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IDENTIFYING WATER-STRESSED AREAS USING GEOGRAPHICAL INFORMATION SYSTEMS AND REMOTE SENSING IN BAHI DISTRICT

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IDENTIFYING WATER-STRESSED AREAS USING GEOGRAPHICAL INFORMATION SYSTEMS AND REMOTE SENSING IN BAHI DISTRICT

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A Dissertation Submitted to the Department of Geospatial Sciences and Technology in Partially Fulfilment of the Requirements for the Award of Science in Geomatics (BSc. GM) of Ardhi University

CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Ardhi University dissertation titled **"Assessment of marine sediment concentration, a case study of Dar es Salaam Cost"** in partial fulfillment of the requirements for the award of degree of Bachelor of Science in Geomatics at Ardhi University.

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Date……………………

DECLARATION AND COPYRIGHT

I, SHAO EDWARD YONA hereby declare that, the contents of this dissertation are the results of my own findings through my study and investigation, and to the best of my knowledge they have not been presented anywhere else as a dissertation for diploma, degree or any similar academic award in any institution of higher learning.

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SHAO EDWARD YONA

22709/ T.2019

Date_________________

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DEDICATION

I dedicate this dissertation to my beloved family; my parents Mr & Mrs Yona U. Shao and Judika K. Tesha, who have raised and educated me since I was a child to become the person I am today. I am grateful for everything they have done for me. They have my undying love and gratitude, and I will never be able to express how much I value and love Them. To my wife Jackline B. Francis, I am grateful for everything she has done for me. To my son Samweli, Gift, Witness and Jeni. To my brothers and Sisters George, Stewart, Saimoni, Wolter, Gasper, Vicktoria and Haika. They are presence always makes me motivated and determined.

ABSTRACT

The main purpose of this study is to identify water-stressed areas as a response to climate variability, aridity, and water exploitation in Bahi District using Geographical Information Systems (GIS) and Remote Sensing (RS). In order to do this, the study set out to determine three things: the district's climate variability, the district's use of surface water (for irrigation), and the locations that ought to be classified as water-stressed areas. The study employed indices that can track climate variability and surface water supplies out of the myriad indices used to calculate water - stress. As a result, the Enric Aridity Index (Im) and the Water Exploitation Index (WEI) were used to calculate the district's aridity and population water exploitation, respectively. The TerraClimate website provided reanalysis weather station data, and the National Bureau of Statistics provided the Irrigation data. The arid, semi-arid, and semi-humid zones are the three primary climatic regions of the Bahi District, according to Im. According to the results, drier regions should experience more water - stress than wetter ones. However, as it will be more difficult to regulate water exploitation, particularly in arid regions, highly inhabited places will contribute more to water - stress.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF EQUATIONS

ACRONYMS AND ABBREVIATIONS

AI	Aridity Index
COWSOs	Community Owned Water Supply Organizations
DUWASA	Dodoma Urban Water Supply and Sanitation Authority
GIS	Geographic Information System
LGA's	Local Government Authorities
NGO's	Non-governmental Organization
RS	Remote Sensing
SDGs	Sustainable Development Goals
USGS	United States Geological Survey
WEI	Water Exploitation Index

CHAPTER ONE

INTRODUCTION

1.1 Background

When there is a long-term imbalance between supply and demand for water, it is said to be under water-stress. It is also known as the inability to supply enough water for ecological and human demands. Population growth affects water demand, whereas the types of water resources accessible, the availability of infrastructure, and the health of the ecosystem affect water supply. A few signs of water - stress are plant water content, soil moisture, surface and ground water resources, or climate factors (Meerganz von Medeazza, 2021).

Understanding the features of water challenged places is crucial in identification and assessment for fair consumption, accessibility, and availability in water management. Water availability and dem are the key determinants of water - stress, while high water extraction, aridity, and the severity of drought are the main causes of water - stress. Arid regions are constantly dry, making them vulnerable to droughts that restrict the amount of renewable water, causing scarcity at first and later water - stress as a result of rising demand out pacing supply (Klemas & Pieterse, 2015).

Climate change and variability have the potential to impose additional pressures on water availability, water accessibility and water demand in Africa. Large and increasing population in general and growing urban population in particular, exacerbated by the effects of drought, have implication to water availability or accessibility especially in African countries. Within the next few years and response to population growth, domestic and municipal water usage will increase significantly, putting even more pressure on existing water sources, this situation implies that prudent water management should high in the agenda of African policy makers. This situation affected the health and education of the population of living in these areas. (Schewe et al., 2014). The United Republic of Tanzania 1991 National Water Policy set a goal of providing clean and safe water to the population within 400 meters of their households. The History of Dodoma town is traced back to 1973 when it was declared the National Capital under Presidential decree No. 320 of 1973. Since then, a series of successful events have followed. In 1995 the Government shifted parliamentary activities to Dodoma and has recently declared the town to be a centre of education.

Dodoma is among the fast-growing cities in Tanzania; the reason accounting for this speed is the shifting of the capital functions from Dar es Salaam to Dodoma. The establishment of Dodoma as a capital city was conceived some decades ago, but it came into reality in 2015 when the government of the United Republic of Tanzania, under the leadership of his Late Excellency Dr. John Pombe Magufuli, deliberately implement this idea (Bilolo, M., & Ndunguru, 2020). Shifting of capital functions has been in combination with shifting of people, capitals/assets and investment opportunities, which have resulted to rapid population growth and expansion of the city that created more demand for water, land, social services and increase of waste production. Shifting of capital functions to Dodoma it also results to the Bahi District That has been exacerbated by population growth and increasing human pressure on natural resources which has been subject to low and erratic rainfall, leading to frequent drought and water demand.

There are several Indices used to compute water-stressed areas such as, first is the Enric Aridity Index (Im). Using the formula proposed by de Enric (1996) that uses the annual precipitation (Pa) and annual maximum temperature (Tmax) which classify the absolute aridity, arid, semi-arid and semi-humid. Enric suggests an alternative strategy to the one de Martonne first suggested. After establishing climate conditions of each area within the district it becomes easy to determine which ones are prone to drought events. The standardised precipitation evapotranspiration index (SPEI) was used to measure drought severity. Potential evapotranspiration (PET) values were computed using MS Excel spreadsheets. Water balance was evaluated as a difference between precipitation and Potential evapotranspiration (PET) which is used in evaluating water exploitation index. The Local Water Exploitation Index (LWEI) was used to measure the impact of population on water resources. Used to determine water Demands on both Domestic Water Demand (DWD) based on population Density and Agriculture Water Demand (AWD) based on irrigated lands. Whereas water-stressed classification is found. Other approaches, like the Standardized Precipitation Index (SPI), use rainfall alone to assess if a region is experiencing water - stress (Luus et al., 2022).

Infrastructures for irrigation, groups representing water users, community water rights, and appropriate land management for agriculture. There are currently 8 mechanized irrigation schemes (Bahi Sokoni, Nguvumali, Mtazamo, Uhelela, Chikopelo, Mtitaa, Chipanga, and Lubala drip irrigation) found in the Council, in addition to 6 traditional irrigation schemes (Bahi Makulu, Nagulo Bahi, Matajira, Chali, Mkakatika, and Kongogo). A few examples of crops grown with irrigation are horticulture crops, grapes, and rice. (Bilolo, M., & Ndunguru, 2020).

1.2 Statement of research problem

In Tanzania, 42% of rural families and 85% of urban households have access to improved water supplies (Mackay, M., & Mwangoka, 2021). This implies that 58% of rural families and 15% of urban households are facing water-stressed problem. Arid and semi-arid areas like Dodoma Region are more affected by this water-stress. This study entails identification of the water-stressed areas in Bahi District using Remote Sensing (RS) and Geographical Information System (GIS) which can later be used to inform/ help in developing strategies to adapt to water-stressed periods and improve accessibility to water and sanitation services as advised in National and World Sustainable Development goals (SDGs).

1.3 Objectives of the study

1.3.1 Main objective

- To identify water-stressed areas due to severity, aridity, and water exploitation in Bahi District using GIS and Remote Sensing techniques.

1.3.2 Specific objectives

- To analyze average rainfall and temperature from 2001-2022 in Bahi District
- To identify water-stressed areas within the district based on aridity, drought severity and water exploitation using the water indices such as Enric Aridity Index (Im), Potential Evapotranspiration (PET) and Water Exploitation Index (WEI).

1.4 Research questions

Completion of this research will answer the following questions.

(i) What is the trend of average rainfall and temperature in Bahi District from 2001 to 2022?

(ii) How Enric Aridity Index (Im), Potential Evapotranspiration (PET) and Water Exploitation Index (WEI) used in identification of water - stressed areas from a given Landscape?

1.5 Significance of the research

The use of GIS and remote sensing research to identify water-stressed areas is important for a variety of reasons. It allows for a comprehensive view of the current water availability situation, allowing for the identification of areas that have the greatest need for water resources. This can be especially useful for the planning and management of water resources, as well as for assessing the potential long-term impacts of climate change. Second, GIS and remote sensing research can provide detailed insights into the physical characteristics of water-stressed areas, such as soil type, topography, and vegetation, which can help inform decisions about water conservation and management.

1.6 Beneficiaries of the research

GIS and remote sensing are valuable tools in identifying water-stressed areas and informing policy makers. By using GIS and remote sensing, policy makers can gain a better understanding of the geographic locations of water-stressed areas and the extent of the water scarcity. This will help them to better plan and develop strategies to address water stress.

1.7 Scope and limitation of the research

This research is limited to the use of GIS and Remote Sensing in identifying water-stressed areas. Other methods of identification, such as field surveys, direct observation, and hydrological modelling, are not included in this research. Additionally, the research is limited to identifying water-stressed areas within the geographical boundaries of a specific region or country.

1.8 Dissertation structure

Divided into five (5) chapters that explain the modelling and prediction.

Chapter one

It provides an overview of the research, the problem statement, the main and specific objectives that give an overview of the research findings, significance, beneficiaries, scope and limitation, and the research questions derived from specific objectives.

Chapter two

Literature review includes information on aridity indices and water exploitation. The review in this chapter gives a brief description of the methods applied to yield estimation in earlier investigations.

Chapter three

Includes a summary of the methods used to accomplish the study's goals as well as a flow diagram that illustrates the entire procedure.

Chapter four

This chapter on the findings, analysis, and discussion offers a strategy for fulfilling the study's goals.

Chapter five

The recommendations and findings are included in this chapter. It concludes with recommendations based on the research's findings and the study's aims.

CHAPTER TWO
LITERATURE REVIEW

2.1 Overview

Water-stress is a term used to describe an area where the demand for water is greater than the available supply. On the demand side, the vast majority roughly 70% of the world's freshwater is used for agriculture, while the rest is divided between industrial (19%) and domestic uses (11%), including for drinking. On the supply side, sources include surface waters, such as rivers, lakes, and reservoirs, as well as groundwater, accessed through aquifers (Le Blanc, D., & Perez, 2018).

Factors for identifying water-stressed areas using GIS and Remote Sensing are as follows Evapotranspiration is a process in which water is lost from the soil and vegetation due to evaporation and transpiration. Precipitation is the process where the amount of rain received and its distribution in the area will help determine the water availability. Land Use/Land Cover changes in different landscapes can affect the water availability and stress levels in an area. Soil Moisture the amount of water available in soil affects the water availability in an area and can be used to identify water-stressed areas. Water Bodies such as rivers, lakes and streams also play an important role in determining the water availability in an area. Remote sensing and GIS can be used to identify the location and extent of these water bodies (Malunda, 2019).

2.2 Backgrounds of water - stress

Short-term variations in climate variables like temperature, solar radiation, evapotranspiration, and rainfall are referred to as climate variability. It has a negative effect on the socio-economic status of a society, threatens food security, water resources, and biodiversity protection. While climate change is more gradual over a longer time span, it experiences brief fluctuations on a multi-seasonal time scale. Even though this demonstrates the diversity of climate events, the long-term average might not be impacted. These brief shifts in the climate have a significant impact that cannot be disregarded (Oluwaseyi, 2018).

Both high and low rainfall areas experience drought. Therefore, a region's climate could be classified as either humid or arid depending on the amount of moisture present. If a place receives little rainfall frequently or has less moisture, it is considered to be arid. While droughts can occur in humid regions as well, because of their dry conditions, arid regions are more susceptible to them. A population that frequently endures dry periods and lives in arid conditions will probably overuse water resources in an effort to cope with the effects of drought. Water - stress will therefore be a result of this ongoing misuse of water supplies (Dubey & Singh, 2017).

2.3 Water Resources in Bahi District

According to the Water Resources Management Authority of Tanzania, the water resources in Bahi District are plentiful and diverse. The district's resources include rivers, springs, wetlands, lakes, and groundwater. The Bahi River is the main water resource in the district, with other rivers such as the Nkunguru, Mhumba, and Kilombero also contributing to the district's water supply. Groundwater is also abundant in Bahi District, with several aquifers located in the area. The district is also home to several wetlands, including the Mhumba Wetland Reserve and the Kilombero Wetland Reserve. This is according to Water Resources Management Authority of Tanzania.

2.3.1 Salt-water resources in Bahi District

Salt-water resources in Bahi District, Tanzania include Lake Manyara, which lies on the edge of the district. The lake is a major source of salt-water for the district and provides a wide range of fishing opportunities for the local communities. Additionally, the district also has numerous salt-water springs that feed into nearby rivers and streams. These springs provide drinking water for the local communities as well as a source of salt-water for irrigation and other purposes (Ma et al., 2018).

2.3.2 Fresh-water resources in Bahi District

According to the Tanzania Water Resources Management Authority (TWRA), water resources in Bahi District, Tanzania, include rivers, springs, wells, and dams. Major rivers in the area are the Kilombero, Zombe, and Kilosa rivers, and the main springs are located in the village of Mzimu. The district also has several dams and over 500 wells, providing access to clean water for thousands of people. This is according to Tanzania Water Resources Management Authority.

2.3.3 Groundwater resources in Bahi District

According to a report by the United Nations Environment Programme (UNEP), the Bahi district in Tanzania has approximately 1.14 million cubic metres of groundwater available for use every year. This water is mostly used for domestic purposes, as well as for livestock and agricultural purposes. The groundwater resources of Bahi district are not yet fully exploited and have the potential to provide additional water supplies for the region. The report also states that climate change is expected to have a significant impact on the availability of groundwater resources in the region. The availability and utilization of groundwater resources in Bahi District, Tanzania were studied using a combination of field techniques, laboratory analysis and numerical modeling (Tano, 2017). Groundwater samples from 12 wells were collected and analyzed for a range of physical, chemical and biological parameters. The results indicated that the groundwater in the area is of good quality and is suitable for domestic use. The results also revealed that the groundwater is mainly of the calcium-chloride type. The numerical modeling study showed that the groundwater in the area is mainly recharged from precipitation and surface runoff. The results indicated that the groundwater resources in the area are adequate for domestic use and future development plans.

2.3.4 Surface water resources in Bahi District

According to a study conducted in 2019, the amount of surface water resources in Bahi District, Tanzania was estimated to be 158.2 million cubic meters per year. This data was based on the results of a hydrological survey of the district. The study also noted that the surface water resources are mainly used for domestic consumption, livestock, and irrigation (Mwegelo et al.,2019). The study concluded that the water resources in the district are adequate to meet the current and future needs of the communities living there.

2.4 Pressure on surface water resources in Bahi District

Prior research has tracked the effects of water - stress in a variety of settings, including soil moisture, vegetation, surface, groundwater, and rainfall deficit. The concept that drought, abstraction, or even aridity are the primary causes of water - stress has been used in the majority of studies on the topic. They came to the conclusion that, regardless of the subject of the study, climate fluctuations, particularly drought, are the primary cause of water - stress (Reed, 2019). Resources for ground water and surface water are both beneficial for meeting all human needs. This does not negate the fact that rainfall serves other purposes for people. As a result, a decrease in rainfall may also be referred to as "water - stress." Water - stress is a two-word idea that combines stress and water. Water demand is the action of making water less available. This makes evapotranspiration a stressor for both rainwater and surface water supplies, according to some experts. It is possible to say that water - stress has happened in this situation. In other instances, climate change and abstraction have contributed to the depletion of water supplies. In the context of this study, water - stress is understood as a result of decreasing surface water owing to climate change and population water demand. In dry areas with more frequent droughts, this process is more prominent (Smith, 2020).

2.5 Causes of water - stress in Bahi District

Low rainfall occurrences, racial tensions, political breakdowns, a lack of physical resources, rapid population development, and a sluggish economy are all blamed for difficulties with managing water resources in Bahi District. Aridity, drought brought on by climate change, abstraction, population growth, and the implementation of policies for the management of water resources are only a few of the factors (Francis, 2020).Due to the many ways that each of these elements affect water supplies, each has a specific function within the ecosystem. To be able to develop potential solutions to water - stress, it is crucial to investigate how each of these elements' influences water resources.

2.6 The role of climate change to influencing water-stress

The main factors contributing to climate change that have an impact on water supplies are precipitation, temperature, and evapotranspiration. According to the global assessment of water resources, climate change and population growth projections would put stress on water supplies globally. The equilibrium between water demand and supply will eventually be impacted by the rise in temperature and decline in precipitation. It is anticipated that regional climate change would increase the frequency of both floods and drought in some regions. Additionally, this will result in aridification of the land due to a decrease in the amount of soil moisture, anticipated rainfall, and severe agricultural dryness (Adams, B. and Peck, 2018).

2.6.1 The role of abstraction to influencing water-stress

The definition of abstraction is the removal of water for ecological purposes. Evapotranspiration, which is the result of the interaction of climate and water resources, and human water extraction for domestic, industrial, or agricultural use are both examples of abstraction (Vorosmarty, C. J et al., 2018). As a result, abstraction rates will change as the population and climate change.

2.6.2 The role of policy to influencing water-stress

The role of policy in Tanzania to address water - stressed areas is to provide access to safe and reliable water for all. This includes enhancing water resource management, improving service delivery, and developing sustainable water resources. According to the Ministry of Water, "The Government of Tanzania has adopted several policy initiatives to improve access to safe and reliable water for all in Tanzania. These initiatives include the Water Sector Development Program (WSDP) and the Water Resources Management Plan (WRMP)" (Ministry of Water, 2017). The WSDP focuses on improving access to safe and reliable water, while the WRMP aims to ensure that water resources are managed in a sustainable manner.

2.6.3 The role of population growth rate to influencing water-stress

Population growth rate is one of the main causes of water - stress in Tanzania. According to a study by the Tanzanian Ministry of Water, the population of Tanzania has grown by 2.4% annually, resulting in a doubling of the population in the past 30 years. This population growth has led to an exponential increase in water demand, far outstripping the current supply of water resources and resulting in water scarcity in some areas. The study also found that, due to limited access to safe drinking water, over two-thirds of Tanzanians are exposed to water-borne diseases which can have severe impacts on the health of individuals and communities in water - stressed areas.

2.7 Impact of water - stress in Tanzania

The impacts of water - stress in Tanzania are varied and far-reaching, ranging from decreased crop production to an increased risk of waterborne diseases. In a study conducted by the World Bank, it was found that water - stress is a major contributing factor to poverty in Tanzania, with an estimated 31.6% of the population living below the poverty line (Madulu, 2013).

This is due to the fact that water scarcity has a direct impact on the availability of food and the ability of people to access clean drinking water, both of which are essential for human health and wellbeing. In addition, water scarcity can lead to an increase in water-related diseases, such as diarrhea, cholera, and malaria, which can further exacerbate the poverty cycle.

2.8 The impact of water - stress in Bahi District

Water - stress in Bahi District of Tanzania has severe impacts on the livelihoods of people living in the area. It has been found that water scarcity in this region has caused a decrease in crop production, resulting in a decrease in food security and income levels. Additionally, water scarcity has led to an increase in water-related diseases such as diarrhoea, cholera and typhoid (Kauhala at el., 2017). Furthermore, water scarcity has led to a decrease in access to safe drinking water, which has caused an increase in water-borne diseases.

2.9 Indices used to monitor water - stress

There are various types of water - stress. It can be observed in the water content of vegetation, the depletion of water supplies, and a decrease in precipitation amount, which is also referred to as drought. Climate change is frequently to blame for these circumstances (Białowiec et al., 2019). Land becomes dryer as a result of climate change, which leads to regular instances of water scarcity. As a result, in order to monitor water - stress, it is important to take into account the state of the climate and how extreme weather occurrences and abstraction are related.

2.9.1 Indices used to Determine climate condition

There are various climate indices that are used to determine the climate of a specific area. These includes the de Martonne aridity index (MA), the Köppen and Geirge (KG), the enrich index (AI), and the UNEP index (AI) to mention a few.

2.9.2 De Martonne Aridity Index (MA)

This index was first developed by Emmanuel de Martonne in 1926 to precisely evaluate a climate's aridity-humidity. The study examined the regional fluctuations of temperature and precipitation and found that precipitation was more prevalent near the equator and temperature was more prevalent at higher latitudes (de Martonne, 1926). Therefore, combining the temperature in degrees Celsius and the amount of precipitation in millimeters was the most accurate approach to depict the climate.

Divides the mean annual precipitation (Pam) by the mean annual temperature (Tam) + 10, was considered to be the best way to depict this relationship. In order to prevent negative values for negative temperatures, it was advised to adjust the temperature with a value of 10.

The MA is employed because it can accurately identify climate areas. Some researches claim that if the MA is less than 30, irrigation is required for agricultural reasons in the area. Above 30, precipitation suffices and irrigation techniques are not required. The MA was proven to be successful in detecting climate zones and validating the necessity for irrigation for agricultural practices using the Normalised Difference Vegetation Index (NDVI) (Mavrakis, A. and Papavasileiou, 2013). Because it may be calculated for particular months, the MA is adaptable. This is advantageous since it would be possible to determine which months would require irrigation methods.

The MA has more representations of climatic classes than other approaches, despite the fact that all of these methods are simple to apply and employ readily available data. This indicates that compared to other methods, it has a better likelihood of identifying and differentiating various climatic zones. The MA is superior to the AI since it uses measured temperature data as compared to the AI's estimated ETa data. Because the MA can identify climate zones, it is simple to apply, and it makes use of readily available variables like temperature and precipitation, this study will concentrate on using it to assess the climate of the study area.

Table 2. 1: The Pinna and the de Martonne Aridity Index Classification

De Martonne classification			**Pinna combinative index**	
Classification	MA	Precipitation	**Classification**	PCI
Dry	< 10	<200	**Dry**	<10
Semi-Dry	10 – 19.9	200 – 399.9	**Semi – dry Mediterranean**	10 - 20
Mediterranean	20 – 23.9	400 – 499.9		
Semi-Humid	24 – 27.9	500 – 599.9		
Humid	28 - 34.9	600 – 699.9		
Very Humid	35 – 55	700 – 800		
Extremely-humid	>55	>800		

2.9.3 The Pinna Combinative Aridity Index

The Pinna combinative index (PCI) rather than the MA, in the opinion of Baltas (2007), reflects climatic zones and seasons where irrigation is required better. Dry climates are those with PCI values under 10, and semi-dry Mediterranean climates with traditional Mediterranean vegetation are those with values between 10 and 20. P and T stand for the driest month's mean values of precipitation and air temperature, respectively. The MA and the ratio of precipitation to temperature for the driest month are averaged to create the Pinna Combinative Aridity Index. According to Baltas, (2017), the PCI is superior to the MA since it can distinguish between climate conditions in various places better thanks to the additional variables. MA is more appropriate over the PCI on two points.

i. Compared to the PCI's two classes, it uses six more classes for categorisation.
ii. There was no regional difference in the classification of the climate, despite the Pinna having more input variables. Considering this, the MA has a definite advantage over the PCI, especially because it has more classes (Table 2.1).

Source: (Baltas, 2017). The Standardized Precipitation Index (SPI) and the NDVI are two drought indices that several studies have discovered to correlate with the de Martonne index.

2.9.4 Martonne Aridity Index (MA)

The de Martonne aridity index (MA) was used to classify the climate of the Bahi District. Using the formula proposed by de Martonne (1926) it uses the annual precipitation (Pa) and annual mean temperature (Tam). The MA is an index that works better in areas with temperatures greater than -10 ^{o}C. De Martonne (1926) used 10 as an adjustment value to make sure temperatures less than zero do not cause the results to be negative.

Table 2. 2: De Martonne Classification

Classification	**MA(j)**	**Precipitation (j)**
Dry	< 10	<200
Semi-Dry	10 – 19.9	200 – 399.9
Mediterranean	20 – 23.9	400 – 499.9
Semi-Humid	24 – 27.9	500 – 599.9
Humid	28 - 34.9	600 – 699.9
Very Humid	35 – 55	700 – 800
Extremely-humid	> 55	>800

Source: (Baltas 2017)

The precipitation-based frequencies were representing the expected values, and the observed values were obtained from the frequencies built based on the actual MA classification

2.9.5 UNESCO Aridity Index (AI)

An aridity index (AI) was created by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) and is based only on the ratio between mean annual precipitation and annual evapotranspiration ETa. Aridity cannot be adequately described by precipitation alone. As a result, the temperature starts to play a big role. Using temperature as a foundation, evapotranspiration is estimated. Accordingly, as temperature changes (up or down), ETa does as well (Shen et al., 2013). To estimate Eta, various techniques are utilized. Due to its simplicity and use of straightforward input variables, the Thornthwaite approach has been adopted by certain researchers for this purpose.

Table 2. 3: Classification of the UNESCO Aridity Index

AI	**Classification**
< 0.03	Hyper-arid
0.03 – 0.2	Arid
0.21 – 0.5	Semi-arid
0.5 – 0.65	Dry Sub-humid
>0.65	Humid

Source: (Rohatyn et al., 2018).

A user may utilize either of the current ETa methodologies for a study that employs the UNESCO index, depending on the data that is available.

2.9.6 The Standardised Precipitation Evapotranspiration Index (SPEI)

The advantage of the SPEI over the SPI is that it can compute drought using a variety of climate variables as opposed to just one. Studies comparing the SPEI and SPI indicated that the PET considerably improves the SPEI's performance since it takes into account the balance between precipitation and evaporation (Begueria, at el., 2011). The SPEI is therefore preferred as a substitute approach rather than the SPI, despite the fact that the process is similar. The SPEI's vulnerability stems from its sensitivity to the PET computation method used. The SPEI will function in accordance with the PET method's precision or robustness. Therefore, the SPEI was put forth in order to take evapotranspiration's contribution into account. Drought should be classified using values between -2 and 2, as indicated in Table 2.4.

Table 2. 4: Classification method of the SPI as proposed by McKee et al (1993)

Class	Description
SPI ≥ 2	Extremely wet
1.5 ≤ SPI < 2	Very wet
1 ≤ SPI < 1.5	Moderately wet
-1 ≤ SPI < 1	Near Normal
-1.5 ≤ SPI < -1	Moderate Drought
-2 ≤ SPI < -1.5	Severe Drought
SPI <-2	Extreme Drought

2.9.7 Palmer Drought Severity Index (PDSI)

Using information on temperature and precipitation, the Palmer Drought Severity Index (PDSI) tracks relative dryness. It follows a set formula that ranges from -10 (dry) to +10 (wet). According to Dai (2017), the indicator is based on a combination of supply and demand theory and water balance. This index's measurement of standardized moisture levels for comparison between months and locales serves another use. This indicator works well for predicting prolonged droughts and takes historical events, global warming, and PET into account. Its lack of multi-temporal elements, which makes it challenging to correlate with water resources, is a shortcoming. Studies that compared the SPI to the PDSI found that the SPI was superior because it can accurately pinpoint the beginning and conclusion of a drought event Additionally, it was discovered that the SPI had superior spatial standardization than the PDSI with regard to extreme drought.

2.9.8 The Z-score Index

As a standard variate between each observation and the empirical mean, the Z-score is calculated. Its computation is straightforward, and it has thus far been applied to a single variable (rainfall). However, if several variables could be integrated into a single variable, this index could be utilized with multiple variables with ease. The Z-score has the benefit of not requiring data to fit a particular statistical distribution model in order to function (Wu et al., 2001). However, other studies claimed that the Z-score might not accurately depict drought at shorter time scales. Additionally, in comparison to the SPI, the Z-score is more likely to favor positive values that describe wet circumstances. Other indices, such as the China-z index, could be explored as well. The SPEI is still the best approach, nevertheless, according to numerous researchers. This is based on the fact that it accepts numerous climatic factors as input variables and is multi-temporal.

2.9.9 Measuring water exploitation

Water exploitation can be measured using a number of different techniques. The Local Water Exploitation Index (LWEI), the Water Poverty Index (WPI), and the Water Supply Stress Index (WSSI) are a few examples of these techniques (Brown, 2011).

2.10 Water Poverty Index

The WPI was founded with the goal of assisting decision-makers and empowering underprivileged populations to more fully engage in interventions in the water sector. Adjusted water availability (A), access to clean, safe water (S), and the amount of time needed to obtain domestic water (T) are among the variables. The availability of water, the proportion of clean water, and the amount of time it takes to collect abstracted water are averaged to create the water poverty index. The WPI's level determines how much water is being exploited. As a result, there is less water - stress the greater the WPI (Sullivan, 2012). A strategy using a matrix was suggested to categorize the WPI.

2.10.1 Local Water Exploitation Index (LWEI)

An index that gauge's water exploitation from a particular water source is called the Local Water Exploitation Index (LWEI). This index's goal is to track how susceptible water resources are to climate change and how abstraction affects water bodies (Barbara et al.2014). To compute LWEI, four stages are typically needed. First, determine the different categories of water demand, then calculate the weights to be given to each type, then calculate the present water demand (PWD), and then divide the PWD by the total runoff. Domestic water demand (DWD), industrial water demand (IWD), and agricultural water demand (AWD) are the three categories of water demand that are most common. Water exploitation index presented as a ratio of industrial, domestic and agricultural water demand to total runoff. Values of the WEI are classified from very low water - stress to very high-water - stress (Table 2.5).

Table 2. 5 Classification of water exploitation Index as proposed by the European Agency

Class	Description
<0.2	Very low water - stress
0.2 - 0.4	Low water - stress
0.4 – 0.6	Medium water - stress
0.6 – 0.8	High water - stress
>0.8	Very high-water - stress

Source: (Barbara et al. 2014)

2.10.2 Water Supply Stress Index (WaSSI)

Given that it is calculated as the ratio of water supply to demand (total runoff), WaSSI employs a strategy similar to that of the WEI. The total groundwater supply also includes the watershed, yearly flow accumulations, and upstream water flows. The ability to apply and adapt these two methods to any restrictions or the lack of either of the variables has been demonstrated by numerous researchers (Reilly et al. , 2018). In order to evaluate water availability, all forms of available water are typically added together.

CHAPTER THREE

METHODOLOGY

3.1 Overview

A powerful tool for mapping water resource accessibility, allocating water, creating irrigation plans, and identifying environmental changes brought on by climatic variability is the application of GIS and Remote Sensing. A more efficient method for water management techniques is to use GIS and remote sensing, which have the capacity to combine data from many sources and to identify and understand both climate variability means to analyze average rainfall and temperature from 2001-2022 in Bahi District and to identify water - stressed areas in Bahi District based on water indices. Climate variability factors must be taken into account in order to accurately assess water - stress in a location because arid areas are more vulnerable to drought events than humid areas. Although dry conditions in arid regions increase the frequency of drought events in the area, they may not inevitably cause drought (Chege, S. M, 2020).

Rainfall occurrences must be lower than the region's long-term average rainfall in order for the area to be considered water - stress. Additionally, due to population dynamics (farming, domestic, and industrial water use), abstraction, which is a combination of domestic water demand and agricultural water demand, will exceed the amount of renewable water available and cause water - stress by making it impossible to meet human and ecological needs. This study will make use of GIS and Remote Sensing to assess and map areas facing water-stresses areas problem in Bahi District. The study will make use of various data and go through various stages as detailed in figure 3.1

Determining water demand based on population density and irrigated land was the first step in mapping water exploitation. Then, calculate the amount of renewable water to determine the supply to demand ratio. To account for the real amount of water required to grow the crops, the sorts of crops grown in this area, however, were not taken into account. For the three years under consideration, the same datasets of irrigated lands were used. This indicates that the quantity of water on hand was the only variable.

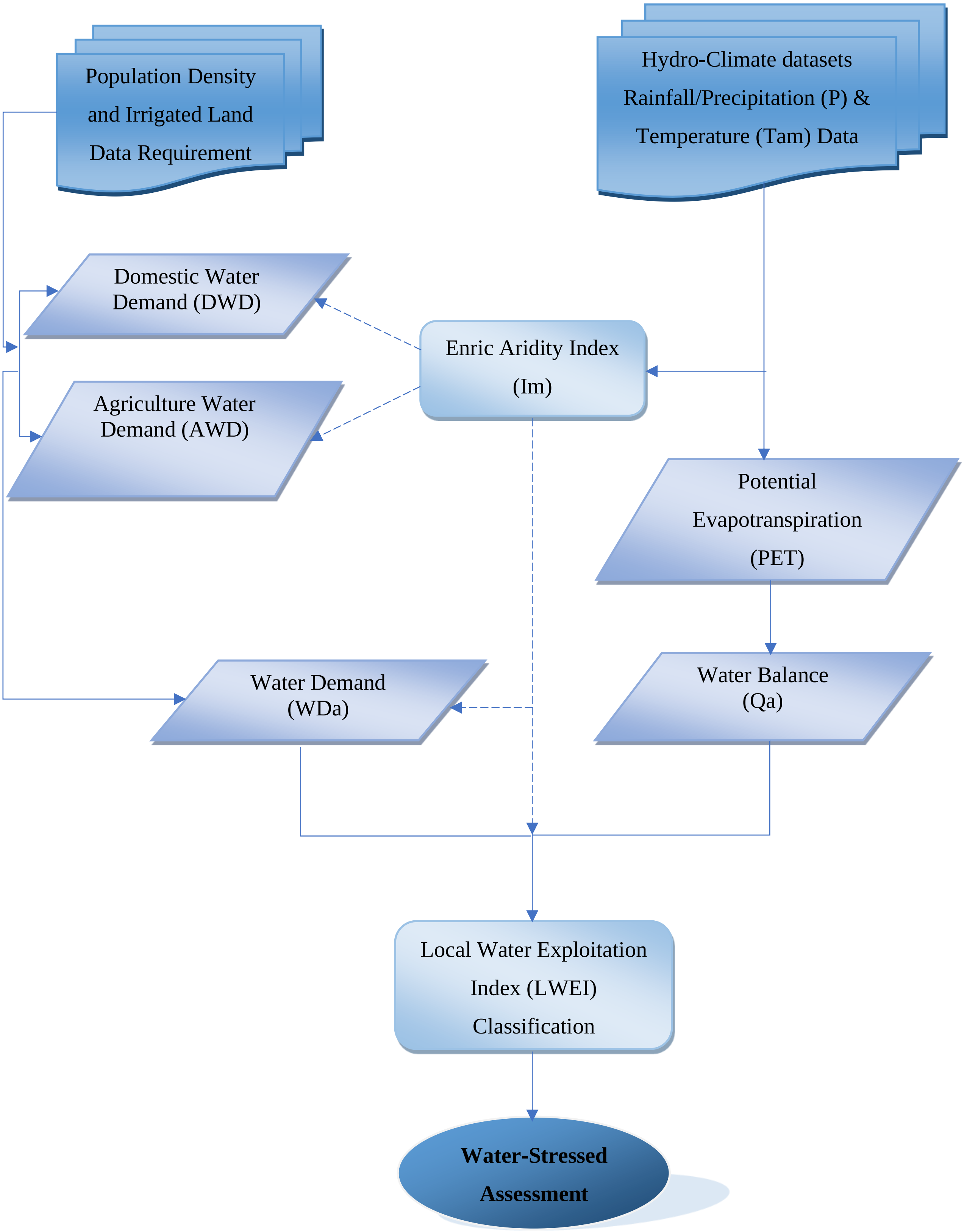

Figure 3.1: Methodology Workflow

3.2 Data collection and desription

The data that utilized in this research are summarized in the table 3.1.

S/N	DATA TYPE	SOURCE	USE	DATA FORMAT	SOFTWARE PACKAGE
1	Rainfall/Precipitation (P)	TerraClimate Web CHIRPS	used to identify the amount of water available and areas with low rainfall, high runoff in a given area.	Raster e.g GeoTIFF, JPEG. And CSV	ArcGIS
2	Temperature (Tam)	TerraClimate Web and MODIS	used to measure evaporative demand and to detect changes in land cover which is an indicator of water availability	HDF, NetCDF and CSV	ENVI and QGIS
3	Population Density and Irrigated Land	National Bureau of Statistics	used to measure population density, areas of irrigated land in wards.	Vector include Shapefiles, GeoJSON files	ArcGIS and QUANTUM QGIS
4	Potential Evapotranspiration (PET)	MODIS	used areas where water resources are likely to be limited due to higher evaporation losses than precipitation returns.	Raster e.g GeoTIFF, ArcGrid and Vector e.g Shapefiles.	ArcGIS and QGIS
5	Administrative Boundaries	ArcGIS And Open Street Map	used in Extraction of the area of interest	Vector e.g Shapefiles.	QGIS

Table 3. 1: Characteristic of research data

3.3 Description of the Study area

Bahi District Council is one of the eight local government authorities of Dodoma region. The District lies in the central plateau of Tanzania between latitude 4°and 8° South and longitudes 35°and 37° East of Greenwich Meridian. (See Figure1). Its altitude stretches between 900 – 1,200 meters above sea level. The District headquarters is Bahi town, which is located about 56 kilometres from Dodoma town. The District Council borders Manyoni District (Singida Region) on the western part, Chemba District in the North, Dodoma Municipal and on the East and Chamwino on the Southwest part.It covers an area of 3,067 km2 and has a population of 322,526 (National Bureau of Statistics, 2022). The district is characterized by a semi-arid climate with a mean annual rainfall of 500-900 mm and a mean annual temperature of 22°C. Bahi district experiences one rain season between November and April. Due to short rainfall duration, heavy water runoff and hence poor water infiltration in the region commonly is leading in terms of less moisture reserve in soils.

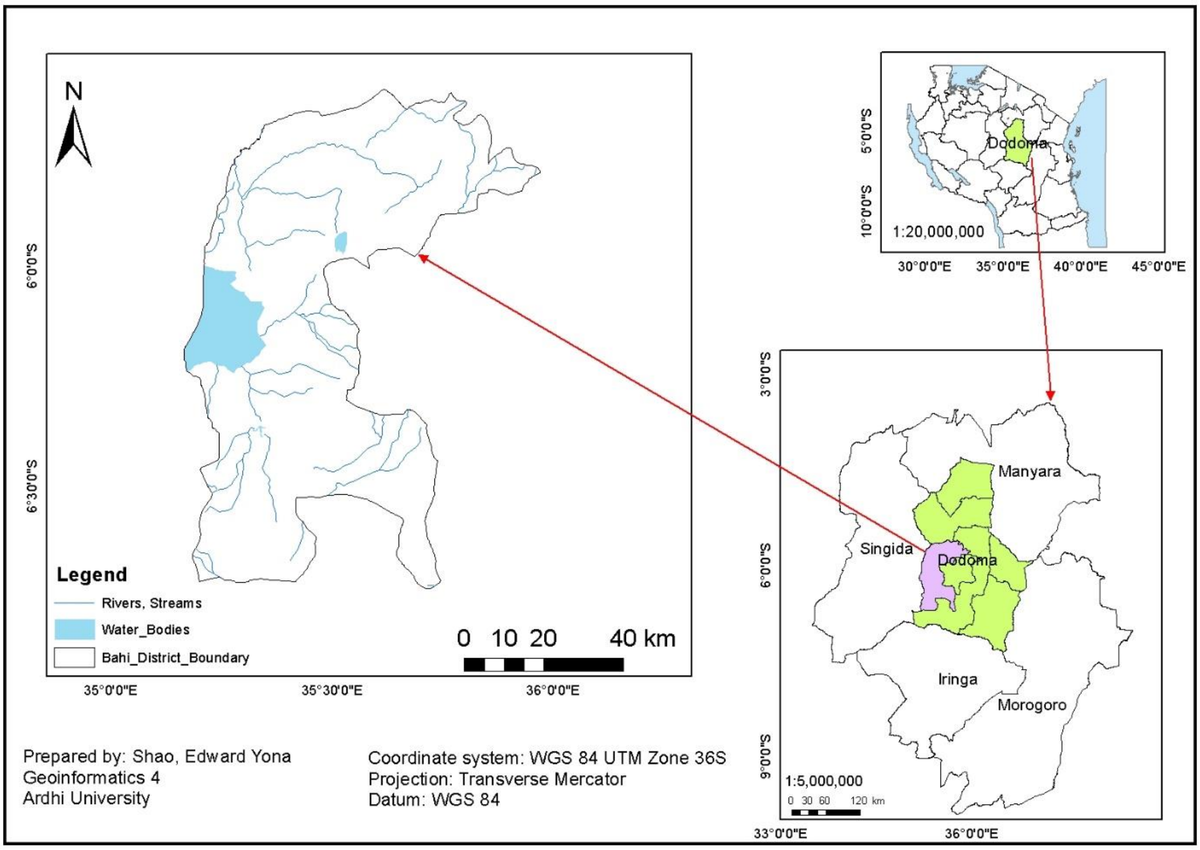

Figure 3.2: Location of Bahi district showing existing water sources in the district and its location in Dodoma region in Tanzania.

3.4 Classification of climate condition of the Bahi District.

Enric suggests an alternative strategy to the one de Martonne first suggested. Instead, according to(Malunda, 2019), Enric recommended that the aridity index be calculated using the ratio of annual mean precipitation (Pam) to annual mean maximum temperature (Tmax).

$$Im = \frac{Pam}{Tmax} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots eq1$$

Equation 1: Enric Aridity Index

Table 3. 2: Aridity Classification as introduced by Enric (1996)

Im	Climate Type	Vegetation Type
< 8	Absolute Aridity	Desert
8 – 15	Arid	Desert –like Steppe
15 – 23	Semi – Arid	Steppe
23 - 40	Semi – humid	Forest
40 – 50	Humid	Humid Forest
>55	Very Humid	Very Humid Forest

Source: (Alam & Iskander 2013)

3.5 Quantifying water balance

The water balance was evaluated as a difference between precipitation and evapotranspiration as the input value to calculate the probabilities. The Potential Evapotranspiration (PET) was estimated using the Thornthwaite' method given by:

$$PET = 16\left(\frac{L}{12}\right)\left(\frac{N}{30}\right)\left(\frac{10Tam}{L}\right)^{\alpha} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eqn\ 2$$

Equation 2: Thornthwaite' PET method

Where L = average day length (hours) of the month being calculated; N = number of days in the month being calculated; Tam = the monthly mean Temperature (°C; if negative, use 0) of the month being calculated.

I = Heat Index and α, the constant.

$$L = \sum_{1}^{12}\left(\frac{Tam}{5}\right)^{1.514} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eqn\ 3$$

$$\alpha = 6.75 * 10^{-7} * L^3 - 7.71 * 10^{-5} * L^2 + 1.792 * 10^{-2} * L + 0.49239 \ldots\ldots\ldots\ldots\ldots\ldots Eqn\ 3$$

Equation 3: Heat Index

For cases when there is no rainfall, the probability of non-exceedance (H(x)) was used to adjust since the inverse normal distribution cannot estimate standard values when the input is zero.

$$H(x) = (1-q)P(x) + q \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eqn\ 4$$

Equation 4: Probability of non-exceedance used to adjust for probabilities when there is no rainfall. These values were computed using MS Excel spreadsheets.

3.6 Measure the impact of population on water bodies

The Local Water Exploitation Index (LWEI) was used to measure the impact of population on water resources. One of the purposes of this index is to monitor vulnerability of water resources under climate change (Barbara *et al.* 2014). Four main steps were taken to compute LWEI including to determine individual water demands, to evaluate water demand, to estimate availability of renewable water and to measure water exploitation index.5

3.6.1 Determine individual water demands

There are two types of water demands in the Bahi, namely, agricultural water demand (AWD), and domestic water demand (DWD). Their respective weights were computed and assigned to each water demand. For DWD, the weight was computed as the ratio of the population in a ward (*p*)to the total population (P) of the Bahi District. For AWD, the weight was computed as the ration of the surface area of Farm (irrigated) lands (F_a) divided by the total District area (M_a) (Barbara *et al.* 2014). Therefore, the respective weights of AWD and DWD becomes:

$$DWDa = \frac{p}{P} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eqn\ 5a$$

$$AWDa = \frac{Fa}{Ma} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eqn\ 5b$$

Equation 5: Individual Water demands weights, [5a] domestic weight based on population density, [5b] agricultural weight based on irrigated lands

3.6.2 Evaluate water demand

Water demand (WD) was evaluated as the sum of DWD and AWD (Equation 6&7). All water data was collected in units of million m^3/month. This data was adjusted to million mm^3/month since the rainfall data is also used in mm/month.

$$WDa = DWDa + AWDa \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eqn\ 6$$

Equation 6: Annual water demand based on the sum of agricultural and domestic water

3.6.3 Estimate availability of renewable water

The amount of renewable water was evaluated using the Thornthwaite water balance (Q) equation between annual precipitation (Pa) and annual evapotranspiration (PETa)

$$Qa = Pa - PETa \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eqn\ 7$$

Equation 7: Water balance model estimated as a difference between annual precipitation and annual evapotranspiration

3.6.4 Measuring water exploitation index

To measure water exploitation in the district, WDa was divided by Qa

$$LWEIa = \frac{WDa}{Qa} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eqn8$$

Where by WDa is Annual Water Demand, Qa is Annual Water Balance and LWEIa is Annual Local water exploitation index. Equation 8: Local water exploitation index estimated as the ration between water demand and water balance. Table 3.3 entails classification of water exploitation indices.

Table 3. 3: Water exploitation index classification

S/No	Class	Description
1	**>0.8**	Very high-water - stress
2	**0.8 - 0.6**	High water - stress
3	**0.6 - 0.4**	Medium water - stress
4	**0.4 - 0.2**	Low water - stress
5	**<0.2**	Very low water - stress

Source: (Barbara *et al.* 2014)

3.7 Classify water - stress level within the district

To identify water - stressed areas within the district, weighted average overlay analysis was used. The three layers namely, Aridity, Drought severity and Water exploitation were used as the input data. Given that the three factors are all contributing to the occurrence of water - stress, and each factor influences the other in one way or another. The first step was to determine weights for each variable.

CHAPTER FOUR

RESULTS, ANALYSIS AND DISCUSSION

4.1 Overview

The results and analysis clarify a path to achieving the research objectives, thus the outputs for the entire study are described in this chapter utilizing maps. The chapter provides a detailed review of the research findings and results through the use of maps for analysis.

4.2 Identifying the best interpolation method

Results showed the IDW as the best method to compute interpolations. While comparing the r^2 and the RMSE between the IDW and the Kriging, it was discovered that the IDW had a better spatial correlation than the Kriging method. In addition, the RMSE was lower for the IDW than that of the Kriging. This implies that, to compute interpolation for the MA, it will be more appropriate to use the IDW. Table 4.1.

Table 4. 1 Accuracy assessment for the IDW and the Kriging interpolation method, including the regression result and the RMSE.

Accuracy Assessment of Interpolated results		
Regression Statistics	**IDW**	**KRIGING**
r^2	0.780972	0.715561
RMSE	1.39162	1.543378
Observations	20	20

The study used ArcGIS software to run interpolations on the index calculated using the adjustment values identified in Table 4.1 above. The study used the IDW to compute the interpolation of the aridity index since it provides a more accurate estimation than the kriging method.

4.3 Present climatic regions in Bahi district

Figure 4.1 includes a rainfall classification, the Enric Aridity Index (Im) classification and Temperature classification. The rainfall map shows two distinct climate regions; the arid and the humid region. This classification agrees with the one presented by the optimized (Im), and matched better the rainfall classes and the index classes as proposed by (Baltas, 2017).

Study found the western part is the Arid region, the central part semi-arid region, and north-east together with south-east the semi-humid zone in the district

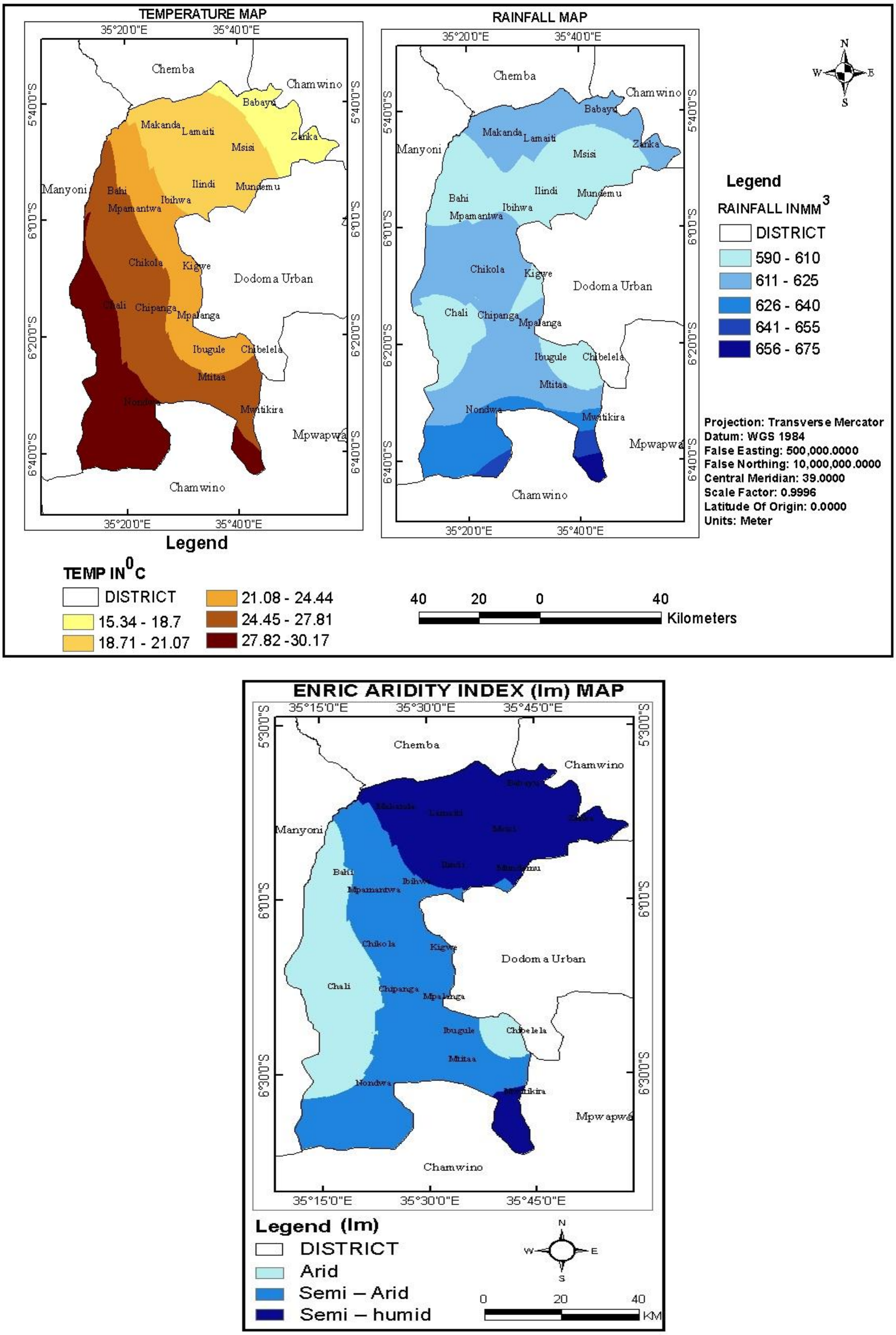

Figure 4.1: Temperature, Rainfall and Enric Aridity Index (Im)

4.4 Present water demand

Water demand was determined as a combination of agricultural water demand (AWD), and domestic water demand (DWD). According to Barbara et al. (2014), the amount of water taken from a water body to supply the population is the standard method for determining water demand. The population without access to piped water is not taken into consideration by this method, though additionally, using weights is worthless if abstraction data is utilized to determine how much water is taken from water resources. Therefore, the study estimated water demand based on the amount of available water in order to be able to account for all water access (legal and illegal). The AWD map included in this study showed that the arid region had a larger water demand than the humid zone.

4.5 Proactive measures to implement

These can include keeping water from the plastic and simtanks containers during raining seasons. Most rural towns that rely on long-distance water transportation have employed this type of water storage (Figure 5.1). Another efficient way of reducing wastage of water is to reduce the time spent in showers like already implemented in Bahi Town. In order to enhance weather monitoring systems that aid farmers in local weather forecasting, the district should also invest in weather stations so as to give its farmers the necessary information given the recent increase in the need to understand climatic variability and how it affects water supplies.

Figure 4.2: Water storing containers during raining seasons

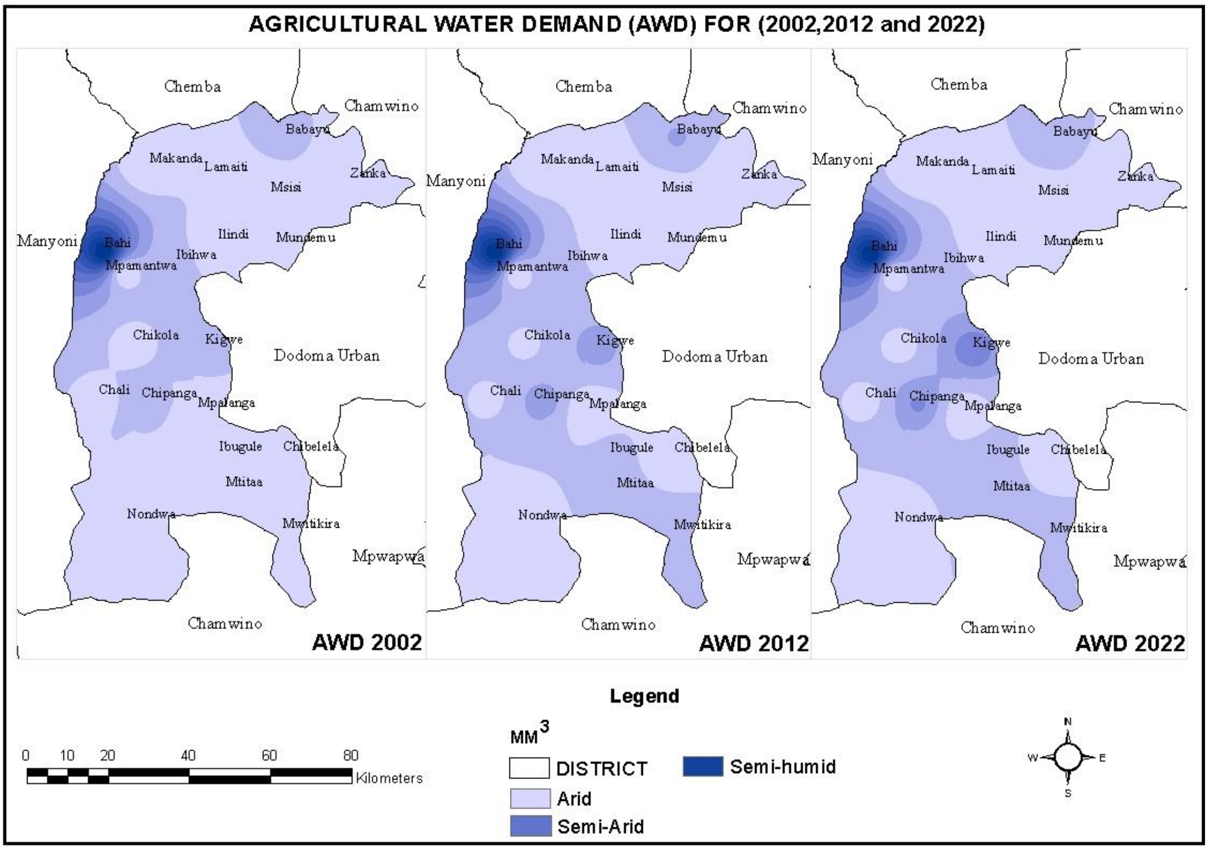

Figure 4.3: Agricultural water demand for the years 2002, 2012 and 2022

This indicates that AWD fluctuated evenly to become higher in the semi-arid zone, and was lower in the semi-humid. (Figure 4.2).

The demand for AWD seems to have been slightly different in 2002 than it had been in the previous two years, where it was significantly lower. This can be likely the result of increased demand and improved water availability. This may appear to be in opposition to the idea that if there is less water available, water - stress will grow. However, water demand in this case is measured as a product of water available to the size of the irrigated land.

Since there are more irrigated lands in the arid region, it makes sense that there is a higher demand from this area. Results, however, indicated that this region had a reduced water demand. This is as a result of the semi-humid region's substantially greater farmland property, which would necessitate more water. Additionally, the assessment of water consumption was based on individual farms, disregarding their proximity and clustering. Consequently, this could be the reason why the arid region had higher demand than the semi-humid region.

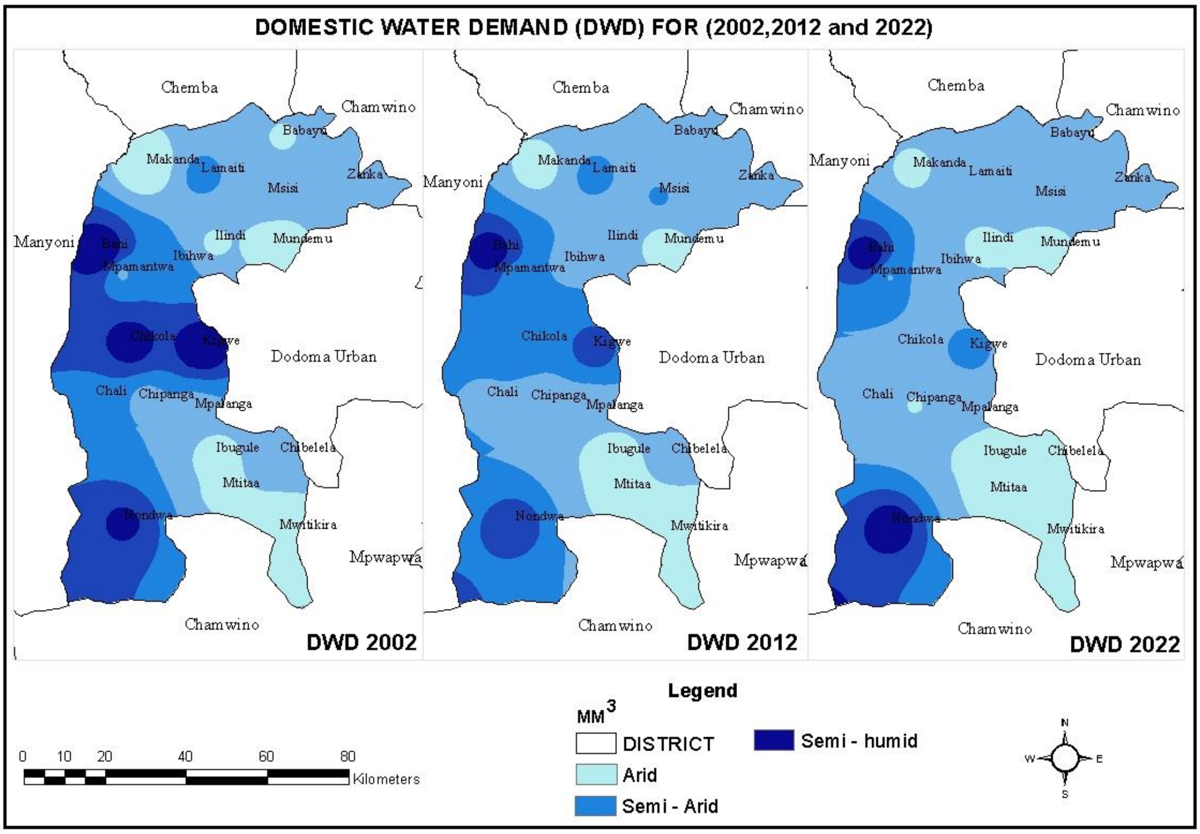

Figure 4.4: Domestic water demand computed as a ratio of population in town to population in district based on the years 2002 - 2022.

Domestic Water Demand (DWD) for the district. The findings show that the arid region had a higher water demand than the toward semi-humid region. Given that DWD was calculated based on population size, the main cause of this increased water demand was not decreasing rainfall as much as it was population size.

Given that the climates in 2012 and 2022 were not similar, it is challenging to infer that the climate played a role based just on the circumstances of a single year. This argument is supported by the fact that only the climate and the amount of water are subject to change between 2012 and 2022, while the population remains constant. Therefore, it may be concluded that the climate variability throughout that time (2002-2022) was the cause of the DWD appearing to be comparable in both years.

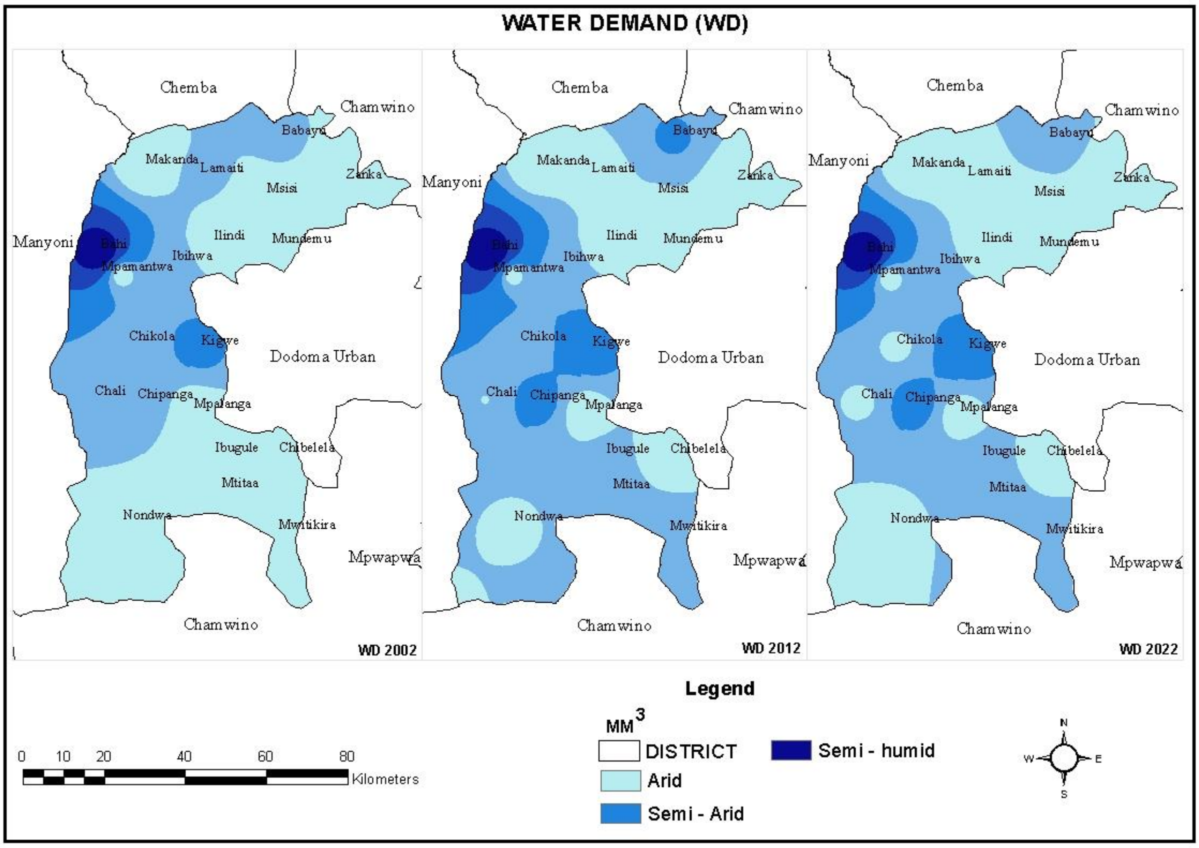

Figure 4.5: Water Demand (WD) in the Bahi District for the years 2002,2012 and 2022 computed as a sum of AWD and DWD

After calculating the three regions' water demands, it was found that the arid region has a higher water demand than either the semi-humid zone. The AWD had a larger demand for the semi-humid regions, and this was influenced by the size of the farms in these regions, according to the results from the AWD and the DWD. While in the DWD, the semi-humid region's higher water demand was determined by its higher population density.

It is important to remember that when rainfall increases, so does the amount of water that is readily available. Because the water exploitation index is calculated based on the year's available water independently of the other years, this subsequently increases the predicted quantity of water demand. Since the method implies that the distribution of the available water is proportional to the population or farm size, if the amount of water grows, water demand will likewise increase (Barbara et al. 2014). This approach needs to be changed since it does not effectively explain water exploitation—according to the rationale, as water resources increase, water exploitation should decrease.

4.6 Identifying water - stressed areas

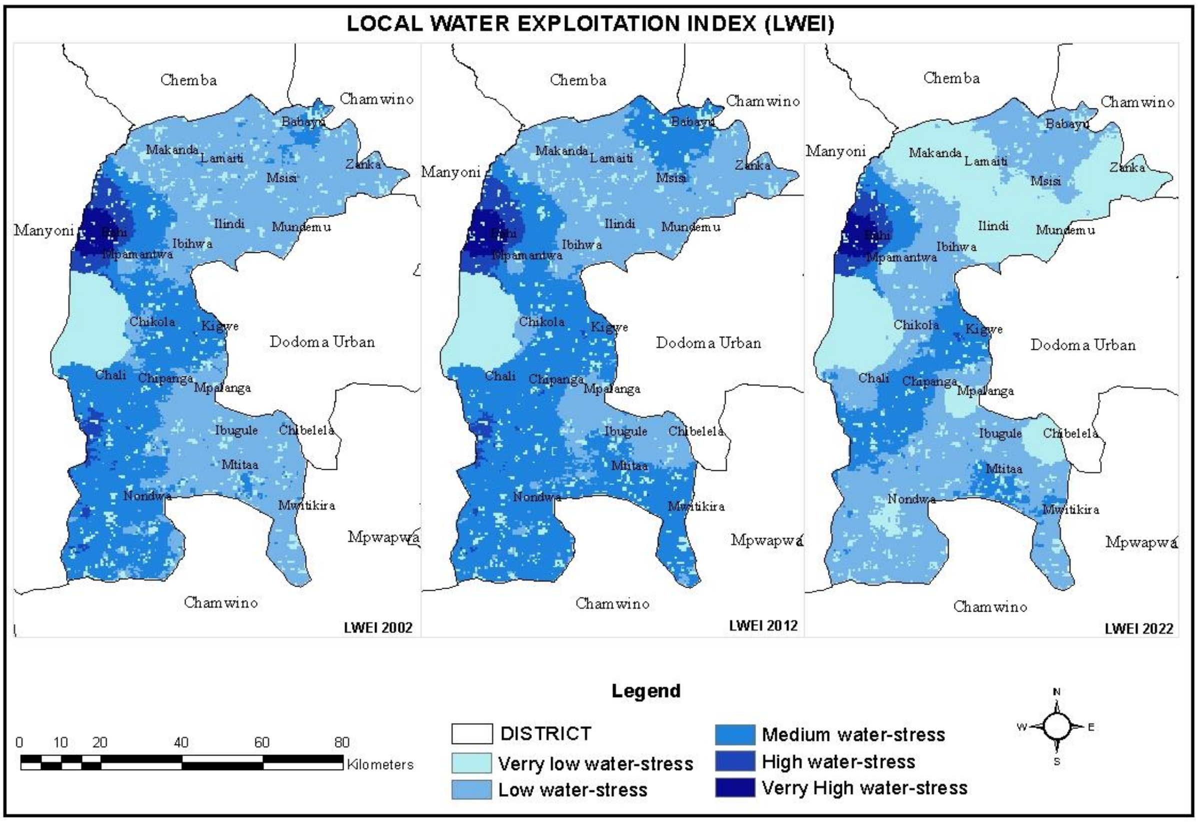

Figure 4.6: Water - stress map of the Bahi District derived based on weighted average of the water demand (WD) and water balance (QA)

Figure 4.5 findings after classifying Local Water Exploitation Index (LWEI) in the Bahi District. A water-stressed area would be the semi-arid region. There are primarily two causes for this circumstance the high population density in towns like Bahi and the regular lesser rainfalls that could not keep up with water demand. However, it seems that during wet conditions, climate variability has a greater impact on the water - stress score. Water - stress was only low in semi-humid zone when rainfall events were frequent. These areas endure high to very high-water - stress when there are droughts. This is unquestionably a result of the population growth that overuses water supplies. As a result of their excessive consumption of water resources, the densely inhabited places described above should be designated as water-stressed areas. Due to its limited rainfall, the arid region must be designated a water-stressed area. The district as a whole appears to be at risk of developing water - stress, despite the fact that the study was able to pinpoint specific sections that are water - stressed regions. particularly if drought events last longer. As a result, it is necessary to regularly monitor droughts because they significantly increase water - stress. Additionally, because they will experience severe water - stress, places with a population density above 5% need to be properly watched.

CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

5.1 Overview

This study's objective was to use GIS and remote sensing to pinpoint regions of the Bahi District that are experiencing water - stress as a result of aridity and water overuse. The study involved categorizing water - stress, monitoring water extraction, and categorizing climate conditions (aridity). Drought tends to occur more frequently in drier locations than in wetter ones, according to statistical and spatial analysis. According to the results, drier regions should experience more water - stress than wetter ones. However, as it will be more difficult to regulate water exploitation, particularly in arid regions, highly inhabited places will contribute more to water - stress.

5.2 Conclusion

- Based on the Temperature and Rainfall in Bahi District study found that average it was within to the range, and the area shows that the both temperature and rainfall is higher in Southern part while moderate on the other parts of the area.

- According to Im, the study found that semi-arid it covers the more than half part of the area. Water-stress tends to be less near the semi-humid zone and higher in the arid region, which are drier locations

- The results can help in water management plans, by effectively conserve and distribute where there is abundant water

5.3 Recommendations

Based on the findings and conclusion of this research, further studies on water-stress other than population size, irrigated land not only this also there is needfully of considerations of surface water bodies (dams), river flow and ground water and available water demand

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