to concentrates on quantifying and analyzing impacts of droughts on water supply through field survey analysis and to develop drought severity maps of west Hararghe Zone by using GIS based drought indicators, as well as describing sources of water supply affected by drought from drought index analysis of 20 years between Jan. 2000 to Dec. 2021.

1.7. Limitation of the Study

Lacks of organized meteorological data, and lack of well recorded ground water table and surface water data as well as drought affected population data of the study area were the major limitations of the study.

1.8. Organization of the Thesis

The thesis was organized in to five chapters. The first chapter is about introduction of the paper dealing with background, objectives, statement of the problem, research questions, scope, and limitation of the study as well as organization of the paper. Chapter two is devoted to literature review. The third chapter introduces the study area and describes methodology of the study. It deals about description of study area, data sources, software used, image preprocessing and classification. Chapter four is all about results and discussions. The last chapter focuses on conclusion and recommendation based on the findings of the study.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Concepts and Definitions

Drought is described by many as insidious natural hazard that has a slow on-set and develops over months or even years (Apurv, *et al*., 2017) to reach with a full blown impact. In its final stage of occurrence, it often covers a large geographic area or region.

Drought occurs when the seasonal precipitation drops below normal or long term average. Drought in Ethiopia occurs during the different seasons that occur in different regions in the country and it exists when seasonal rainfall drops below normal by almost 30% to 50%. Some argue that it is difficult to give a universal definition for drought, because drought is a complex phenomenon (Van loon, *et al*, 2014). However several authors have given their version of the definition of drought or discussed its definitions in their articles (Van loon, *et al*., 2014). The simplest definition of drought from hydrological point of view is given as "a deficit of water compared with normal conditions" (Sheffield J, *et al*., 2009).

Climate variability and extreme weather events (drought) threatens the livelihood of many populations throughout the world. Available reports suggest that the recurrence period of such extreme climatic events (drought) is shortening (Apurv, *et al*., 2017). Drought in Ethiopia has shown a spatial and temporal distribution over the last fifty years and there are certain regions in the country that are affected by drought more frequently; the eastern and south eastern and rift valley regions. The recurrence frequency was one in ten years during earlier periods.

Recently it was observed that drought frequency shortens and devastating drought occurred in three successive years. It is believed that global warming has played a pivotal role in shortening the recurrence frequency of the droughts in Ethiopia, and it is believed to have increased the severity of the impact as well (Sheffield J, *et al*., 2009). The fourth assessment report of the intergovernmental panel on climate change has reinforced this assessment and it indicated that the tropics of Africa and Asia are expected to experience a significant change in the frequency and this has come as serious concern for many developing countries in these two regions; Africa and Asia.

According to National Meteorological Services of Ethiopia, the average minimum and maximum temperatures have been increasing by about 0.25°C and 0.1°C, respectively over the past decade whereas the rainfall has been characterized by a very high level of variability over the past 50 years. This consequently leads to drought. Decision makers need timely and accurate climate information and about the on-set and development of drought conditions (Wilhite, 2005). In the Ethiopian case, rainfall and socio economic indicators were important variables for monitoring the onset and progress of drought in Ethiopia. However, securing sufficient and reliable climatic and socio economic data in time remains a challenge as the rainfall observation stations in many parts of the drought prone areas in the country are still insufficiently covered with meteorological stations and the existing ones are thinly distributed and have a history of poor data collection.

Developing a full-blown early warning system requires resources; finance, skilled manpower and technological capacities and commitment. In developed countries, satellite tracking system and a web-based interface on climate data is being used for data collection, transmission, directly inputting and analysis. Development partners in Ethiopia presented their intent to support the development of drought early warning system at Woreda/district level using IT based platform – at least invitation for a consultancy service was put out in public. The result of this study is unknown. In addition there has been an ongoing and relentless effort on monitoring and predicting the El Niño by many international organizations, and Ethiopia has had full access to this information through.

2.2. Drought Risk in Ethiopia

In Ethiopia, drought monitoring mechanisms were based on meteorological information obtained from ground stations such as rainfall, weather conditions, crop performance and water availability. In other words, until recent times, ground stations used to be the major sources of national information for agricultural drought risk assessment. However, this reliance on ground data could not lead to successful results, as a poor density of weather stations, for instance, could make it difficult to acquire sufficient spatial and temporal climate data (Birtukan, 2014).

Besides, the conventional approach does not cover man's influences on the wellbeing of the eco-system, such as land use changes, irrigated area developed and the area affected due to water logging and salinity. The Remote-Sensing based method for identification of drought prone areas on the other hand, uses historical vegetation index data derived from satellite series and provides spatial information on drought prone area (Van loon, *et al*, 2014).

2.3. Types of Drought

Drought is the deficit that results when soil moisture is insufficient to meet the demands of potential evapotranspiration (Wondwosan, 2017). Normally, drought occurrence, as a climate change phenomena, becomes obvious when there are abnormal dry weather conditions, events of lower rainfalls and insufficient soil moisture in an area. In some cases, it results in decreased water levels of rivers, ponds and lakes with long lasting impacts on agricultural production, livestock and overall economic activities (Asfaw *et al*., 2018). Other climatic factors, like high temperature, high wind and relatively lower humidity may also indicate the appearance of drought. In some countries, like Ethiopia, drought occurrence is closely associated with the timing of the rainfall (Cai *et al*., 2015).

The dissatisfaction with the conventional drought definition, persistently, continued as more people began to come up with new ideas for not only categorizing, but also for localizing drought meaning (Bachmair *et al*., 2016). One of the new arguments, for instance, holds that, since the actual impacts of drought, characteristically, vary from region to region, its definition should also be regionalized, accordingly. Evidently, therefore, the need to characteristically delineate and categorize drought broadly as; meteorological drought, Agricultural drought, hydrological drought and socio-economic drought (Apurv *et al*., 2017).

2.3.1. Meteorological Drought

Precipitation has been commonly used for meteorological drought analysis. As a matter of fact, several studies have dwelled on analyzing droughts using monthly precipitation data. These approaches focused on analyzing drought duration and intensity in relation to precipitation shortages. Daily rainfall information, temperature, humidity, wind velocity and pressure, and evaporation are the major data sets required to assess meteorological drought in general (Edossa *et al*., 2010).

Definitions of meteorological drought are region specific, since the atmospheric conditions that result in deficiencies of precipitation are highly region specific. Many authors explain meteorological drought by comparing the degree of specific area dryness with that of normal or average amount, and the duration of the dry period. (Mersha, 2018) for instance, described drought as a recurring extreme climate event over a given land, characterized by below-normal precipitation over a period of months to years. According to (Lui *et al*., 2018) it is believed that the duration of meteorological drought can vary due to anomalies, as in large term blocking patterns or a flux in the global wind patterns. The duration of meteorological drought as a period of months to years with below-normal precipitation, usually accompanied by above-normal temperature in contrast to the permanent aridity (Gebrehiwot, *et al*., 2016).

2.3.2. Agricultural Drought

As stated earlier, the world has been experiencing disastrous effects of drought for a long period of time. In particular, agricultural drought, manifested in the form of erratic spatio-temporal distribution of rainfall and insufficient amount of moisture has been claiming life in different parts of the world (Wondwosan, 2017). In most scanty rainfall dependent agricultural areas like that of Ethiopia, for instance, the scarcity of precipitation and diminished amount of soil moisture have negatively affected crop production and the normal public food supply. In the real sense of the word, agricultural drought has become the biggest threat to life in most developing countries of the world. Apparently, therefore, today, greater attention is given to the study of agricultural droughts, more than ever before (Wondwosan, 2017).

On the other hand, it appears that some researchers found it difficult to associate particular drought characteristics to agricultural problems. In other words, despite the recent efforts made to delineate drought definition based on the principles of the four different disciplinary area categories, some of the basic characteristics of drought still appear to be so intrinsically interwoven with each other that it is difficult to single out and assign them to a particular area discipline.

Evidently, therefore, agricultural drought impacts have to be realized as the combination effects of different drought elements on vegetation and crops. Therefore, many of the area researchers, had to define agricultural drought, more or less, by linking various characteristics of meteorological and hydrological drought impacts on agricultural situations by focusing on precipitation shortage, differences between actual potential evapotranspiration, soil type, soil water deficit, and reduced ground water or reservoir levels resulting in reduced crop yield.

Wondwosan, 2017 defines agricultural droughts in west Hararghe zone as the decline in the productivity of crops due to irregularities in the rainfall as well as decrease in the amount of soil moisture. According to the information available so far, therefore, data sets required to assess agricultural drought are soil texture, fertility and soil moisture, crop type and area, crop water requirements, pest infestation and the general climate conditions.

2.3.3. Hydrological Drought

Hydrological drought refers to a persistently low discharge and/or volume of water in streams and reservoirs, lasting months or years. It is the slowest type of drought to form, but lasts the longest. Hydrological drought is, normally, a natural phenomenon, but it may be exacerbated by aggressive human activities. Hydrological droughts are usually related to meteorological droughts, but their recurrence interval may vary accordingly. Changes in land use and the consequential land degradation can affect the magnitude and frequency of hydrological droughts (Mohammad, *et al*., 2018).

Stream flow data have been widely applied for hydrological drought analysis. In general, however, data sets required to assess hydrological drought are surface-water area and volume, surface runoff, stream flow measurements, infiltration, water-table fluctuations, and aquifer parameters (Mohammad, *et al*., 2018).

2.3.4. Socio- economic Drought

Socio-economic definitions of drought are closely associated with the demand and supply of some economic goods, with elements of meteorological, hydrological, and agricultural droughts. It differs from the other types of droughts in the sense that its occurrence depends on the processes of supply and demand. The supply of many economic goods such as water, forage, food grains, fish, and hydroelectric power, depends on the weather. Due to the natural variability of climate, water supply is ample in some years, but insufficient to meet human and environmental needs in other years. Socio-economic drought produces a complex web of impacts that spans many sectors of the economy.

According to Kuri *et al*., (2014) economic drought is a severe dilemma which influences different aspects of mankind's life. It can cause many economic and environmental problems, especially, in the agriculture sector. Data sets required to assess socioeconomic drought are human and animal population and growth rate, water and fodder requirements, severity of crop failure, and industry type and water requirements (Mohammad *et al*., 2018).

2.4. Impacts of Drought

Drought's consequences are far-reaching, impacting water quality, public health, the economy, the natural environment, public infrastructure, and more.

Based on past experiences, drought affected nearly all sectors in Ethiopia; agriculture (loss of crops and livestock), water resources (increase in evaporation and decline in availability of fresh water which results in water stress), inadequate water for industry, reduced electricity production [from hydropower], etc. Although it has not been assessed and documented properly, the impact on ecosystems is significant (loss of wet lands and lakes, loss of forest and soil cover, increased soil erosion and land degradation).

The social and economic impacts (increased human and livestock diseases, migration, and conflict over water, and the decline in the National Gross Domestic Product (GDP)) are hugely important. Perhaps nowhere else is the change in weather (drought) and climate regimes more noticeable than in water sector (Byrne, *et al*., 2018), which in turn affects all other sectors significantly, and this is as a result of the meteorological drought (Van Loon *et al*., 2014).

2.4.1. Environmental impacts of drought

The droughts in the 1970s were longer and more intense, and occurred most of the time in both short and long rainfall seasons. The 1974 drought resulted in the death of approximately

250,000 people in Ethiopia (Cai, *et al*., 2015). Since then, the adverse climatic variability and extreme climatic events increased in the magnitude of the social, economic and environmental impacts. Drought as an environmental phenomenon is an integral part of climatic variability. The impact of drought not only leads to the shortage of water and food but also have a long-term environmental, socio economic and health impact on the population (Sheffield *et al.*, 2009).

2.4.2. Impacts on Ecosystems

Globally, biodiversity is being lost and increasingly threatened through a range of anthropogenic actions. The Convention of Biological Diversity (CBD) defines "biodiversity loss" as "the long-term or permanent qualitative or quantitative reduction in components of biodiversity and their potential to provide goods and services, to be measured at global, regional and national levels" (Bachmair, *et al*., 2016). Fossil records showed that it took on average one million years before an individual vertebrate species became extinct. Hence, no more than one out of one million species should go extinct.

The most important notable drivers behind the current loss of biodiversity are habitat modification, overexploitation, climate change, invasive alien species, and chains of extinction, known collectively as the evil five biodiversity threats (Bachmair, *et al*., 2016). As mentioned in the IPCC (2010) report, global warming and precipitation is expected to increase, the changing climate is predicted to be one of the worst drivers for the loss of all level of biodiversity over the next 50–100 years, and further exaggerated the effects of earlier threats on biodiversity loss.

However, only few studies have directly quantified climate-induced biodiversity extinctions. Even if it is difficult to disentangle the impacts of climate change from other anthropogenic stressors for a range of species, consequently, predictions may provide insights into the multiple components of climate change and their relative distribution threats to global biodiversity (Birtukan Atinkut, 2014). Predictions of climate induced extinction rates are uncertain and expert opinions differ on the extent of loss due to the great deal of uncertainty regarding the number of species that exist on earth (Schewe, *et al*., 2014).

2.4.3. Impact on water resources

Over the last two decades, Ethiopia has been building massive infrastructure to harvest water for generating electricity and developing irrigation to produce food and fiber crops for domestic consumption and support local industries. Presently several dams are built and as a result the country has increased its water security. Industrialization which requires electric power is also growing to diversify the country's economy. The recent droughts are impacting the country more seriously; far beyond creating shortage of food (Schewe, *et al*. 2014).

The water resources in both manmade and natural water bodies are shrinking severely affecting the availability of water for irrigation and electricity production and in return affects the economy. The drop in lake levels, low flows in rivers/streams and drop in ground water levels are often recognized as hydrological drought (Van and Anne, 2015) is becoming a common phenomenon. It is also characterized by changes in wet lands, decreased biomass or vegetative cover and over all damage to the land (land degradation) in all ecologies due to excessive dryness. In pastoralist areas this situation results in damage and loss of rangelands. Soil loss by wind erosion in pastoralist areas is a common feature during such droughts.

Water resources are the core medium of the environment through which we feel the direct impacts of climate change (Warner, *et al*., 2007), whereby abnormal weather can lead to water scarcity. Extreme inter annual variability of seasonal rainfall and prolonged dry seasons due to climate change pose water shortage challenges to local communities in terms of meeting their water demands. Droughts exacerbate water scarcity and cause negative impacts to people's health and productivity (FAO, 2011). Abnormally dry weather due to extreme drought can cause a serious imbalance in water cycles that changes the precipitation and evaporation processes, atmospheric water vapor circulation, and soil moisture availability (Zhang, *et al*., 2014), resulting in low water volumes in streams, rivers, and reservoirs.

At the same time, the current demand for water exceeds supply, exacerbating the problem even more. This is due to overpopulation and over extraction from human activities. There is also a direct impact on the groundwater recharge process, due to climate change causing abnormal rainfall patterns and an increase in temperature, affecting the amount of water in the ground (Mohammad, *et al*,. 2018).

2.5. Drought Indicators

There are over 150 drought indicators reported in the literature (Wilhite, *et al*., 2020). Careful selection of drought indicators is, therefore, an important decision in this study.

Droughts are multidimensional in nature, manifest at different temporal scales, and cannot be fully characterized using a single indicator (Liu, *et al*., 2018). Droughts are affected not only by rainfall but also other processes such as plant water uptake (plant behavior), humidity and temperature. Rainfall deficits tend to create warmer temperatures due to lowered humidity. Droughts also affect many other hydrologic processes such as exfiltration and base flow to streams. Analysis of droughts using multiple indicators calculated at different time spans is, therefore, necessary to build a better understanding of droughts (Uddameri *et al*., 2019).

2.5.1. Standardized Precipitation Index (SPI)

The SPI indicator, measures precipitation anomalies at a given location, based on a comparison of observed total precipitation amounts for an accumulation period of interest (e.g. 1, 3, 12, 48 months), with the long-term historic rainfall record for that period (Lui *et al*., 2018).

SPI-1 to SPI-3: When SPI is computed for shorter accumulation periods (e.g., 1 to 3 months), it can be used as an indicator for immediate impacts such as reduced soil moisture, snowpack, and flow in smaller creeks. SPI-3 to SPI-12 When SPI is computed for medium accumulation periods (e.g., 3 to 12 months), it can be used as an indicator for reduced stream flow and reservoir storage. SPI-12 to SPI-48: When SPI is computed for longer accumulation periods (e.g., 12 to 48 months), it can be used as an indicator for reduced reservoir and groundwater recharge. It should be borne in mind that the exact relationship between the accumulation period and the drought impact, depends on the natural environment (e.g., geology, soils) and the human interference (e.g., existence of irrigation schemes). In order to get a full picture of the potential impacts of a drought, the SPI should be calculated and compared for different accumulation periods.

2.5.2. Normalized difference Water index (NDWI)

The normalized difference water index (NDWI) suggested by Gao (1996) demonstrated its potential applicability for canopy-level water content estimation based on the liquid water absorption band centered at 1240 nm enhanced by canopy scattering.

Data extracted from a satellite image using the NDWI index is visualized as maps using a color palette and graphs to show how values change over time as a curve. On a map, the higher values approaching +1 usually appear blue and correspond to either a high water content or a water surface, while the lower values all the way to -1 are the tell-tale signs of drought conditions, unless the area of interest is a non-aqueous surface (Gao,1996).

2.5.3. Vegetation Based Drought Indices

NDVI shows seasonal vegetation dynamics, VCI rescales vegetation dynamics in between 0 and 100 to reflect relative changes in the vegetation condition from extremely bad to optimal. VCI and TCI characterizes respectively the moisture condition and thermal condition of vegetation while VHI represents overall vegetation health (Kogan, 2002).

Since favourable weather provides optimal moisture condition, high values of VCI correspond to healthy and unstressed vegetation. On the other hand, low TCI values correspond to vegetation stress due to dryness by high temperature. TCI provides opportunity to identify subtle changes in vegetation health due to thermal effect as drought proliferates if moisture shortage is accompanied by high temperature (Kogan, 2002). Regional VHI maps have been generated through interpolation of the point values and classified using the scheme developed by Kogan (2002) and further modified.

VCI and TCI have been classified following the same scheme as VHI. (Kogan, 2002) formulated, calculated, and applied VCI, TCI, and VHI based on smoothed weekly NDVI and BT values. However, in the present study all these parameters have been calculated and analyzed season wise by averaging weekly values. For comparison and correlation among different kinds of drought, SPI, SWI, and VHI maps of the same years have been displayed one beneath the other.

CHAPTER THREE

3. Materials and Methods

3.1. Description of the Study Area

3.1.1. Location

West Hararghe is one of the zone of Oromia regional state and its absolute location stretches between 7^{0}48'0" to 9^{0}36'0" North latitude and 40^{0}0'0" to 41^{0}20'0" East longitude (Figure 1).

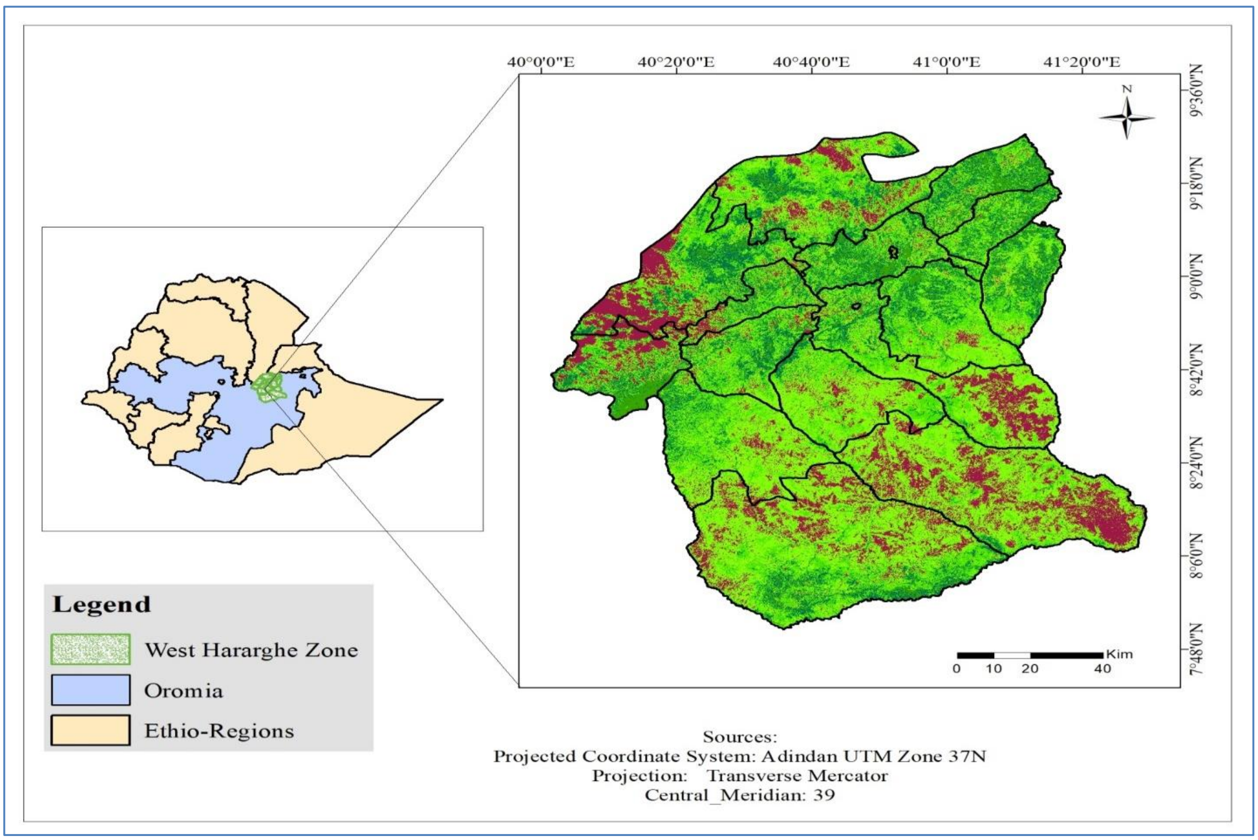

Figure 1: Location map of the study area

3.1.2. Climate

This papers study area; West hararghe zone, is one of the zone in Ethiopia's Oromia region, which combines extremes of terrain, climate and livelihoods, ranging from high-altitude to semi-arid, middle-highland, rain-fed agriculture and arid, lowland agro-pastoralism (Sida *et al.,* (2019) and Levine *et al*., (2019).

The climate of the zone comes under a sub-tropical agro-climatic zone. There are four climatic seasons, *Gena/Kremt*, (from June to August rainy period) *Bona/Bega*, (from December to February dry period) *Belg* (from March to May small rains) and *Meher* (from September to November a spell between the long and small rains) The area is characterized by a bimodal rain fall pattern with annual rainfall range of 650 -1300 mm with the maximum rainfall received in the months of June (https://www.mindat.org/loc-406576.html). The complex topography features of landscape comprising flat to gentle slope, gorges, hilly and mountainous areas is one of driving factor for climatic conditions of the study area.

3.1.3. Population

Based on the 2007 Census conducted by the CSA, this Zone has a total population of 1,871,706, an increase of 47.16% over the 1994 census, of whom 958,861 are men and 912,845 women; with an area of 15,065.86 square kilometers, West Hararghe has a population density of 124.23. While 160,895 or 9.36% are urban inhabitants, a further 10,567 or 0.56% are pastoralists. A total of 395,127 households were counted in this Zone, which results in an average of 4.74 persons to a household, and 380,019 housing units. Projected populations of the Zone by 2022 were 2,743,412 based on 2007 CSA report and growth rate 3.02% per year. (CSA, 2007).

3.2. Research Methodology

3.2.1. Design of the Study

To conduct this study, explanatory research design with the application of both qualitative and quantitative approaches were employed. Thus, the study used mixed research method. The reason for using this method is to compare the results from two different perspectives as relying on quantitative methods alone can hide important facts obtained from qualitative methods. The goal for researchers using the mixed methods approach to research is to gather useful information and minimize the weaknesses of the quantitative and qualitative research approaches.

Mixed approach to research, is used to collect and analyze not only numerical data, which is customary for quantitative research, but also narrative data, which is the norm for qualitative research in order to address the research questions defined for a particular research study.

3.2.2. Data Types and Sources

In order to address the stated objectives of the research both primary and secondary data sources were used during the course of the research works accordingly.

I. Primary data

Primary data sources during the research period include field observations and survey works. These were carried out in order to identify the impacts of drought on water supply. Field inspection was carried out from March to April 2022 to gather all necessary data such as: drought coping mechanisms, water supply wells dried because of drought, main sources of water supply, level of water supply affected, losses due to drought and drought severity qualitative data of the study area.

II. Secondary data

Secondary data sources include satellite images and (SRTM DEM 30m.), and hydro-climatic data (precipitation data) from meteorological station were included. Reviewing of different relevant published and unpublished literatures of the specific study area and related studies of different areas were also undertaken almost throughout the course of the research period. Annual precipitation data from Jan. 2000 to Dec. 2021 were taken from Meteorological station (Table 1) (Appendix I).

Table 1**:** Data Types, Sources, Description and purpose

	Data category	**Source**	**Description**	**Purpose**
1	Landsat7 ETM+ 2000 & Lansat8 OLI/TIRS 2021	USGS	ETM+30m & Landsat 8 OLI/TIRS 30m resolution Path/Raw167 & 054	For retrieval of LST, VHI, NDWI, VHI and NDVI and, analysis,
2	Precipitation	NMA of Ethiopia	Monthly precipitation	Used to improve water

data	from Jan. 2000 to Dec. 2021	management strategies Assess meteorological drought, analyze SPI

Source; NMA Monthly precipitation from Jan. 2000 to Dec. 2021, Moisa *et al*., 2022

3.2.3. Sampling techniques and Sample Size

This study employed both probability and non-probability sampling techniques. Simple random sampling was used for probability techniques, in which districts were randomly selected from the total of 14 districts of the zone based on, their drought severity, whereas purposive sampling method were used for non-probability sampling to select representative sample size for the study. A sample districts were: Hawi Gudina, Gumbi Bordode and Boke, as well as sample respondents were: 10 informants from water sectors of each districts.

The characteristic of participants in this survey has been selected thoroughly throughout specific criteria to fit the survey requirements. The first criterion is that the participants must have knowledge contribution to the topics and the second criteria are that the participant must have a relatively high level of skill, knowledge, or experience, about the current water supply drought. Therefore, it's logical and sufficient to collect information to be more credible from the respondents of the water sector that have direct contact with water, and skillful man power who have fully understood the importance of assessment of the drought impact on water supply availability in the study area.

Field survey for this study was conducted in March 2022 after the drought hot spots were identified and drought severity maps were developed from carefully selected drought indices by the help of Arc GIS 10.1, necessarily to investigate the impacts of drought on water supply availability. In this case based on two main sources of information; which were from statistical analysis and conducting field survey to evaluate water supply status during drought in West Hararghe Zone.

This has given very rich information in real time about the development of the drought and its impacts. That understanding has been combined with results from a quantitative analysis, focused specifically on the three research questions. The intention was to conduct comparative research, in Woredas that had received drought problem (which had been considered from Jan. 2000 to Dec. 2021). It was intended to use the qualitative research to substantiate the findings, through observing what is really on the ground and, especially by using the theory based approach, to investigate the mechanisms by which water supply had brought serious scarcity from drought. A selection of respondent in terms of answering questionnaires was limited to water sectors.

3.3. Quantitative Data Analysis Methods

3.3.1. Selection of standardized drought indices

The selection of the drought indicator used in this study was based on; Objectives of the study; the availability of reliable data to compute the indicators, those based on sound technical principles, those based on standardized approaches that allow comparisons in space and time, and its wide spread acceptance.

Depending up on the above criteria six drought indicators, namely: Standardized Precipitation Index (SPI), Normalized Difference Water Index (NDWI), Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), Vegetation Condition Index (VCI) and vegetation health index (VHI) were selected for this study, in order to identify drought and to develop drought severity maps of the study area. The entire indices used in this study and its purposes were summarized in Table 2.

Table 2: Salient characteristics of drought indicators selected for this study

No	Index category	Data Types	Purpose
1	Standardized precipitation index (SPI)	Accumulated Rainfall from Jan. 2000 to Dec. 2021)	Used to characterize meteorological drought on a range of timescales.
2	Normalized difference water index (NDWI)	Using near-infrared (NIR) and short-wave infrared (SWIR) wavelengths	To identify changes in water contents of leaves and water content in water bodies. Estimation of water content based on

		Use multispectral bands data from Landsat	the liquid water absorption band enhanced by canopy scattering To characterize the drought
3	Normalized difference vegetation index (NDVI)	Near-infrared (NIR) and red band wavelengths	To show seasonal vegetation dynamics because of water shortage or water stress. To show the prevalence of drought
4	Land surface temperature (LST)	Spectral radiance, vegetation proportion and surface emissivity	For assessing thermal conditions of vegetation as drought proliferate and to identify how severe a drought is
5	Vegetation health index (VHI)	Derived from VCI and TCI Uses thermal bands data from Landsat	To assess drought prevalence and to characterize overall vegetation health that needs for drought severity identification
6	Vegetation condition index (VCI)	Used in conjunction with NDVI and TCI	To characterize vegetation moisture condition to detect drought. For assessment of vegetation in drought situations. To identify the behavior or episodes and location of drought.

Source; NMA Monthly precipitation from Jan. 2000 to Dec. 2021; Gao in 1996; Guttmann, 1999; Moisa *et al*., 2022

3.3.2. Identification of drought depending on vegetation status

In this research, Extraction of Spatial Pattern of droughts were analyzed from 2000 to 2021 with ten years interval using Landsat images that obtained during dry season. Multispectral and thermal data from Landsat were used to construct Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) respectively for drought identification. Vegetation condition index (VCI) and Vegetation health index (VHI) are vegetation based indices used for drought identification in the study area.

A. Normalized Difference Vegetation Index (NDVI)

The spatial distribution of drought in west Hararghe was extracted and analyzed depending on the basis of the value of NDVI. The dependent variable (normalized difference vegetation index (NDVI) in light of related independent variables (vegetation, precipitation, soil moisture) is used to extract spatial patterns of drought hot spots.

The values of NDVI generally range between -1 to +1. The -1 value depicts the absence of vegetation and +1 value shows the presence of vegetation**.** Moreover, NDVI values are suitable for the calculation of change detection analysis. Very low value of NDVI (0.1 and below) correspond to barren areas of rock, sand, or snow (Apurv *et al.,* 2017).

The values of NDVI can further categorized as non-vegetated for the value <0, unhealthy vegetation for the value between 0.02–0.03 and moderate values represent shrub and grassland (0.2 to 0.3), while high value corresponds to dense vegetation (0.6 to 0.8). These activities will be computed and analyzed in ArcGIS Software environment.

The Normalized Difference Vegetation Index (NDVI) is one of the most commonly used indices in drought assessment and monitoring Guan L. (2009). To improve the accuracy of this index, especially in drought monitoring, a combined vegetation index is recommended. In this study NDVI was calculated from multi-spectral bands of Landsat images over all the study period. Band 4 for Landsat 5 and 7 and band 5 for Landsat 8 were used to measure near-infrared bands. As well as band 3 for Landsat 5 and 7 and band 4 for Landsat 8 were used to measure red bands of the Landsat data. The formula for this index is presented in (Eq. 1)

$$\mathbf{NDVI} = \frac{\boldsymbol{NIR-R}}{\boldsymbol{NIR+R}} \qquad \text{Eq.1}$$

Where:

- NIR - the pixel digital number (DN) of TM Band 4 and Band 5 (for Landsat7 and 8 respectively)
- R – DN of TM Band 3 and Band 4 (for Landsat7 and 8 respectively) (Gandhi, 2015).

The NDVI values range between -1.0 and 1.0. The NDVI values for healthy and dense vegetation always range between 0.2 and 0.9, whereas rock, water and barren lands have values less than 0.1 (Table 3).

Table 3: NDVI Values and drought ranges

NDVI Value	Drought Classes
>0.4	No drought
<0.4	Slight drought
<0.3	Moderate drought
<0.2	Severe drought

Source; Moisa *et al*., 2022

B. Vegetation Condition Index (VCI)

VCI provides information on the spatial characteristics, duration and intensity of droughts. Vegetation Condition Index was first developed and suggested by Guttman (1999). It shows the closeness of the NDVI of the current month to the minimum NDVI derived from long-term records. Other scholars ascertain that VCI is in good agreement with precipitation patterns as it perfectly indicates the status of the vegetation cover for a given ecosystem over many years whether it is affected by drought or not.

The VCI has been extensively used to monitor vegetation conditions (Winkler *et al*., 2017). It normalizes NDVI on a pixel-by-pixel basis, scaling between the minimum and maximum values of NDVI were (Eq. 2).

$$\mathrm{VCI} = \frac{\mathrm{NDVI-NDVImin}}{\mathrm{NDVImax-NDVImin}} * 100 \ldots\ldots \text{Eq. 2}$$

Where NDVI, NDVImin, and NDVImax are the mean seasonal NDVI, and its absolute long-term minimum and maximum NDVI values, respectively, for each pixel. VCI varies in the range of 0 to 100 percent, reflecting relative changes in the vegetation condition from extremely low to high VCI (Winkle *et al.*, 2017). As recently applied by, a threshold value of below 35% is used to indicate drought conditions as shown in Table 4.

Table 4: Drought categories derived from the Vegetation Condition Index (VCI)

VCI Percentage	**Drought severity level**
>35	No drought
20–35	Moderate drought
10–20	Severe drought
<10	Extreme drought

Source; Moisa *et al.*, 2022

C. Vegetation health index (VHI)

Guan L. (2009) reported that due to a lack of more accurate information on the influence of VCI and TCI on the VHI, the coefficient of the VHI equation was fixed at 0.5. Finally, the VHI was calculated to assess both vegetation stress and vegetation temperature to evaluate drought severity. The VHI was calculated by the following equation (Eq. 3).

$$\mathbf{VHI = aVCI + (1 - a)\ TCI} \quad \text{Eq.3}$$

Where. VHI = Vegetation health index, a = 0.5 (contribution of VCI and TCI), VCI is vegetation condition index, TCI is temperature condition index. VHI based drought severity was classified into five classes, according to the previous work of (Moisa *et al.*, 2022). For this study, the following VHI classification scheme for drought prevalence was proposed table 5.

Table 5: Drought categories derived from the Vegetation Health Index (VHI)

Drought class	**VHI in (%)**
Extreme drought	<10
Severe drought	10–20
Moderate drought	20–30
Mild drought	30–40
No drought	>40

Source; Moisa *et al.*, 2022

3.3.3. Land Surface Temperature (LST)

The LST was calculated from thermal bands of Landsat ETM + of 2000 and Landsat OLI/TIRS of 2021. Thus, LST was retrieved from Landsat 5 and 7 with thermal band of band 6 and Landsat 8 (OLI/TIRS) with thermal bands of band 10 was used (Cheng *et al*., 2015). Digital number (DN) was converted to spectral radiance of thermal bands of Landsat TIRS (Cheng *et al*., 2015). Consequently, LST was estimated by using the brightness temperature of the two bands of thermal infrared, mean and difference in land surface emissivity for assessing thermal conditions of vegetation as drought proliferate and to identify how severe a drought is (Cheng *et al*., 2015).

A. Conversion of digital numbers to top of atmosphere (TOA) spectral radiance

Thermal data in the Landsat sensor and deliver a manner of signifying pixels are stored in the digital number that have not yet been calibrated and converted into radiance units (Cheng *et al*., 2015) by using (Eq. 3).

$$\mathbf{L\lambda = (ML * QCal) + AL} \quad \text{…………………………………………………….Eq. 3}$$

Where, Lλ=Top of atmosphere (TOA) spectral radiance (Wm^{-2} sr^{-1} μm^{-1}). ML=Band-specific multiplicative rescaling factor from the metadata (RADIANCEMULTBAND x, where x is the band number).AL is Band-specific additive rescaling factor from the metadata (Radiance Add Bandx, where x is the band number). Q_{Cal} is quantized and calibrated standard product pixel values (DN).

Conversion of Radiance to Brightness Temperature after the DNs are converted to radiance, the thermal band's spectral radiance should be converted to brightness temperature (BT) as indicated in (Eq. 4).

$$BT = \frac{K2}{\ln(\frac{K1}{L\lambda}+1)} \quad \text{……………………………………………………………Eq. 4}$$

BT=is effective at-sensor brightness temperature (K); K2is Calibration constant 2.

K1is Calibration constant 1. Lλ: is spectral radiance at the sensor's aperture (W/ (m2*sr* μm)); and. Ln: is natural logarithm.

B. Land surface Emissivity Estimation

The NDVI was used to categorize the distributions of vegetation covers and their greenness as well. Consequently, it also explores the transformation of NDVI into values associated with cover portion using empirical relationships with vegetation indices, as a possible basis function (Cheng *et al.*, 2015). The calculation of the NDVI is important to identify the proportion of the vegetation (PV) (Singh *et al.*, 2014). In addition, emissivity (ε), which is related to the PV, should also be calculated (Eq. 5).

Landsat 5 and 7 use band 4 (Infrared) and band 3 (Red), and Landsat 8 data use Bands 5 (Infrared) and 4 (red) to calculate the NDVI values. From the NDVI values acquired, the next step in obtaining land surface emissivity (LSE), namely the calculation of the proportion of vegetation (Pv), was achieved.

C. Calculating the Vegetation Proportion (Pv)

The proportion of vegetation (Pv) is calculated according to equation (Eq. 6)

$$Pv = [\frac{NDVI - NDVImin}{\mathrm{NDVImax} - \mathrm{NDVImin}}]^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. 6}$$

D. Land Surface Emissivity (LSE)

Assessment Land surface emissivity (ε) is significant to estimate LST. According to land emissivity is calculated using (Eq. 7)

$$\boldsymbol{\varepsilon = 0.004 * PV + 0.986} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. 7}$$

The calculated radiant surface temperatures were corrected for emissivity using (Eq. 8).

$$LST = \frac{TB}{\mathbf{1}+\left(\boldsymbol{\lambda}\frac{TB}{p}\right)ln\boldsymbol{\varepsilon}} - 273.15 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. 8}$$

Where; LST is land surface temperature (in Kelvin); TBis radiant surface temperature (in Kelvin). λ is the wavelength of emitted radiance (11.5 μm). ρ = is h × c/σ (1.438×10^{-2}mK); h is Planck's constant (6.26×10^{-34} Js); c is the velocity of light (2.998 × 108 m/s); σ is Stefan Boltzmann's constant (1.38×10^{-23} J K^{-1}); and ε is land surface emissivity. The TCI was calculated using the following equation (Eq. 9).

$$TCI = (\frac{LSTmax - LSTa}{LSTmax + LSTmin}) * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. 9}$$

Where; LSTa is the LST value of current month, and LSTmin and LSTmax denote the minimum and maximum LST values, respectively, calculated from multiyear time series data. Consequently, reported that due to a lack of more accurate information on the influence of VCI and TCI on the VHI, the coefficient of the VHI equation was fixed at 0.5. Finally, the VHI was calculated to assess both vegetation stress and temperature to evaluate drought severity (Moisa *et al*., 2022). The VHI was calculated by the following equation (Eq. 10).

$$\mathbf{VHI} = \boldsymbol{a}\mathbf{VCI} + (\mathbf{1} - \boldsymbol{a})\ \mathbf{TCI} \quad \text{Eq. 10}$$

Where, VHI = Vegetation health index, a = 0.5 (contribution of VCI and TCI), VCI is vegetation condition index, TCI is temperature condition index. Drought based on VHI was classified into five, according to the previous work of (Moisa *et al*., 2022).

3.3.4. Standardized precipitation index (SPI)

The standardized precipitation index (SPI) (McKee *et al*., 1993), is the most commonly used drought identification index and to assess precipitation deficits over user-defined rainfall accumulation periods (Hayes *et al*., 1999. It was recommended as the standard index on Drought identification, and drought water relationships worldwide by the World Meteorological Organization (WMO) and (Van Loon, 2014). Equation 11 below shows the general calculation of the SPI.

$$SPI_{ijk} = \frac{P_{ijk} - \overline{P_{ij}}}{\sigma_{ij}}$$

Where SPI*ijk* is the z-value for the pixel *i* during timeframe *j* for year *k*, P*ijk* is the precipitation value for pixel *i* during timeframe *j* for year *k*, P*ij* is the mean for pixel *i* during timeframe *j* over *n* years, and σ*ij* is the standard deviation of pixel *i* during week *j* over *n* years. As precipitation data is usually not normally distributed, especially when it comes to time frames of 12 months or less, a transformation should be applied. Table 6 below shows classification of SPI values.

Table 6: Classification of SPI values

Criterion	Description
2 or more	Extremely wet
1.5 to 1.99	Severely wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 or less	Extremely dry

Source; Moisa *et al*., 2022, WMO, 2019

3.3.5. Normalized Difference Water Index (NDWI)

Normalized water index is used to analyze water contents in water bodies and water contents in plant leafs or it effectively measures moisture contents. Higher NDWI indicates sufficient moisture while, low value indicates water stress. The lower the value of NDWI the higher the drought severity. Water stress in vegetation leads to changes in different physiological and biochemical characters of crop plants. Remote sensing exploits this change in vegetation body to pick the water stress.

The normalized difference water index (NDWI) suggested by Gao (1996) demonstrated its potential applicability for canopy-level water content estimation based on the liquid water absorption band enhanced by canopy scattering. The NDWI uses two nearIR channels can be written as in Eq. 12 below.

$$\mathrm{NDWI} = \frac{\mathrm{Green} - \mathrm{NIR}}{\mathrm{Green} + \mathrm{NIR}} \quad \text{……………………………………………………………….Eq. 12}$$

Where, NIR: near infrared band

Data extracted from a satellite image using the NDWI index is visualized as maps using a color palette and graphs to show how values changes over time as a curve. on a map, the higher values approaching +1 usually appear blue and correspond to either a higher water content or a water surface, while a lower values all the way to -1 are the tell-tale signs of drought conditions, unless the area of interest is a non-aqueous surface.

3.4. Spatial Interpolation

Spatial interpolation is the procedure of using points with known values to evaluate values at other unknown points. For instance, to map rainfall and temperature of given area based up on nearby weather station. In present study, meteorological data were used to interpolate by Inverse Distance Weighted (IDW) interpolation. Inverse distance weighted is one of the interpolation methods in which the sample points are weighted during interpolation such that the impact of one point to another with distance declines from unknown point.

Inverse Distance Weighted is the simplest interpolation method. Deterministic models include IDW, rectangular, natural neighbors and spine. Interpolation uses vector points with known values to estimate unknown locations to create raster surface covering an entire area. Meteorological data (rainfall data from the year Jan. 2000 to Dec. 2021) of three stations in West Hararghe namely**,** *Bedesa, Gelemso and Hunde lafto,* were obtained from National Meteorological Agency; and interpolated using Inverse Distance weighted techniques in ArcGIS environment.

3.5. Qualitative data analysis method

Qualitative research parts of this study involves; collecting and analyzing non-numerical data such as; text, ideas, and images, to understand concepts, opinions, or experiences about the research objectives. This qualitative parts of the research was designed and data was collected through sample survey, observation, and interviews or questionnaires from the selected districts importantly by focusing on the research objectives and thematic analysis were done and results were quantified through charts, tables and graphs. The researcher closely examines the data to identify common themes, ideas and opinions that exactly fit the research questions.

In order to compile the required primary data sample survey was carried out in sub-districts namely: Hawi Gudina, Gumbi Bordode and Boke districts. This extensive field observation were made for assessment of the impact of drought on water supply availability, which were not available from any known source.

The questionnaires were distributed for the 10 person's sample individuals in each water sectors of the selected districts and these peoples are selected by using non probabilistic systems based on convenience or fulfilling a requirement, depending up on their knowledge, experience about drought causes and impacts, their residents and their age. The gathered data were analyzed by using charts that displays the results.

3.6. Software's used in this Study

To overcome the objectives of this study different software's required are listed in Table 7. The following flow chart (Figure 2) shows the overall work flows of this study.

Table 7: Software's used for the Study

No	Software's	Purpose
1	ArcGIS 10.3	Spatial data analysis and visualization
3	Google earth	Verification of vegetation cover in the study area
4	DrinC	Calculation of SPI

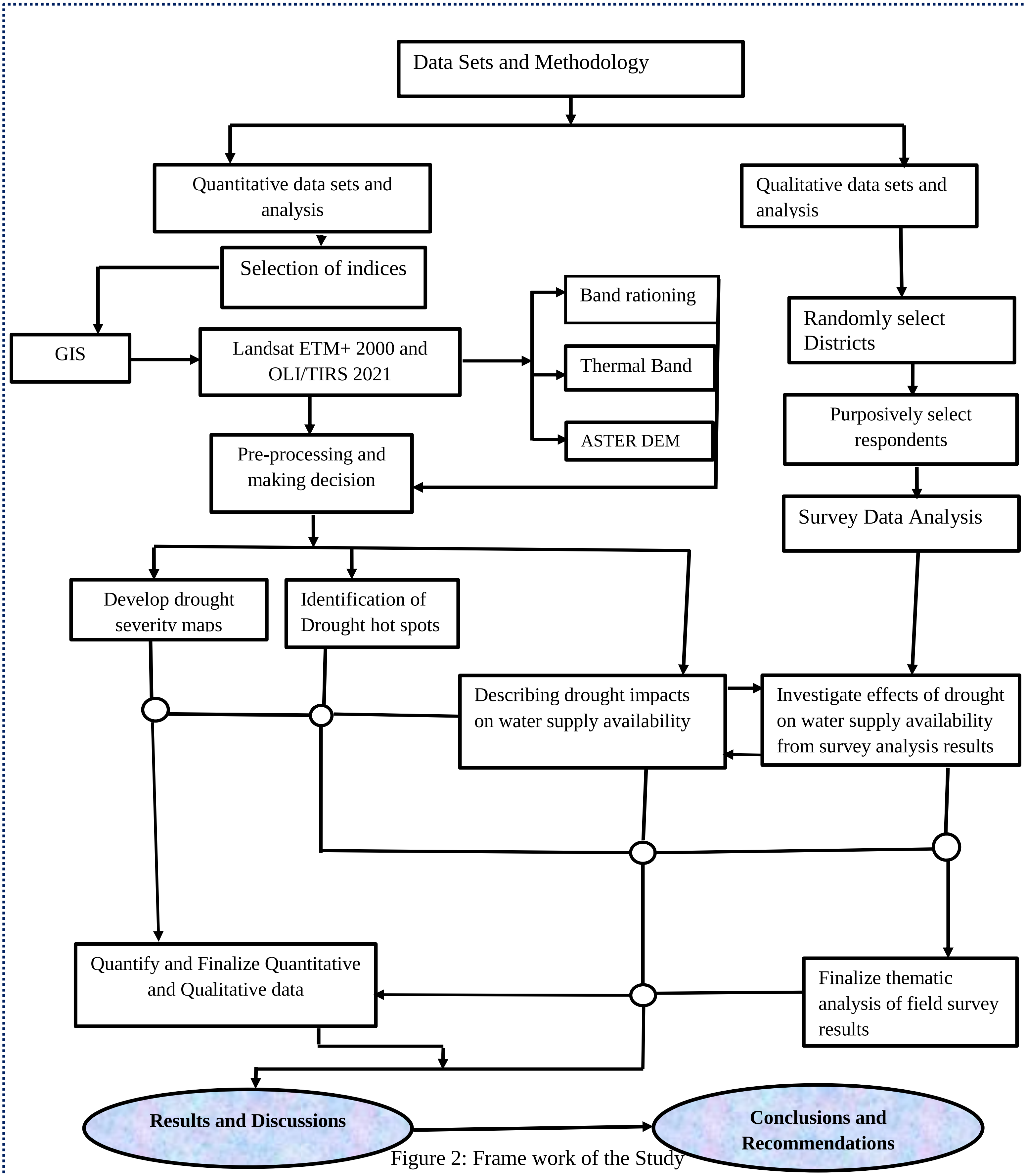

Figure 2: Frame work of the Study

CHAPTER FOUR

4. Results and Discussion

4.1. Identification of drought hot spots and its severity level

This study identify drought prone areas and develop different drought severity maps based on Standardized Precipitation Index (SPI), Normalized Difference Water Index (NDWI), Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), Vegetation Condition Index (VCI) and vegetation health index (VHI) with the help of ArcGIS 10.3 in the case of West Hararghe Zone, Eastern Ethiopia. As it has been concluded from this all drought indices most of districts in the study areas were failed under drought, among these districts Hawi Gudina, Burka Dintu, Gumbi Bordode, Boke, Oda Bultum, Mi'eso, Ancar, Shenen Dugo and Guba Qorica districts were identified.

The study was also describe drought impacts on water supply, based on the description from the indices and through field survey analysis. This description was based on the reality; that the response of the environment to the drought is the second order of drought episodes, in which water or hydrologic cycle destruction were the first order of the drought episodes. Thus, identifying and monitoring drought is essential for balanced water resources.

4.1.1. Analysis of Normalized Difference Vegetation Index from the year 2000 –2021

Findings from the study clearly shows that vegetation cover declined from 2000 to 2021 due to human action for the expansion of agricultural land, clearing forest for various purposes like fire wood, charcoal, and construction, in the study area. Accordingly, the mean NDVI value of the study area in 2000 is about 0.25 and declined to 0.13 and 0.12 by the year 2010 and 2021, respectively (Table 8). Thus, over the last 20 years, the NDVI values declined by 0.13, this result is in agreement with a research conducted by Alemu (2019), who reported that the NDVI values over Andassa watershed, Blue Nile Basin was 0.66 in 1986 and declined to 0.62 and 0.54 by the year 2000 and 2016, respectively. Removal of vegetation covers increased from the central part to the peripheral in all study period (Figure 3).

Table 8: NDVI Value from the year 2000 to 2021

Year	NDVI Value		
	Min	Max.	Mean
2000	-0.34	1.0	0.25
2010	-0.21	1.0	0.13
2021	-0.36	0.73	0.12

Source: Analysis from this study

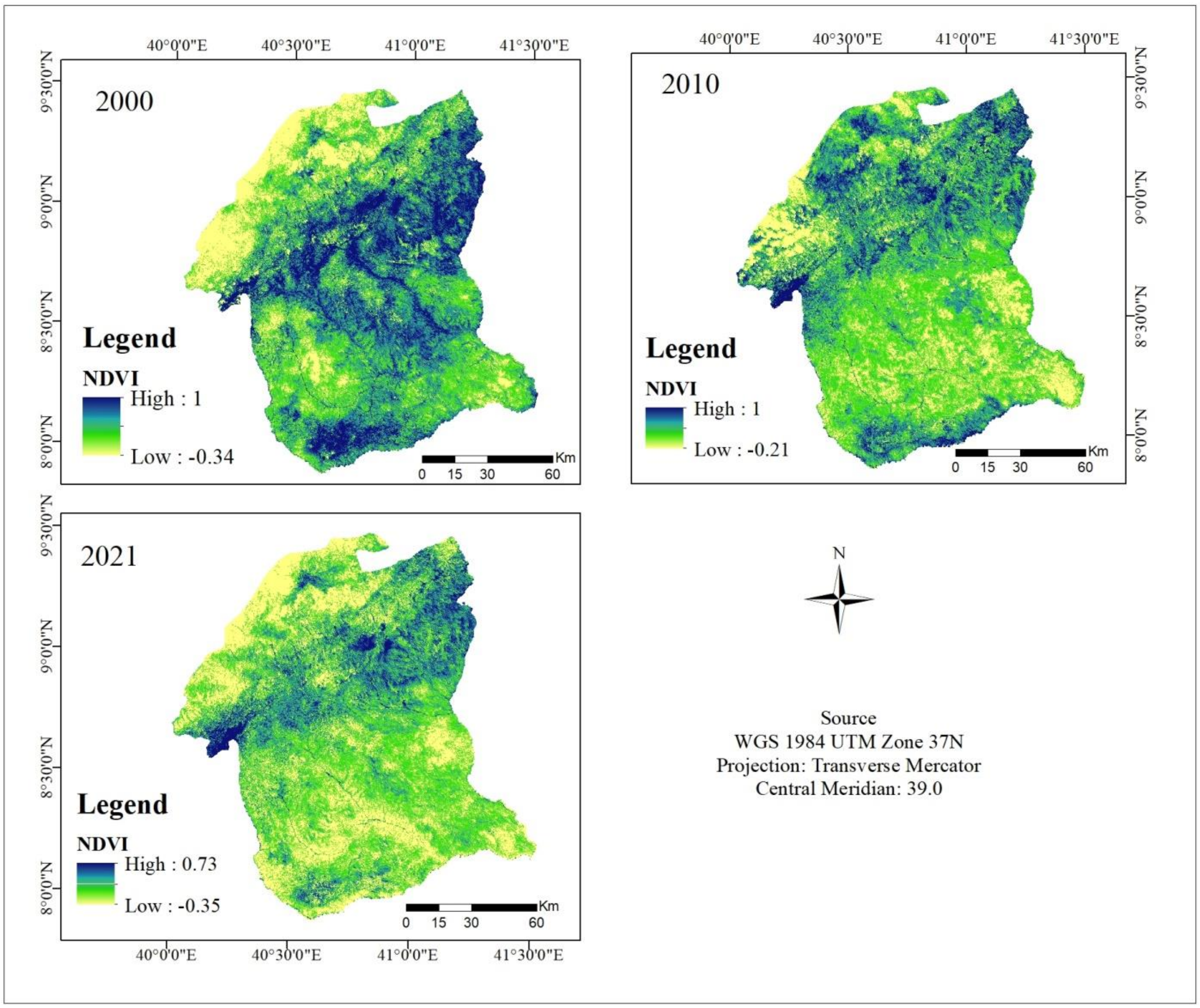

Figure 3: NDVI Value from the year 2000 to 2021

In 2000, major portion of the study area was fall under moderate drought with NDVI value ranges between 0.059 - 0.12 which covers an area of 6,947.24 km^2 (40.01 %). About 2,983.20

km^2 (17.18 %) of the study area falls under NDVI value ranges from -0.34 to 0.059 which clearly reveals the prevalence of severe drought. Therefore, 17.18 % and 40.01 % of the study area is grouped under severe drought and moderate drought, respectively (Figure 4). In contrast to this, central and north eastern parts of the study area have adequate vegetation cover and its NDVI value accounts greater than 0.12. This clearly indicates that there was adequate presence of rainfall and vegetation cover as NDVI significantly depends on the time and amount of precipitation.

In 2010, major portion of the West Hararghe zone was fall under moderate drought with NDVI value ranges between 0.1 - 0.2 which covers an area of 4711.41km^2 (27.14%). About 3529.51km2 (20.33%) of the study area falls under NDVI value ranges from -0.3 to 0.09 which shows the presence of severe drought (Figure 4). This analysis clearly reveals that the coverage of severe drought prevalence in 2000 was increased by 546.31Km2 (3.15%) until 2010 (Table 9).

In 2021, major areas of the West Hararghe zone was fall under moderate drought with NDVI value ranges between 0.07 - 0.13 which covers an area of 6588.41km^2 (37.95%). About 5012.34km2 (28.87%) of the study area falls under NDVI value ranges from -0.43 – 0.06 which shows the presence of severe drought (Figure 4). Area coverage of drought in 2021 was also 1482.83Km2 (8.54%) greater than that of 2010, which truly shows dramatic increasing of drought severity (Table 9).

Table 9: NDVI values based Drought Severity classes from 2000 to 2021

Year	**NDVI value**	**Area (Km^2)**	**Area (%)**	**Drought class**
2000	-0.399 – 0.59	2983.2	17.18	Severe Drought
	0.059 - 0.12	6947.24	40.01	Moderate Drought
	0.12 - 0.21	4348.45	25.05	Slight Drought
	0.32 – 1.00	722.12	4.16	No drought
2010	-0.3 - 0.09	3529.51	20.33	Severe Drought
	0.1 - 0.20	4711.41	27.14	Moderate Drought
	0.21 - 0.30	4565.22	26.29	Slight Drought
	0.41 - 1	1680.01	9.68	No drought

2021	-0.43 – 0.06	5012.34	28.87	Severe Drought
	0.07 - 0.13	6588.41	37.95	Moderate Drought
	0.14 - 0.20	3745.17	21.57	Slight Drought
	0.33 - 0.73	366.35	2.11	No drought

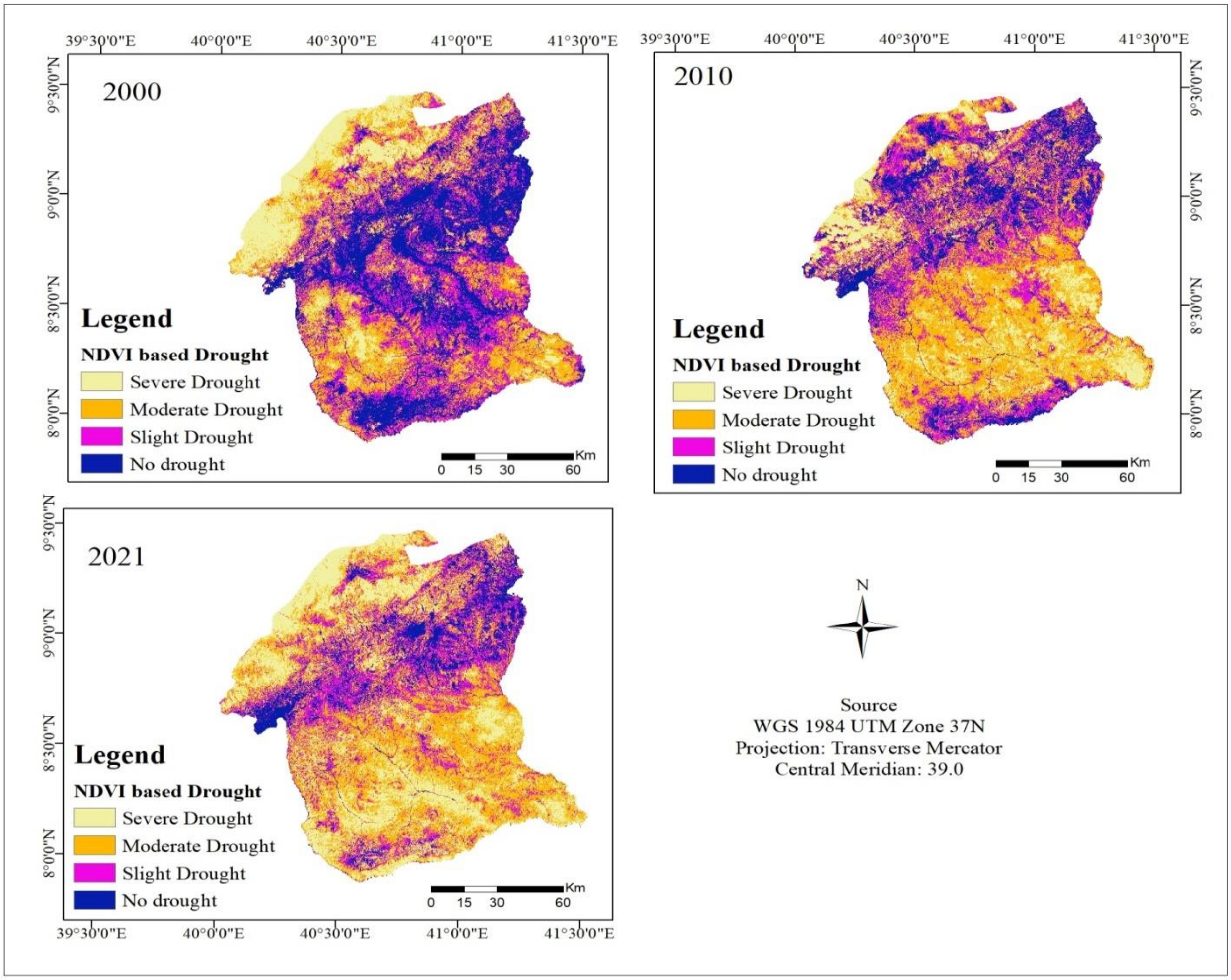

Figure 4: NDVI based drought severity map

4.1.2. Analysis of Land Surface Temperature (2000– 2021)

In this study drought Severity has also been detected by LST in the study area (Figure 5). The result indicates that severe drought hit about 2831.0 km^2 (16.30%) in 2000 and it was increased to 6156.85 km^2 (37.8%) in 2021. Furthermore, moderate drought increased from 4564.4 km^2 (26.28%) in 2000 to 6443.36 km^2 (33.61%) in 2021 (Table 10).

Table 10: Land Surface Temperature based drought classification

LST based Drought	2000		2010		2021	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
No drought	3264.7	18.80	1275.07	17.45	1379.89	13.20
Slight Drought	6702.4	24.60	7078.27	35.34	4253.06	21.52
Moderate Drought	4564.4	26.28	5936.45	30.29	6443.36	33.61
Severe Drought	2831.0	16.30	3072.82	22.62	6156.85	37.8

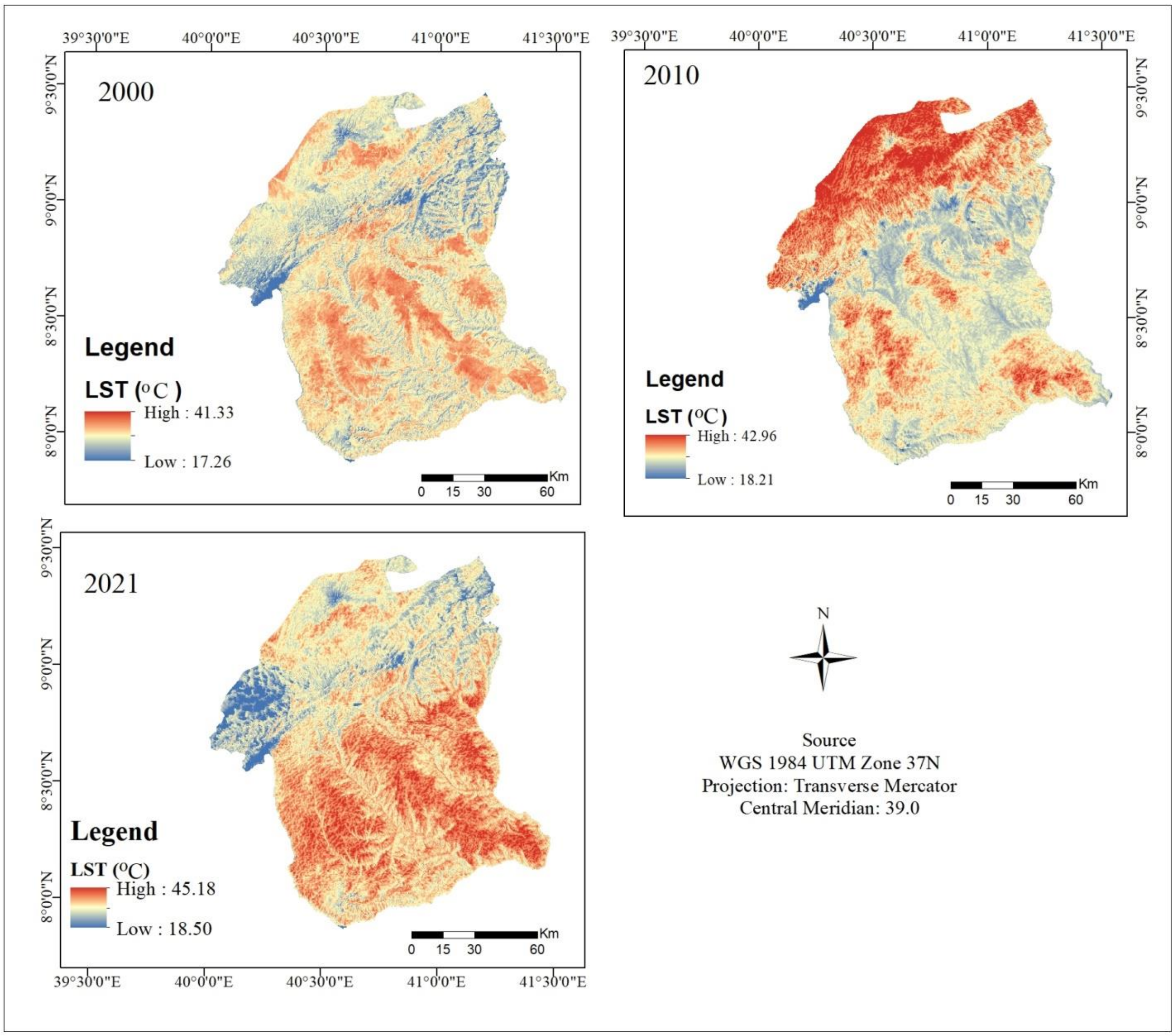

Figure 5: LST based drought severity map

4.1.3. Analysis of Vegetation Health Index (2000– 2021)

Extreme drought has also been detected by VHI in the study area. The result indicates that severe drought struck about 2767.15 km^2 (16.79%) in 2000 and it was increased to 6126.79km2 (40.7%) in 2021. Furthermore, moderate drought increased from 5702.94km2 (28.6%) to 6643.32km2 (37.41%) in 2021 (Table 11). Spatial distributions of severe and moderate drought were increased in the year 2021 (Fig. 6). The findings of the study are more consistent with earlier research, such as: (Gebrehiwot *et al*. 2016; Gidey *et al*., 2018. Analysis of VHI is crucial for decision and policy makers to design appropriate mitigation and adaptation strategies to minimize the potential impacts of drought.

Table 11: VHI based Drought Severity Classes

VHI based Drought	2000		2010		2021	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
No drought	2479.42	13.13	1376.08	12.5	1279.89	9.2
Slight Drought	5472.75	32.67	6178.23	39.27	4253.06	21.5
Moderate Drought	5702.94	28.6	5216.17	35.14	6643.32	37.41
Severe Drought	2767.15	16.79	3137.43	30.19	6126.79	40.7

The year 2021 observed extreme drought period across the study area. (Liu *et al*., 2018) suggested that during the extreme drought period there will be an integral problem occurred such as; catastrophic shortage of livestock forage, drinking water supply loss and environmental crisis.

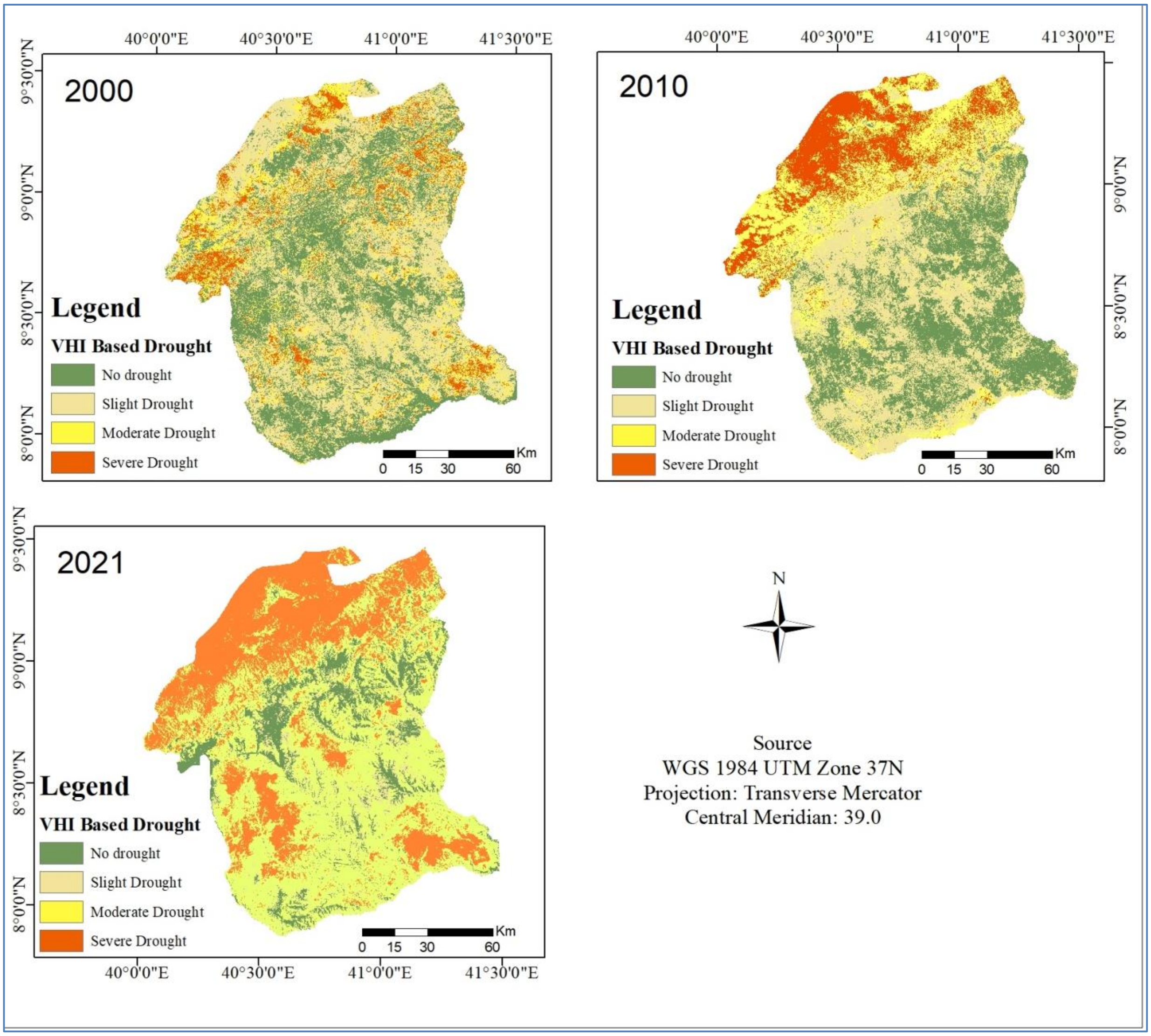

Figure 6: VHI based drought severity map

4.1.4. Analysis of Vegetation Condition Index (2000 – 2021)

Findings from this study shows that extreme drought was increased from 2,567.15 km^2, 4732.18 km^2 and 6225.70 km^2 in 2000, 2010 and 2021, respectively. Area affected by severe drought increased by 19% and 24.42% by the year 2010 and 2021, respectively (Table 12). Severe drought was more expanded in 2021 due to decline of vegetation cover (Figure 7).

Table 12: Vegetation Condition Index (VCI) Based Drought Classification

VCI based Drought	2000		2010		2021	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
No drought	2279.42	13.13	1670.32	18.35	1279.89	8.37
Slight Drought	5672.75	32.37	7172.14	45.12	4253.06	23.50
Moderate Drought	6843.32	38.15	5046.65	35.16	5702.94	33.85
Severe Drought	2567.15	16.35	4732.18	39.17	6225.70	41.77

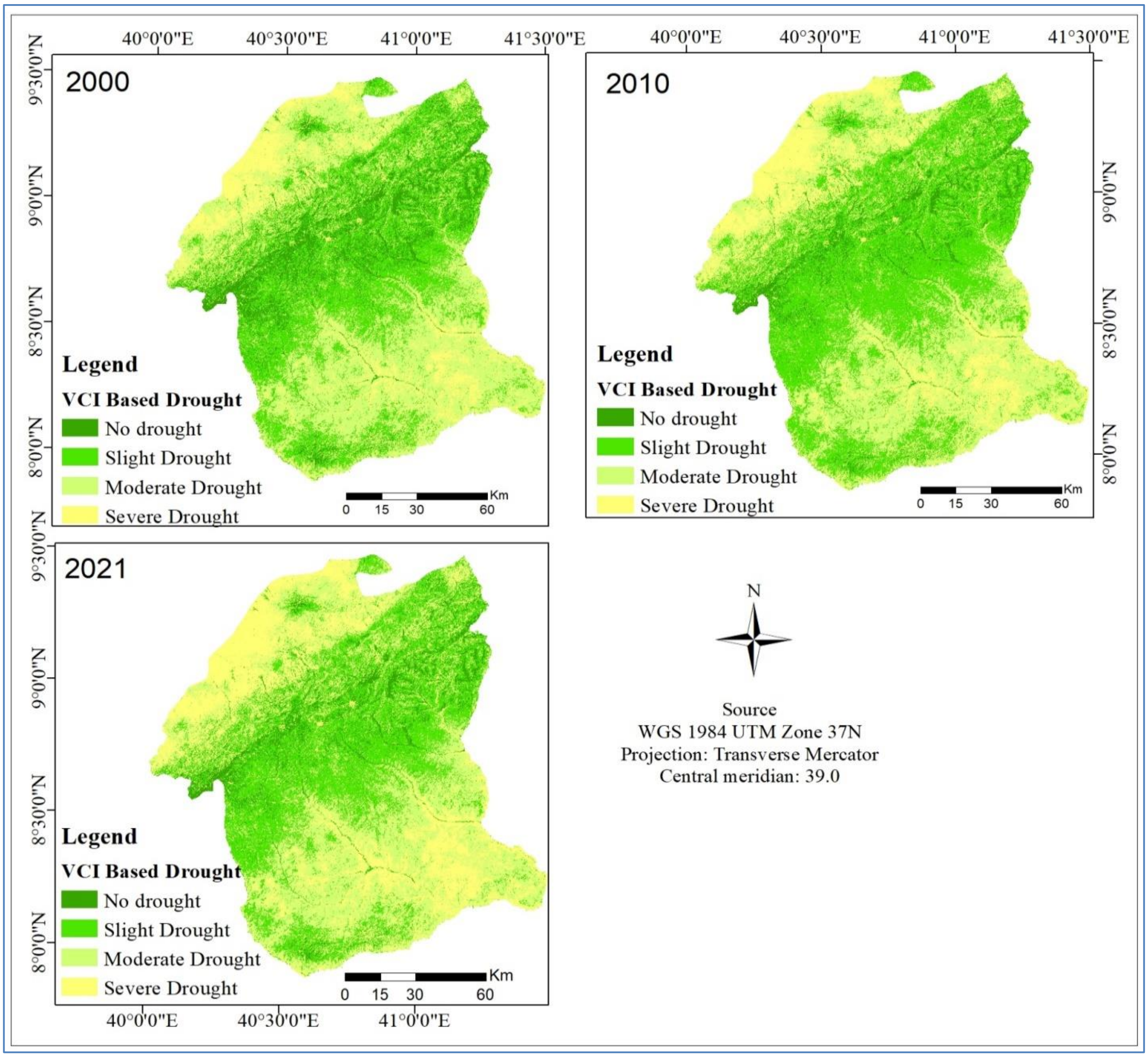

Figure 7: VCI based drought severity map

4.2. Drought Detection Using SPI

This paper presents the effect of SPI values, and the analysis of drought events depending on three meteorological stations in west Hararghe zone.

The analysis of SPI allows to monitor short-term water supplies, such as shallow well, which is important for domestic water supply, and long-term water resources, such as deep well groundwater supplies, stream flow, and lake and reservoir levels (Mersha and Van Loon, 2018). Analysis shows that the SPI at shorter time scales has high variability and shows more short-term drought events. Longer SPI time scales do not necessarily detect all the negative deviations that are evident on shorter time scales. It is also evident that SPI values at shorter time scales show slight increases in precipitation during dry periods, which do not necessarily reflect an improvement in drought situation on a longer time scale. When analyzing past periods, we have to keep in mind that several consecutive months of negative index values do not necessarily indicate drought.

Negative index values actually identify the months with less precipitation compared against the long-term comparative period. Precipitation deficit in winter months is regard to ground water recharge and recharge of other water resources, which are among the important factors affecting the status of drinking water supply in west Hararghe zone.

The index value calculated at a specific time scale must be representative of the drought status in a hydrological system to be operative for water resources management purposes (Maeasho et al. 2019). The only input data for calculating the SPI are monthly precipitation data. In this research, three meteorological stations in West Hararghe (*Hunde Lafto*, *Gelemso*, and *Bedesa*) were used and SPI-12 was computed mainly to detect reduced stream flow and ground water table and can be also used as an indicator for reduced reservoir and groundwater recharge (WFP, 2015).

SPI-12 analysis from all stations shows rain fluctuation was very high and reduced especially between 2000 to 2007 as well as shows high failures in 2018 to 2021, (Figure 8). This fits the results from field survey analysis in sample districts that shows high prevalence of drought observed and shows the presence of high loss of water supply scheme which will be discussed in section 4.5 of this study. The description from SPI-12 analysis also found to correlate best with water supply wells dried from the implication of drought.

Description from SPI analysis shows the correlation with the decline of groundwater levels and the significant rainfall failures. Results from SPI analysis of all stations in the study area have a similar distribution of major dry and wet periods (Figure 8). Positive values of SPI (up arrows) or blue line shows wet period, and negative values (down arrows) or red lines shows dry period which indicates drought conditions.

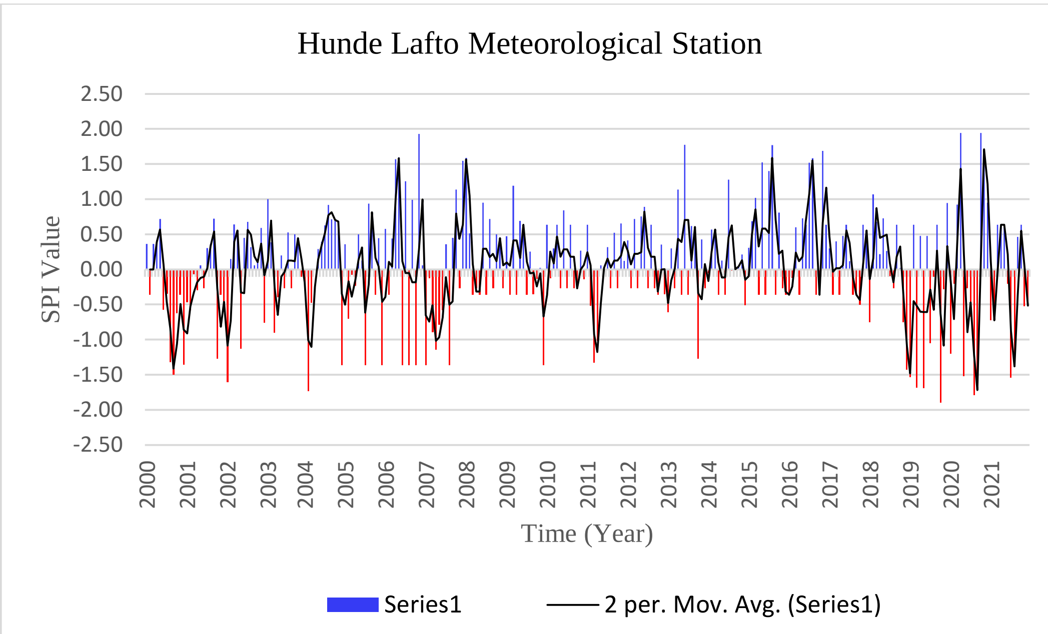

Figure 8: SPI-12 Hunde Lafto meteorological stations (2000-2021)

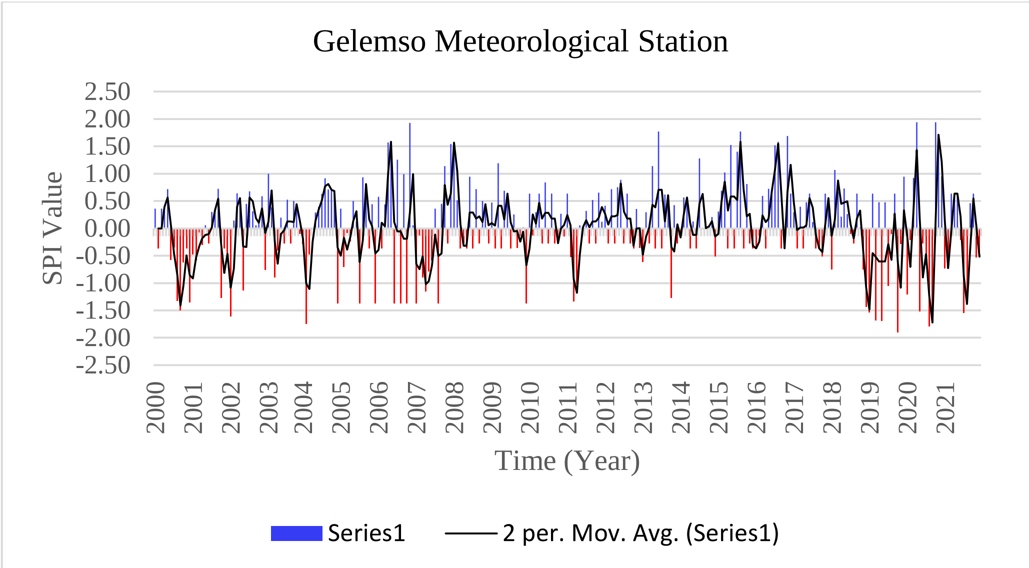

Figure 9: SPI-12 Gelemso meteorological stations (2000-2021)

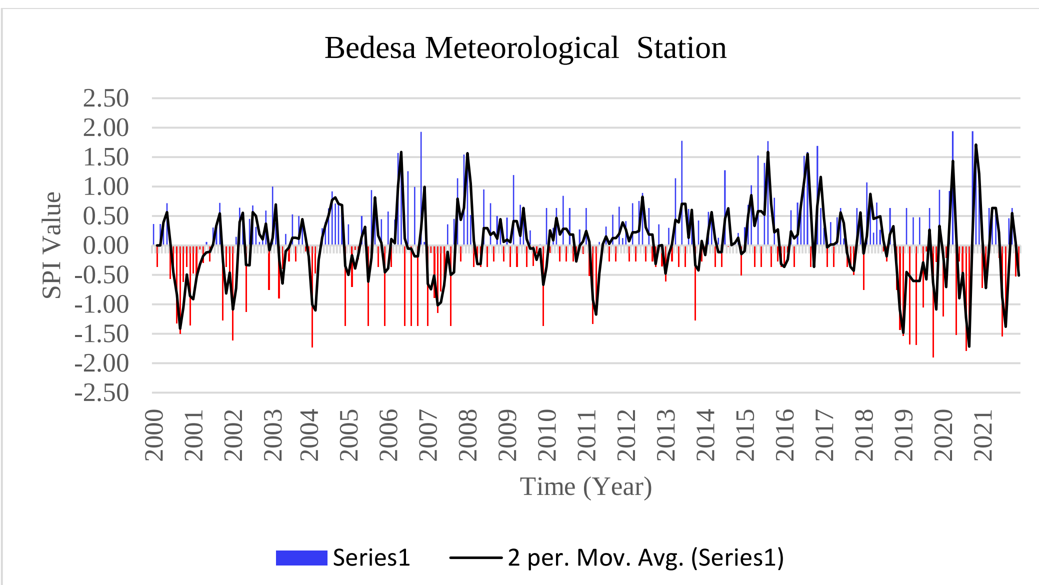

Figure 10: SPI-12 Bedesa meteorological stations (2000-2021)

4.3. Analysis of Normalized Difference Water Index (2000– 2021)

Extreme drought has also been detected by NDWI in the study area. The result indicates that severe drought struck was cover about 6526.79 km^2 (40.7 7%) in 2021. Furthermore, severity of the drought also increased from 2867.16 km^2 (26.35%) to 3172.82 km^2 (24.19%) in 2000 and 2010, respectively (Table 13). The normalized difference water index (NDWI) suggested by Gao (1996) also demonstrated its potential applicability for canopy-level water content estimation based on the liquid water absorption band centered at 1240 nm enhanced by canopy scattering.

Table 13: NDWI based Drought severity classes

NDWI based Drought	2000		2010		2021	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
No drought	1079.49	13.14	1375.07	6.34	1379.89	7.39
Slight Drought	4672.75	42.47	7178.27	45.39	4353.06	24.50
Moderate Drought	5843.38	18.16	5836.45	27.7	5302.94	32.85
Severe Drought	2867.16	26.35	3172.82	24.19	6526.79	40.77

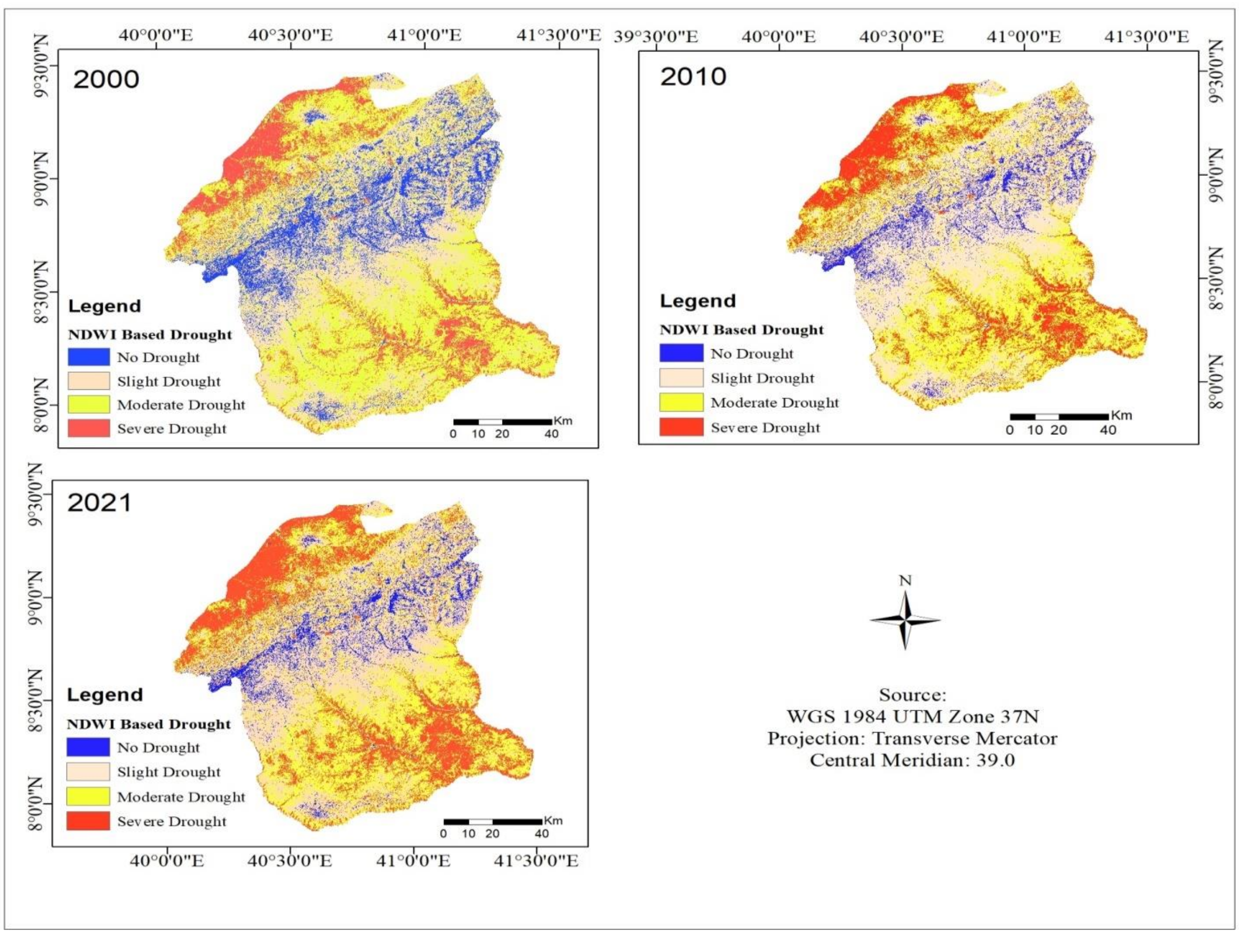

Figure 11: NDWI based Drought severity map

4.4. Average areas of drought severity classes from NDVI, LST, VHI, VCI and NDWI

Analysis from NDVI, LST, VHI, VCI and NDWI indices shows that average areas of: 1,965.03 km^2, 5,373.82 km^2, 5,980.26 km^2, and 2,803.13 km^2 represents no drought, slight drought, moderate drought and Severe drought respectively in the study area during 2000 (Figure 12) (Table 14). These value changed to: 1,475.31 km2, 6,434.43 km2, 5,349.43 km2, 3,528.95 km2 (Figure 13) (Table 15) and 1,137.18 km2, 4,171.48 km2, 6,136.19 km2 and 6,009.69 km2 (Figure 14) (Table 16) in 2010 and 2021 respectively, which shows that average area coverage of severe drought is increased by 3,206.56 km2 in the past two decades in West Hararghe zone.

Table 14: Average areas of drought classes from NDVI, LST, VHI, VCI and NDWI drought index of 2000

Drought Class	Drought Severity Average Area From Indices (km2)
no drought	1,965.03
Slight drought	5,373.82
moderate drought	5,980.26
severe drought	2,803.13

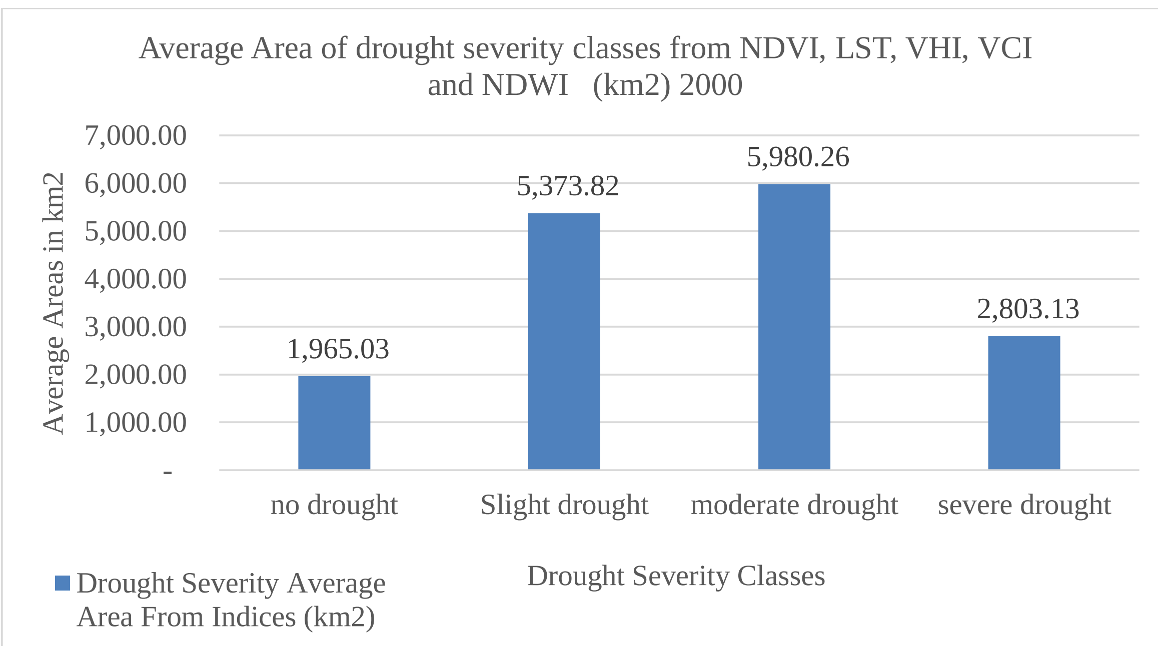

Figure 12: Average areas of drought severity classes from indices 2000

Table 15: Average areas of drought classes from NDVI, LST, VHI, VCI and NDWI drought index of 2010

Drought Class	Drought Severity Average Area From Indices (km2)
no drought	1,475.31
Slight drought	6,434.43
moderate drought	5,349.43
severe drought	3,528.95

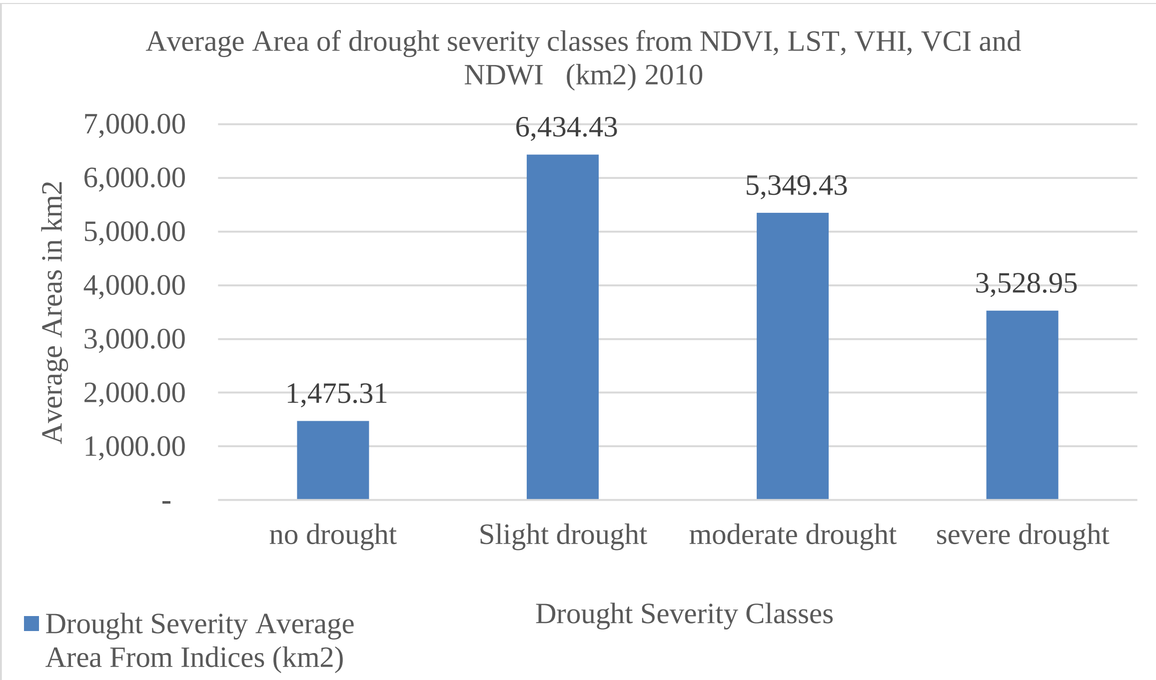

Figure 13: Average areas of drought severity classes from indices 2010

Table 16: Average areas of drought classes from NDVI, LST, VHI, VCI and NDWI drought index of 2021

Drought Class	Drought Severity Average Area From Indices (km2)
no drought	1,137.18
Slight drought	4,171.48
moderate drought	6,136.19
severe drought	6,009.69

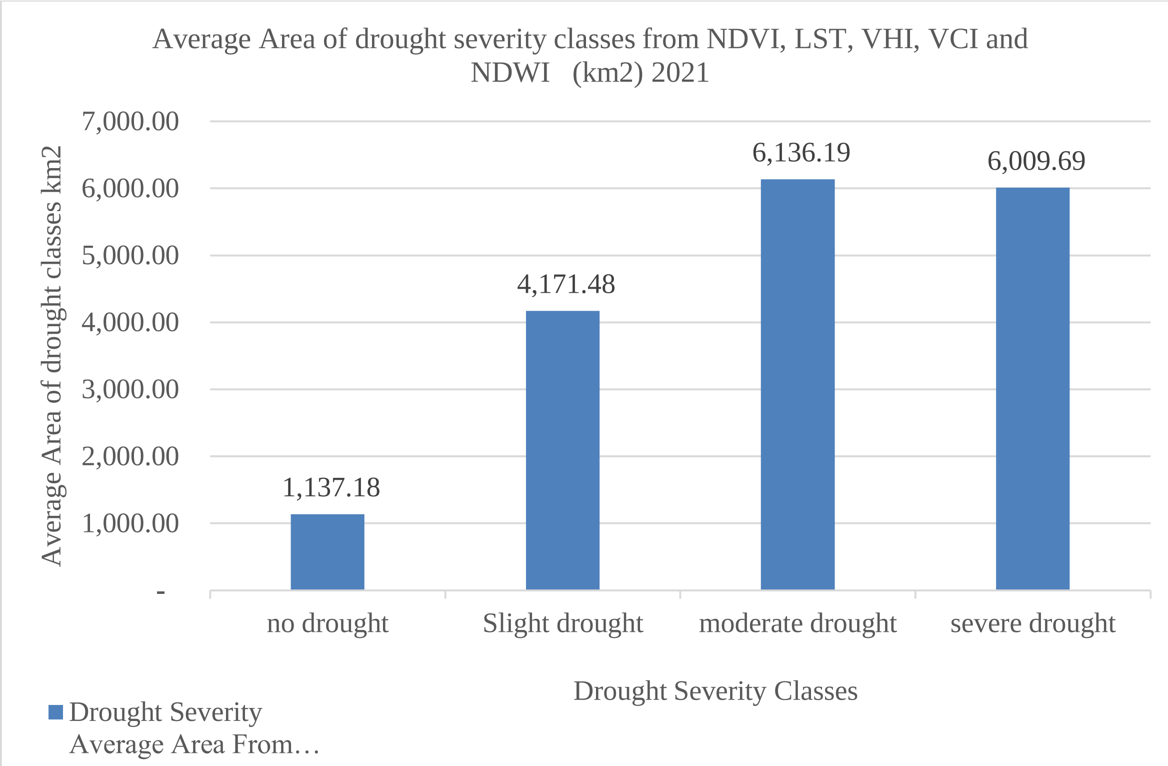

Figure 14: Average areas of drought severity classes from indices 2021

4.5. Inverse Distance Weighting (IDW) Spatial Interpolation Results

An IDW interpolating method was applied to predict the spatial distribution of precipitation in the study area. An interpolation result was checked by statistics that indicated the degree of matching between the models and reality (Zhang, *et al*., 2014).

Through various statistical calculations, the differences between the predictions obtained by means of the different interpolation methods and the measured data recorded at the rain stations can be observed. Cross validation (Geo-statistical Analyst) uses all the data to estimate the trend and autocorrelation models; by removing each data location once at a time and predicts the associated data value. In this study, an interpolation method was used to estimating the yearly time series from 2000 to 2021 using rainfall stations precipitation data (Appendix I, II, & III). The study area rainfall data for 20 years were used to generate the spatial rainfall-interpolation method in ArcGIS.

Figure 15 shows the results of the spatial variations of monthly rainfall interpolated from all months which showed the highest monthly rainfall in the central and northern part of the study area, and lower values appeared in the southern, southeastern and northeastern with significant differences.

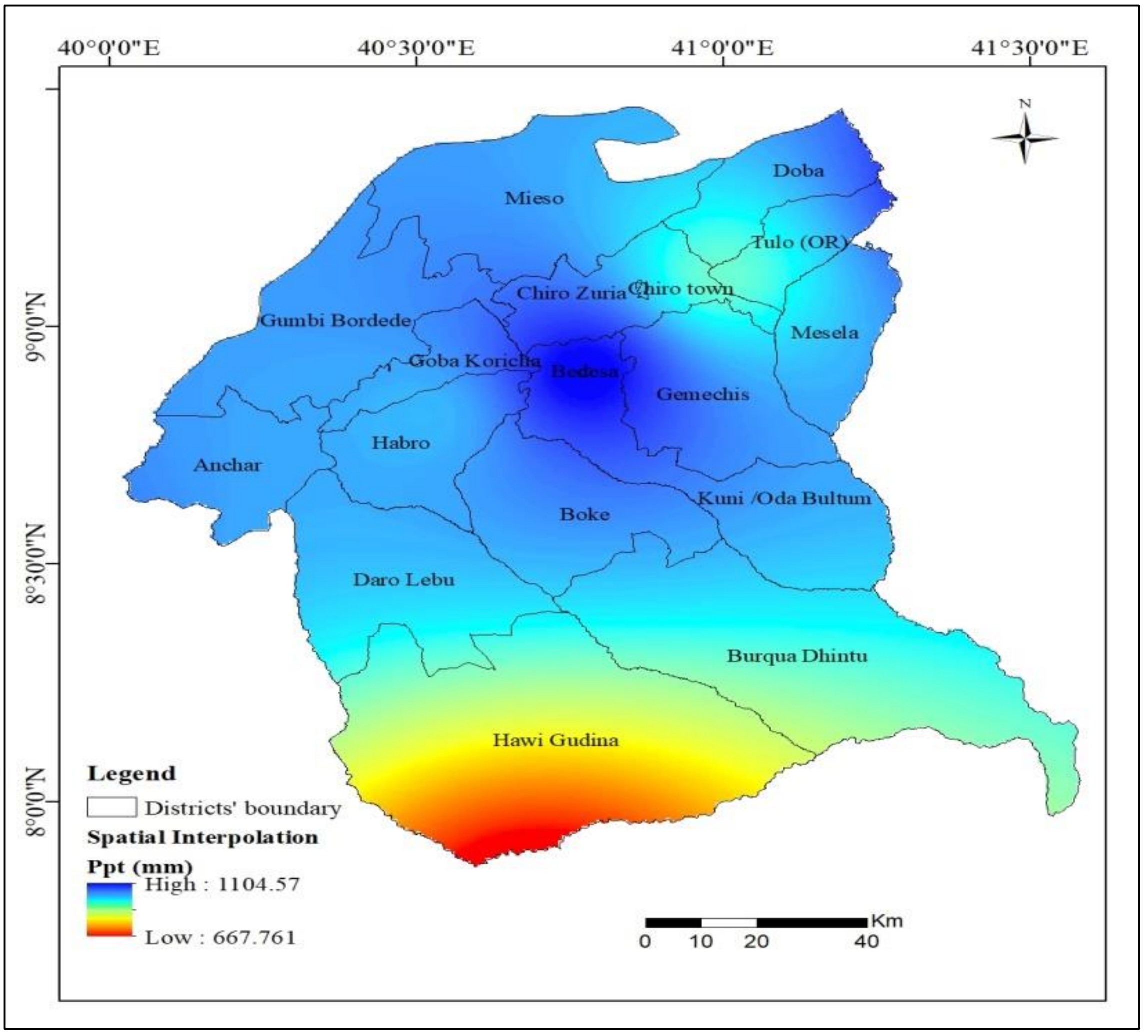

Figure 15: Spatial Interpolation Results

4.6. Sample survey analysis of Drought impacts in the study area

4.6.1. Respondents Response analysis on drought severity classes

This study uses qualitative information by conducting field survey to evaluate water supply drought impacts and statistical analysis to locate and map drought severity in the study area. This has given very rich information about the drought and its impacts on water supply and useful for decision makers to monitor drought in West Hararghe zone.

According to field survey analysis, which were carried out in three districts that were selected through simple random probability techniques: the average respondents of drought severity classes were; 0%, 20%, 30%, & 50%, which represents no, slight, moderate and severe drought respectively for Hawi Gudina districts and also; 0%, 20%, 20% and 60%, which represents no, slight, moderate and severe drought respectively for Gumbi Bordode districts and as well as; 0%, 40%, 20% and 30%, which represents no, slight, moderate and severe drought respectively for Boke districts. Among these all percentages of respondents on drought severity classes; percentage respondents of Severe drought in Boke, Gumbi Bordode, and Hawi Gudina were; 30%, 60%, and 50%, respectively (Figure 16). This results really shows the drought observed on the ground and almost the same with what was analyzed and mapped in quantitative analysis parts of this study.

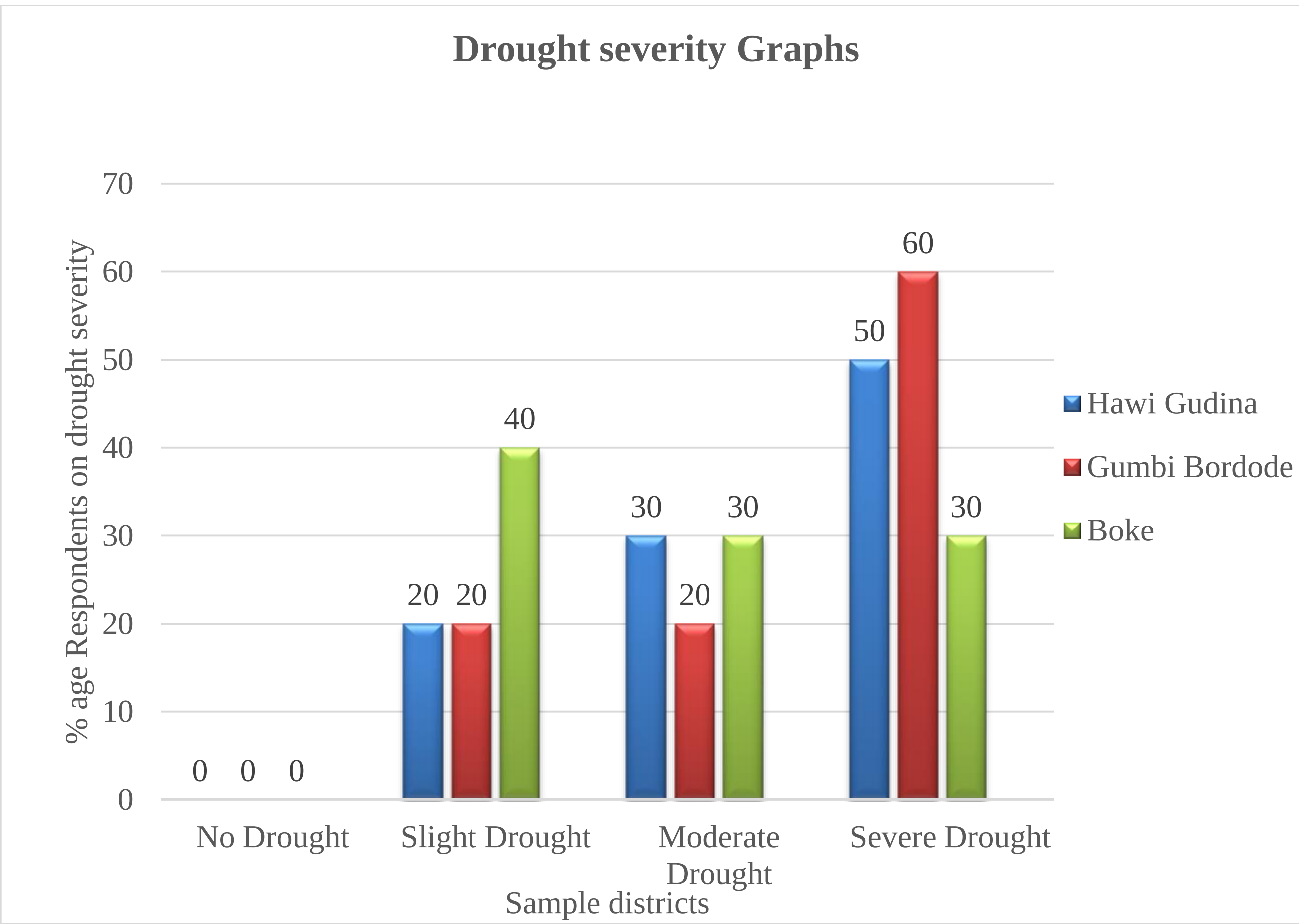

Figure 16: Drought Severity response Graphs from sample survey analysis of Hawi Gudina, Gumbi Bordode and Boke districts

4.6.2. Losses due to drought in West Hararghe Zone

According to this survey the agricultural loss in West Hararghe was clearly identified and is perhaps better understood as a deepening of a chronic crisis, rather than as a short-term natural disaster. There had been poor rains for several years. The short rains present may failed, and though there was some rain in the long rainy season, the pattern of poor and irregular rains was seen in the past two decades and leads to agricultural loss. Although many spoke of the rainy seasons failing completely, most people managed to get some harvest (Appendix VI).

Survey analysis shows that the highest losses due to drought in Hawi Gudina, Gumbi Bordode and Boke were: Health loss, Livestock loss and agricultural loss respectively. The loss of livestock in the past two decades was slightly higher in Gumbi Bordode districts (Figure 17).

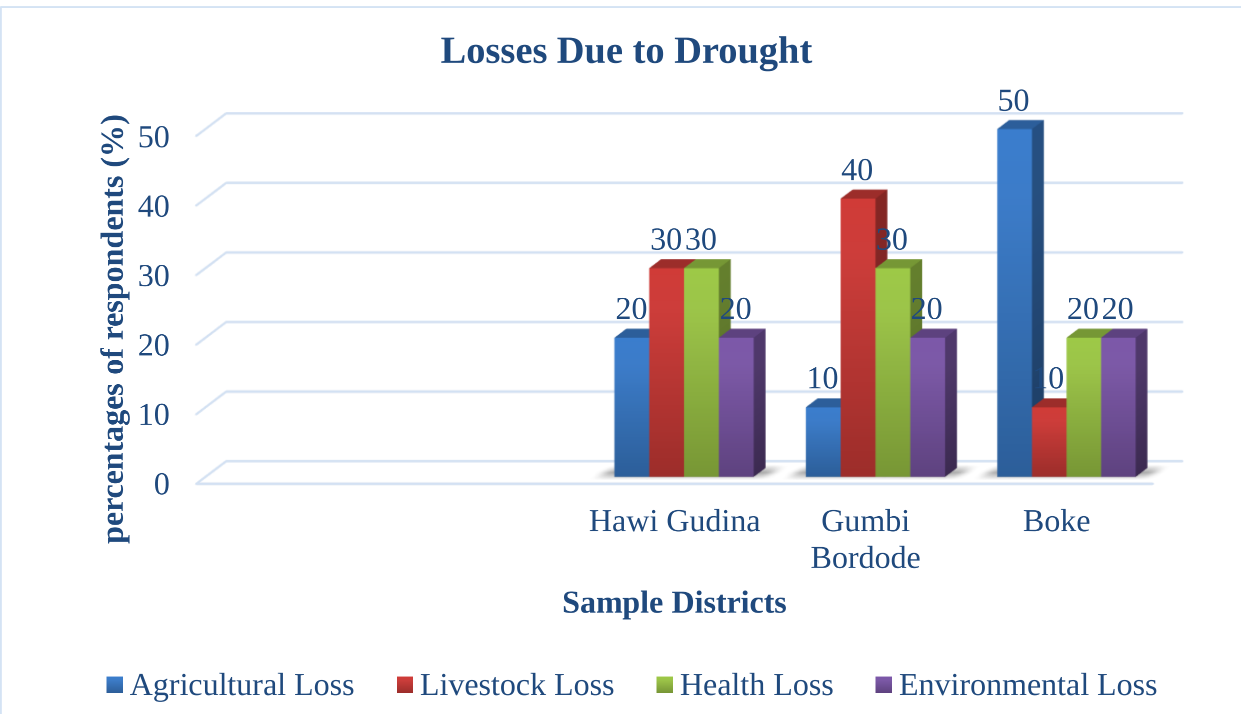

Figure 17: Percentages of respondents for losses due to drought (sample survey analysis of Hawi Gudina, Gumbi Bordode and Boke districts)

Herd loss was much lower for those who had smaller herds, because of those who had fewer animals were able to protect some them using food aid, bought food, and collecting a variety of vegetation (Appendix VI).

Sample survey analysis of this study shows that there was some human mortality due to the drought. The possible public health implications of drought include: compromised quantity and quality of drinking water; increased recreational risks; effects on air quality; diminished living conditions related to energy, air quality, and sanitation and hygiene; compromised food and nutrition; and increased incidence of illness and disease (WFP, 2015). As observed during field visit, the community in these drought affected area, for instance Gumbi Bordode Woreda not only faced with water supply scarcity but also they are losing their costly counted health.

4.6.3. Estimated percentage of water supply affected by drought

The results from the qualitative data analysis shows that drought impacts water supply by impairing both the surface and groundwater resources in the study area. The sample result shows that the ongoing drought in West Hararghe has severely depleted water supplies and left many Woredas with water shortages. It's been going on for so long that it's now being called "Aridification" in certain areas. Water restrictions have been implemented in parts of Zones.

The lack of water can have an impact on both drinking water quality and water infrastructure. Both natural bodies of water and human-made reservoirs are being depleted because of drought at alarming rates, leading to water shortages and restrictions in the study area. Analysis from Survey study found that droughts lead to elevated levels of naturally occurring dryness in private wells and groundwater, and that the longer a drought lasts, the higher the probability of losing drinking water (Appendix VI).

Survey analysis shows that depending up on percentage of respondents on level of water supply schemes affected by drought were; 10%, 20%, & 70%, which represents slight, moderate and highly affected water supply respectively for Hawi Gudina districts and also; 10%, 30% and 60%, which represents slight, moderate and highly affected water supply respectively for Gumbi Bordode districts and as well as; 20%, 30% and 50%, which represents slightly, moderately and highly affected water supply respectively for Boke districts. Percentages of highly affected water supply schemes for Boke, Gumbi Bordode, and Hawi Gudina were; 50%, 60%, and 70%, respectively (Figure 18).

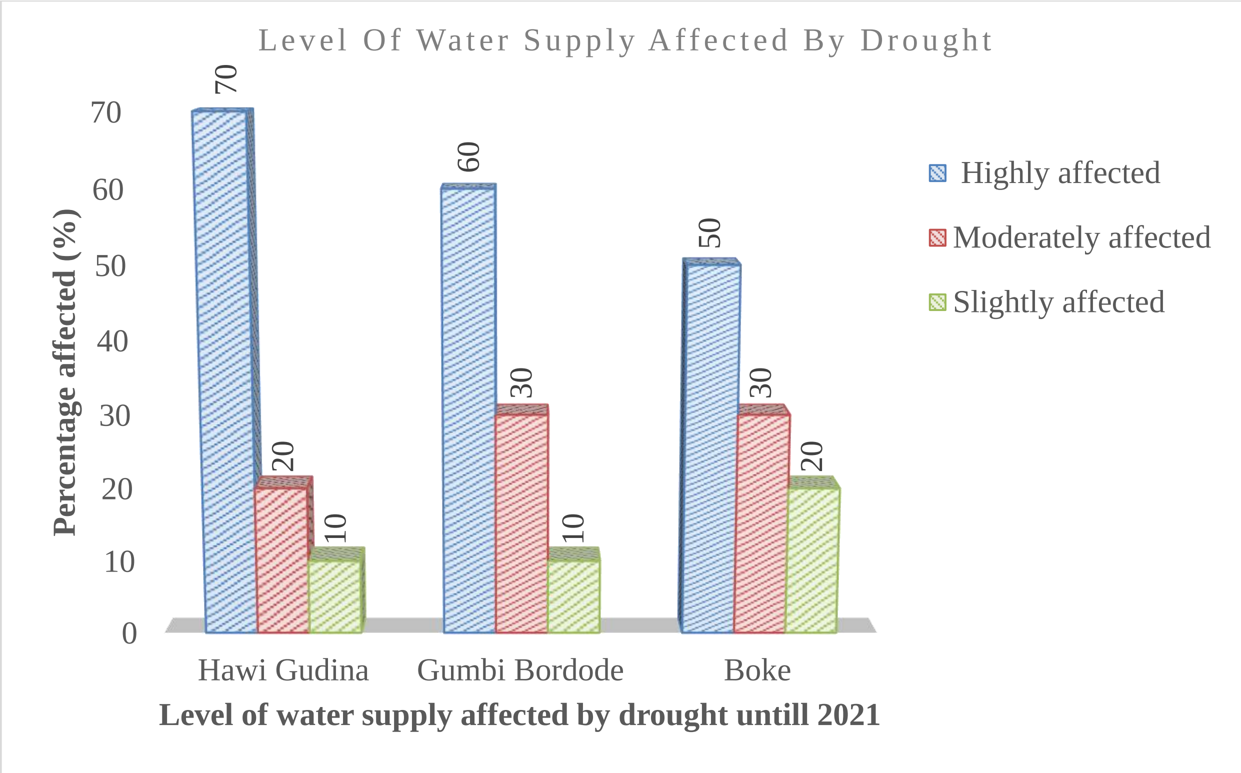

Figure 18: Graph shows percentages of water supply Schemes affected by drought (sample survey analysis of Hawi Gudina, Gumbi Bordode and Boke districts)

4.6.4. Main sources of water supply in the study area

Based on the information available, most of People in the study area use ground water wells for their domestic water supplies which were little flow or may be dried during a drought. These low water supply flow caused by droughts can have also an impact on water supply systems.

Depending up on the questionnaires analysis, the percentage of Ground water supply sources for Boke, Gumbi Bordode, and Hawi Gudina were; 70%, 80%, & 70% respectively, and also; 20%, 10% and 20%, percentages for Surface water supply sources in Boke, Gumbi Bordode, and Hawi Gudina districts respectively, and as well as; 10%, 10% and 10%, percentages for others water supply sources such as: those supplied by cars for emergency service in Boke, Gumbi Bordode, and Hawi Gudina districts respectively. It can be concluded from this survey analysis that above 80% of water supply is ground water in the study area (Figure 19). Thus, understanding the sources of water supply enables resource managers and policy makers to better prepare for and respond to drought.

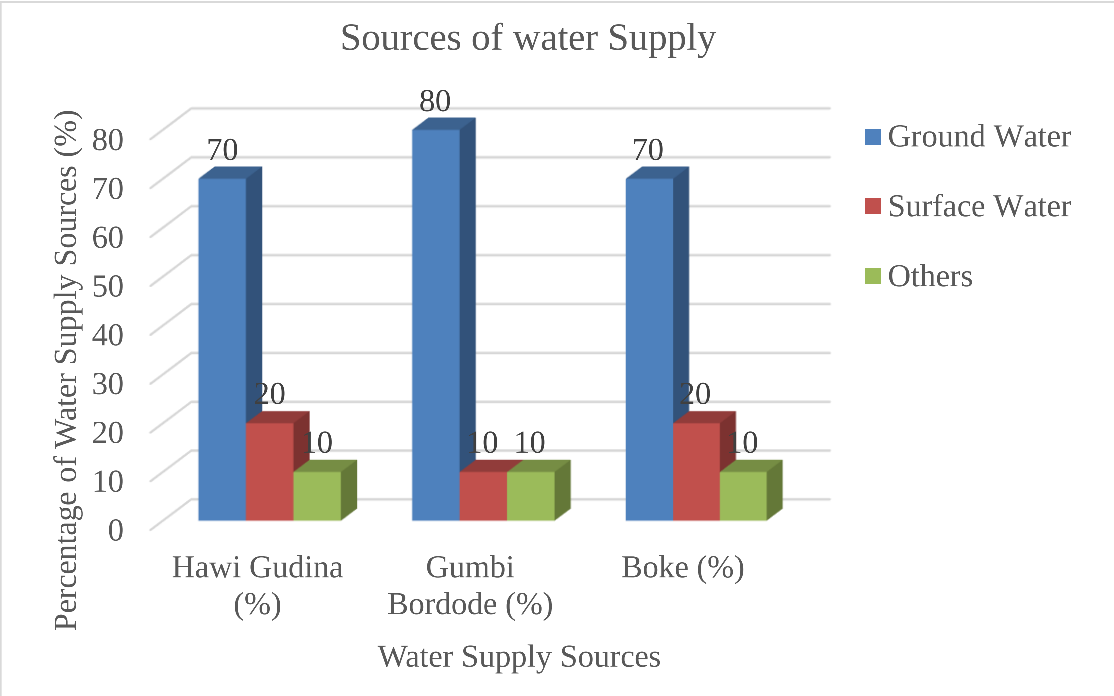

Figure 19: Graphs shows sources of water supply (from sample survey analysis of Hawi Gudina, Gumbi Bordode and Boke districts)

4.6.5. Estimated water supply wells dried because of drought in the study area

As it was seen from the results of survey analysis, ground water is the most sources of water supply in the study area. Depending up on the questionnaires analysis, the percentage of respondents for wells dried because of drought were: 20%, 30% and 50%, responds for < 25%, 25-50%, > 50%, percentage of wells dried respectively in Hawi Gudina districts and also for Gumbi Bordode percentage of respondents and percentage of dried wells respectively were: 40%, 20% and 40%, responds for < 25%, 25-50%, > 50% and as well as: 30%, 20% and 50%, responds for < 25%, 25-50%, > 50% which represents Boke Woreda districts respectively (Figure 20).

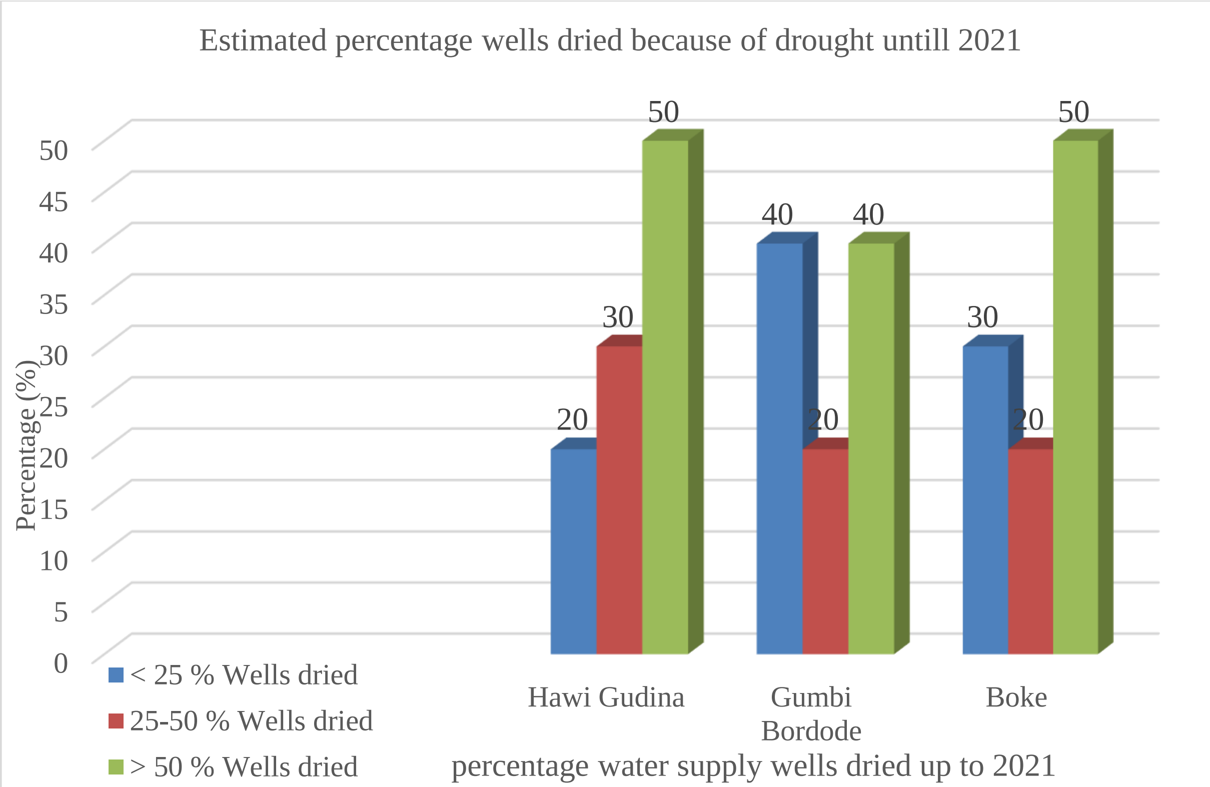

Figure 20: Graphs shows water supply wells dried because of drought (from sample survey analysis of Hawi Gudina, Gumbi Bordode and Boke districts)

4.7. How do people adapt, to cope up with drought impacts and concerning its mitigation and preparedness?

Survey results shows that community in the sample districts were using aid for asset protection during a drought. However, a very clear strategy would be needed to have a chance of preventing asset loss. This would need to be on a scale many times higher than current aid interventions and be accompanied by a level of investment in planning and preparedness, the need for which has not yet been fully recognized.

Their primary and urgent responsibility in a crisis is saving lives, not documentation. However, responders themselves have a need for coordinated information. Current information management systems do not help agencies to provide the information without an excessive administrative burden, nor does it help them quickly and easily access information in a form that is useful for their decision-making. One respondents in Boke districts says that we get aid different food for herd during drought and save around 5% of our livestock loss, but this is not enough.

Preparedness can be interpreted in two ways, which are not always clearly distinguished:

The first one is giving advance warning of an impending shock, before it arrives. This information can be useful to those who will be affected, so they can take avoidance or mitigation measures. The information is also critical for those who will support affected people (government at different levels, and aid agencies), so that they can plan, prepare and deliver early aid.

The second one is giving warning of the early signs of crisis, i.e. after the shock, so that mitigation measures can be taken to prevent more serious suffering. This can help ensure timely aid. This information is useful to those responsible for supporting the crisis-affected (since the affected population will be aware of their own situation).

Analysis from sample survey shows that in the study area people uses aid from non-governmental agencies and from government, for instance water supply by cars were delivered for the areas seriously in attack by drought (Appendix VI).

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Based on the objectives of the study, modern Geographical Information System based drought indices as well as ground based observations mechanisms were used to collect and analyze twenty years' data (Jan. 2000 to Dec. 2021) on the behaviors of drought and its impacts on water supply in West Hararghe Zone. Applying, Standardized Precipitation Index (SPI), normalized difference water index (NDWI), Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), Vegetation Condition Index (VCI) and vegetation health index (VHI) indices, the actual impacts (onset, distribution, and severity levels) of the drought in the Zone's and its integral effects on water supply have been thoroughly investigated and analyzed. Using the results of the investigations and the analyses, a comprehensive map, clearly showing the proper drought risk prone areas of the Zone, and as well as the level of its severity were produced. Accordingly, it has been possible to draw the following major themes from the long processes of the study.

- Based on the analysis of the six indices given above a comprehensive maps were produced which clearly demonstrating the major drought risk prone areas and drought severity level in West Hararghe Zone, eastern Ethiopia.
- As described from the results of indices there is a dramatic destructions in water supply, Aridification and an increase in coverage areas or intensifications of drought from year to year in the last two decades.
- The indices, were found to be good indicators of the occurrence of drought and to draw its severity level based on, Geographic Information System (GIS) which were effective in providing information regarding climate change patterns and its impacts on the natural environment.
- The results from all these indices and field survey analysis clearly reveals that the study area is seriously faced with severe drought and sinks of rainfall from the normal condition which resulted in possible and drastic failures in surface water and water well yield reduction or drying.

- Results from the ground based experiences and responses of the local informants and discussants have been found to be fairly congruent with the GIS based index derived data analysis results and shows clearly that the drought affects above 60% average percentages of water supply as a whole in the study area. Furthermore, survey analysis shows that above 50% of water supply wells were dried in this zone in which about 70% of domestic water supply source is groundwater.
- NDVI, results shows that, severe drought expands from 2,983.2 km^2 (17.18%) to 5,012.34 km^2 (28.87%) areas in the zone in 2000 and 2021 years respectively.
- NDWI, results also shows that, severe drought expands from 2,867.16 km^2 (26.35%) to 6,526.79 km^2 (40.77%) areas in the zone from 2000 to 2021 years respectively.
- Analysis from LST shows that, severe drought expands from 2,831.0 km^2 (16.3%) to 6,156.85 km^2 (37.8%) areas in the zone from 2000 to 2021 years respectively, furthermore VHI shows severe drought coverage area scale up from 2,767.15 km^2 (16.79%) to 6,126.79 km^2 (40.7%) and drought severity from VCI analysis ranges from 2,567.15 km^2 (16.35%) to 6,225.70 km^2 (41.77%) areas in the zone from 2000 to 2021 years respectively.
- Analysis from NDVI, LST, VHI, VCI and NDWI indices shows that average areas of: 2,803.13 km^2, 3,528.95 km2 and 6,009.69 km2 represents severe drought in 2000, 2010 and 2021 respectively in the study area.
- There is a pendulum deviation of rainfall from the normal condition and shows the value of SPI below -1.5 and below -2 which represents severely dry and extreme dry conditions; especially in the years; 2,000 to 2007 and 2018 to 2019 respectively and this failures in rainfall becomes changed over time and shows seasonal fluctuation and extreme dry conditions as identified from field survey sample districts in the study areas.

5.2. Recommendations

As has been shown in the conclusion section, the study has revealed considerable valid truths about on drought effects on water supply and the prevalence of various levels of drought risk in the different parts of West Hararghe Zone. It is anticipated, therefore, that some of these findings can be beneficial for different individuals and groups with varied interests.

- ✓ The comprehensive master map, composed from the drought severity maps from indices are clearly delineating the major drought prone areas of West Hararghe Zone, which can be used as a reliable guide for concerned decision makers, development planners and professional field activists, on where and when to embark on for the campaign to combat the severe water supply drought problems of the Zone.
- ✓ The recurrence pattern and frequency of the local water supply problems, underlined in the discussion of the results, and described from the index analysis can remind the concerned local development authorities and field actors on the need to prepare pertinent strategic plan and build appropriate capacity to effectively mitigate the impacts of drought on water supply and ensure the sustainability of reliable water supply in the area.
- ✓ Results of the study and the analyses methods and principles applied, can be used as stepping stones for interested academicians, Scientists and action researchers those undertake other similar works.

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Appendix I: Average Monthly Precipitation Data of Gelemso Station (mm) from Jan, 2000 to Dec, 2021

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
2000	0	0	0	42.19	42.19	36.91	110.2	142.38	52.73	58.01	0	0	474.61
2001	0	5.27	73.83	15.82	68.55	52.73	168.75	226.56	94.92	52.73	10.55	0	669.73
2002	5.27	0	58.01	63.28	21.09	52.73	73.83	89.65	21.09	10.55	21.09	21.09	437.7
2003	5.27	26.37	26.37	73.83	0	21.09	84.38	137.11	42.19	5.27	42.19	42.19	506.25
2004	5.27	0	26.37	26.37	0	15.82	110.74	84.38	58.01	26.37	26.37	26.37	406.05
2005	10.55	5.27	31.64	121.29	142.38	5.27	116.02	47.46	15.82	21.09	0	0	516.8
2006	5.27	42.19	73.83	105.47	36.91	31.64	258.4	142.38	58.01	47.46	36.91	36.91	875.39
2007	10.55	31.64	42.19	84.38	84.38	31.64	179.3	152.93	79.1	36.91	36.91	0	769.92
2008	5.27	0	0	26.37	21.09	26.37	200.39	195.12	84.38	63.28	79.1	0	701.37
2009	52.73	0	26.37	68.55	15.82	47.46	184.57	131.84	84.38	94.92	0	58.01	764.65
2010	0	79.1	100.2	89.65	89.65	94.92	189.84	200.39	121.29	15.82	5.27	5.27	991.41
2011	0	0	15.82	36.91	68.55	47.46	79.1	68.55	15.82	15.82	47.46	0	395.51
2012	0	0	0	110.74	26.37	31.64	205.66	253.12	84.38	5.27	0	5.27	722.46
2013	15.82	0	47.46	121.29	36.91	52.73	247.85	200.39	63.28	52.73	79.1	0	917.58
2014	0	10.55	36.91	63.28	47.46	31.09	152.93	131.84	94.92	131.84	21.09	26.37	738.28
2015	5.27	5.27	15.82	31.64	121.29	152.93	73.83	184.57	63.28	31.64	79.1	31.64	796.29
2016	36.91	26.37	68.55	279.49	131.84	52.73	163.48	184.57	89.65	52.73	47.46	10.55	1144.34
2017	0	26.37	68.55	63.28	158.2	52.73	179.3	216.21	205.66	52.73	42.19	0	1065.23
2018	0	47.46	63.28	200.39	84.38	110.74	84.38	195.12	52.73	58.01	184.57	5.27	1086.33
2019	0	0	47.46	73.83	52.73	100.2	73.83	242.58	226.76	110.74	58.01	63.28	1049.41
2020	0	10.55	31.64	242.58	147.66	131.84	200.39	263.67	216.21	73.83	26.37	73.83	1418.55
2021	5.66	21.09	5.27	179.33	168.86	54.85	175.41	190.57	195.07	107.06	191.6	73.21	1367.98

Source; NMA Monthly precipitation from Jan. 2000 to Dec. 2021 (Represents Gelemso Station)

Appendix II: Average Monthly Precipitation Data of hunde lafto station (mm) from Jan, 2000 to Dec, 2021

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
2000	1.0	5.3	0	42.19	42.19	36.91	100.2	142.38	52.73	58.01	0	0	174.61
2001	0	5.27	73.83	15.82	68.55	52.73	168.75	126.56	94.92	52.73	10.55	0	669.73
2002	6.27	0	58.01	63.28	21.09	52.73	73.83	89.65	21.09	10.55	21.09	21.09	407.7
2003	7.27	26.37	26.37	73.83	0	21.09	84.38	137.11	42.19	5.27	42.19	42.19	506.25
2004	5.27	0	26.37	66.37	0	15.82	110.74	84.38	58.01	26.37	26.37	26.37	436.05
2005	1.65	5.27	31.64	11.29	142.38	5.27	116.02	47.46	15.82	21.09	0	0	516.8
2006	5.27	42.19	73.83	15.47	36.91	31.64	258.4	142.38	58.01	47.46	36.91	36.91	775.39
2007	10.52	31.64	42.19	84.38	84.38	31.64	179.3	152.93	79.1	36.91	36.91	0	969.92
2008	5.28	0	0	26.37	21.09	26.37	220.39	195.12	84.38	63.28	79.1	0	701.38
2009	5.73	0	26.37	68.55	15.82	47.46	194.57	131.84	84.38	94.92	0	58.01	764.65
2010	2.4	79.1	100.2	89.65	89.65	94.92	169.84	200.39	121.29	15.82	5.27	5.27	891.42
2011	0	0	15.82	36.91	8.55	47.46	79.1	68.55	15.82	15.82	47.46	0	495.52
2012	1.9	0	0	10.74	26.37	31.64	205.66	254.12	84.38	5.27	0	5.27	822.46
2013	15.82	0	47.46	121.29	36.91	52.73	247.85	200.39	63.28	52.73	79.1	0	717.58
2014	0	10.55	36.91	3.28	47.46	21.09	152.93	131.84	94.92	131.84	21.09	26.37	838.29
2015	5.27	5.20	15.82	31.64	121.29	152.93	73.83	184.57	63.28	31.64	79.1	31.64	696.28
2016	3.91	26.37	68.55	79.49	131.84	52.73	163.48	184.57	89.65	52.73	47.46	10.55	2144.34
2017	1	6.37	68.55	63.28	158.2	52.73	179.3	316.21	205.66	52.73	42.19	0	2065.34
2018	0	47.46	63.28	20.39	84.38	110.74	84.38	195.12	52.73	58.01	184.57	5.27	3076.33
2019	4	0	47.46	73.83	52.73	100.2	73.83	242.58	226.76	110.74	58.01	63.28	1249.41
2020	0	10.5	31.64	242.58	147.66	131.84	200.39	273.67	216.21	73.83	26.37	73.83	1218.55
2021	5.67	21.11	5.27	279.33	68.86	54.85	475.41	290.57	95.09	17.16	171.12	73.21	2467.87

Source; NMA Monthly precipitation from Jan. 2000 to Dec. 2021 (Represents Hunde Lafto station)

Appendix III: Average Monthly Precipitation Data of Bedesa station (mm) from Jan, 2000 to Dec, 2021

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
2000	0	0	0	0	52.73	0	100.2	142.38	0	58.01	0	0	577.62
2001	0	0	73.83	15.82	94.92	21.09	168.75	126.56	21.09	52.73	10.55	0	687.43
2002	0	0	58.01	21.09	21.09	42.19	73.83	0	42.19	10.55	21.09	21.09	657.79
2003	6.26	26.37	21.09	47.46	42.19	0	84.38	21.09	0	5.27	42.19	42.19	607.28
2004	7.29	0	47.46	36.91	0	15.82	110.74	42.19	58.01	26.37	26.37	26.37	306.05
2005	0	5.27	36.91	63.28	142.38	5.27	116.02	0	15.82	21.09	0	0	516.8
2006	0	42.19	63.28	47.46	36.91	21.09	258.4	142.38	58.01	47.46	36.91	36.91	875.39
2007	10.55	31.64	42.19	36.91	84.38	47.46	15.82	42.19	79.1	36.91	36.91	0	687.43
2008	0	0	0	63.28	21.09	36.91	15.82	68.55	21.09	63.28	79.1	0	657.79
2009	58.73	0	26.37	21.09	15.82	63.28	5.27	21.09	47.46	94.92	0	58.01	607.28
2010	0	79.1	100.2	47.46	89.65	21.09	52.73	121.29	36.91	21.09	5.27	5.27	306.05
2011	0	0	15.82	36.91	68.55	21.09	79.1	15.82	63.28	47.46	47.46	0	395.51
2012	0	0	0	68.55	26.37	47.46	205.66	253.12	21.09	36.91	0	5.27	833.46
2013	5.82	0	47.46	121.29	36.91	36.91	247.85	21.09	52.73	63.28	79.1	0	827.59
2014	0	26.37	36.91	121.29	47.46	63.28	152.93	47.46	21.09	131.84	21.09	26.37	738.28
2015	5.28	21.09	15.82	15.82	121.29	152.93	73.83	36.91	47.46	31.64	79.1	31.64	996.29
2016	7.91	47.46	68.55	253.12	131.84	52.73	163.48	63.28	36.91	52.73	47.46	10.55	395.51
2017	0	36.91	68.55	200.39	158.2	52.73	179.3	216.21	63.28	52.73	42.19	15.82	833.46
2018	0	63.28	63.28	200.39	84.38	110.74	121.29	195.12	121.29	58.01	15.82	21.09	827.59
2019	0	0	47.46	121.29	52.73	100.2	15.82	242.58	15.82	110.74	15.82	47.46	738.28
2020	0	10.55	31.64	15.82	147.66	131.84	253.12	263.67	253.12	73.83	5.27	36.91	2418.55
2021	9.67	21.09	5.27	253.12	168.86	54.85	200.39	190.57	200.39	107.06	52.73	63.28	3167.98

Source; NMA Monthly precipitation from Jan. 2000 to Dec. 2021 (Represents Bedesa station)

Appendix IV: Drought Water Supply Impact Assessment Questionnaire

These questionnaire is to assess the drought severity and its potential impacts on water supply availability. The survey can be completed by placing an 'X' in a circle near to the response(s) which best completes the statement.

1. Specify Drought severity in your districts?
    - No Drought
    - Slight Drought
    - Moderate Drought
    - Severe Drought
2. Identify losses due to drought in your districts and estimate percentage of loss?
    - Agricultural loss
    - Livestock loss
    - Health loss
    - Environmental loss
3. Identify level of water supply affected by drought in your districts?
    - Highly affected
    - Moderately affected
    - Slightly affected
4. What are the main sources of water supply in your districts?
    - Ground water
    - Surface water
    - Others
5. Can you estimate percentage of wells dried because of drought?
    - Below 25 % Wells are dried
    - Between 25 %-50% Wells are dried
    - Above 50 % Wells are dried
6. How do people adapt, to cope up with drought impacts and concerning its mitigation and preparedness?

Sector Name: ______________________________

Sector Representative Signature: ______________

Address: __________________________________

Date: ____________________________________

Appendix V: Informants Opinion on drought in sample districts

In April 2022, one informants in Boke Districts was already saying:

"Over the past two decades, we have lost two months from each rainy season. Now the rain is not coming at the right time: it starts late and finishes early. We were losing our drinking water supply sources because of this shortage of rains. Our women's are keeping all of their activities on finding water supply for domestic use, we go up to 30 km to find drinking water, after we reach there; there may also be the probability of getting no water, because the water may be finished and we stay there for the next day of our chance, so we had injured!…so we had stressed!…so we had suffocated!...Just from water scarcity!...I don't know what tomorrow will bring, but all I do know is that the weather are changing from time to time, our water supply scheme are losing their discharge from time to time and they fall at the wrong time" (Valid interview during field observation, April 2022) (figure 18).

In March 2022, one informants of Gumbi Bordode districts was already saying:

"In West Hararghe, the onset of the drought was seen as a continuation, and intensification, of an existing trend over several years of poor and unpredictable rains"

"Over recent years especially in the past two decades, we have faced with new additional drought season per year! The drought severity we face in this year is more severe than that we was faced in the last year! it becomes more and more severe. We fear now in the future that there may a drought that can make us alive" (Valid interview during field observation, March 2022).

Appendix VI: Photo taken during field observation

Figure 21: Photo shows Loss of Agriculture

(Source: Photo taken during field observation, Boke Woreda, March, 2022), no changes were made to this image.

Figure 22: Photo shows livestock loss.

(Source: Photo taken during field observation, Gumbi Bordode Woreda, March, 2022), no changes were made to this image.

Figure 23: Photo shows people using unprotected surface water, Gumbi Bordode Woreda

(Source: Photo taken during field observation, March, 2022) No changes were made to this image.

Figure 24: Photo shows ground water well water points on the verge of drying and dried surface water reservoir

(Source: Photo taken during field observation, Hawi Gudina Woreda, April, 2022), no changes were made to this image.

Figure 25: Shows Water Supply Stress in Boke Districts

(Source: Photo taken during field observation, Boke districts, April, 2022), no changes were made to this image.