

**INTEGRATED SURFACE WATER RESOURCE
MODELING AND IRRIGATION
PRODUCTIVITY IN LOWER BARO, ETHIOPIA**

Thesis

Submitted in partial fulfilment of the requirement for the Degree of

DOCTOR OF PHILOSOPHY

by

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DEPARTMENT OF WATER RESOURCES AND OCEAN

ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY KARNATAKA

SURATHKAL, MANGALORE – 575 025

MARCH 2024

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MARCH 2024**

DECLARATION

By the Ph.D. Research Scholar

I hereby declare that the research Thesis entitled “**Integrated Surface Water Resource Modeling and Irrigation Productivity in Lower Boro, Ethiopia**”, which is being submitted to the **National Institute of Technology, Karnataka, Surathkal** in the partial fulfillment of the requirements for the award of the degree of **Doctor of Philosophy** in the **Department of Water Resources and Ocean Engineering**, is a *bonafide report of the research work carried out by me*. The material contained in this Research Thesis has not been submitted to any University or Institute for the award of any degree.



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Date: 27-03-2024

CERTIFICATE

This is to *certify* that the Research Thesis entitled “**Integrated Surface Water Resource Modeling and Irrigation Productivity in Lower Baro, Ethiopia**”, submitted by FISEHA BEFIKADU DENEKE (Register Number: 197086197AM003) as the record research work carried out by him, *is accepted as the Research Thesis submission* in the partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy**.

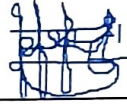


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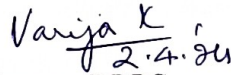
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ABSTRACT

The management of surface water resources is hampered in many river basins by a lack of data. The problem is for several of Ethiopia's river basins increasing the productivity of surface irrigation and scientifically understanding the factors that led to integrated surface water modeling, particularly in Ethiopia's lower Baro is useful. The objectives of this study were (i) to review the land cover (LC) change implications to hydrological variables soil erodibility and yield reduction (ii) to explore statistical and trend analysis of hydrometeorological data, (iii) to quantify the surface water potential and irrigation water demand, and (iv) to investigate the satellite-ET based irrigation performance using Water Productivity Open-access Portal database and to come up with a strategy for quantifying the spatial and temporal increase water use efficiency (WUE) and system water use efficiency (sWUE) in the rainfed and irrigated area of lower Baro watershed. GIS-based multi-criteria evaluation used with the interaction of 8 factoring parameters, to see the low level of irrigation development. In the eight sub-classes, a total of 20, 325 km² of appropriate pastoral land has been transformed into rainfed rice, sugarcane, maize, and vegetable land. This study used GIS, RS, Water Evaluation and Planning (WEAP), Cropwat8.0, and EasyFit software. The soil moisture rainfall-runoff method was computed using the WEAP hydrological model for the surface water demand and potential simultaneously from 2000-2014 and 2020-2030. This work used systematic reviews and a meta-analysis technique to examine the LC change and its effects on hydrological variables, soil erodibility, and yield reduction. Record identified through Scopus Searching, Web of Science Searches, and Google Scholar. Fully articles were assessed for eligibility and excluded for reasons. In the data search, 85 articles with investigations published between 2007 to 2022 were examined. Then, for surface water potential and irrigation productivity, only 2% of the abstracts that were eventually evaluated for assessment were selected. Four crops were selected to grow in these identified irrigable areas, and their gross irrigation demand was calculated using Cropwat8.0. In addition to annual streamflow variability, using graph pad prism 9.4 the monthly streamflow variability was determined. With the help of the WEAP system's parameter estimation tool weekly, average streamflow calibration was performed.

As a result, of the review, in the lower Baro, built-up/ settlement, agricultural land, water body, bare/ outcrop, and commercial farm rose roughly +195, +48, +35, +35, and +1%, respectively. On the other hand, shrubland, rangeland, forest land, and wetland decreased by 1, 0.5, 5, and 10%, respectively. But the revised universal soil loss equation looks to be a good alternative and soil water conservation measures are crucial for minimizing soil erodibility in lower Baro. As a result, of the water balance obtained the maximum estimated monthly hydropower potential, irrigation water demand, livestock water demand, and surface water potential were 60.3 Mm³ and the corresponding outflow value was 52.4 Mm³. The total estimated mean annual surface runoff leaving each station of the watershed was 462.06 Mm³. The coefficient of determination (R^2) result was 0.88 and the Nash efficiency coefficient (NSE) was 0.91 highest at the Baro Gambella station. The anticipated irrigation requirement for the selected crop's driest five months of May, February, March, January, and April was 1, 0.9, 0.78, 0.78, and 0.34 l/s/h. The Baro Gambella sub-catchment had maximum critical values test results of $\sigma = 12.6$, $\mu = 11.9$, and $\gamma = 0$, while the Sor Metu showed the smallest value of 0.80, 1.75, and -0.03. Across the watershed, the sWUE varies with runoff, with a coefficient of variation of 71%. As a result, the overall accuracy of the LC change was 81%, the Landsat 8 images of the soil-adjusted vegetation index showed a maximum value of 0.87 and a minimum of -1.5. The normalized vegetation index of 0.58 maximum and -1 minimum was observed. By 2050, the sWUE will be 10% lower temporally, but its spatial variability will be 25% higher. From 2017-2023 an increase in trees (dense forest), scrub/shrub land, flooded vegetation, and bare ground, while there had been a decline in water bodies and crops during the same period. When yield gaps are increased by a factor of 1/3, 2/3, and 3/4, the Baro Gambella sub-catchment has the biggest yield gaps 443.52, 887.04, and 1008.106 kg respectively, while the Gumero Gore sub-catchment experiences the smallest yield gaps 0.01, 0.02, and 0.03 kg respectively. As a result, the crop water productivity, ET, crop index, and temporal fluctuation of the yield gap were investigated. Also, the available dry river flow does not meet the available potential irrigable land. Moreover, to increase the irrigation crop water productivity by 2050 in the lower Baro watershed. Therefore, improve soil infiltration and water storage, which decreases runoff and the water lost by ET and raises sWUE.

Keywords: Surface water potential; soil moisture; irrigation water productivity; yield gap

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LIST OF ABBREVIATIONS

Abbreviations	Descriptions
CSA	Central Statistical Agency of Ethiopia
CZ	Agro-Climate Zone
CWP	Crop Water Productivity
ET	Evapotranspiration
ENMA	Ethiopian National Meteorological Agency
ESRI	Environmental Systems Research Institute
DEM	Digital Elevation Model
DSR	Direct-Seeded Rice
HBV	Hydrologiska Byråns Vattenbalansavdelning
HEC	Hydrologic Engineering Center's
ICTs	Information Communication and Technologies
IWR	Irrigation water requirement
HEC RAS	River Analysis System
LC	Land Cover
NDVI	Normalized Difference Vegetation Index
PRISMA	Preferred Reporting items for Systematic Reviews and a Meta-Analysis
SAVI	Soil Adjusted Vegetation Index
SRI	System of Rice Intensification
SWC	Soil and Water Conservation

SWAT	Soil and Water Assessment Tool
sWUE	System of Water Use Efficiency
SDGs	Sustainable Development Goals
SRTM	Shuttle Radar Topographic Mission
USLE	Universal Soil Loss Equation
UNESCO	United Nations Educational, Scientific and Cultural Organization
UN	United Nations
WUE	Water Use Efficiency
WaPOR	Water Productivity Open-Access Portal
WEAP	Water Evaluation and Planning System

CHAPTER 1 INTRODUCTION

1.1 Introduction

The sustainable development and utilization of surface water resources are necessary to combat poverty and stimulate the economy (Hamza and Getahun, 2022). Irrigated land yields 40% of total grain output from only 20% of the worldwide arable area; while rainfed agriculture produces 60% of total grain output (Gebul, 2021). Information about rainfall is crucial for planning and developing various water resource facilities; floods and landslides are brought on by excessive rainfall, whereas drought can happen when there is not enough precipitation (Phawa, 2023). As part of the land-water cycle, surface water resources are crucial for sustaining and safeguarding the stability of the water and world's habitats. Around 62% of the precipitation that falls on the continents is produced through evapotranspiration (ET) on a global scale; the majority of this occurs through the land surface, with only 3% coming from open-water evaporation (Wang & Yang, 2014). With a 1% annual growth rate, worldwide yearly water use is expected to be 4600 Bm³; the monthly water variability is roughly 3.6 billion people live in potential water-scarce zones, which will climb to 4.8-5.7 billion by 2050; on the other hand, between 2000 and 2050, it is anticipated water use will rise by 55% (Salem et al. 2022). Due to the world's growing population, there is a need for considerable improvements in food production (Tadesse & Zewdie, 2022).

1.2 Irrigation water management

Irrigation techniques that save water have the potential for water scarcity exacerbated by agricultural development useful for land and water management (Abera et al. 2020; Eshete et al. 2020). The irrigation of the entire nation is shown in a less formal document outlining the growth of irrigation in Ethiopia (Gebul, 2021; Eshete et al. 2020). According to statistics, 86.5% of the irrigation systems in the command area are operational, yet only 46.8% of the projected beneficiaries have profited from irrigation (Awulachew & Ayana, 2011). Irrigation now covers 3.07 million ha; however, further irrigation is required (Gebul, 2021). Micro-irrigation systems (drip and sprinklers) are crucial in addressing these issues. Increased input use efficiency also aids farmers in maximizing farm profits.

Although few water energy food resource planning approaches have been incorporated; moreover, the knowledge gaps about incorporating spatiotemporal drivers accessibility of agricultural sectors (Shannak et al. 2018; Fikadie et al. 2022). In East Africa, there has been a greater geographical range in precipitation ranging from a 25 to 50% fall and rise (Abebe et al. 2022; Multsch et al. 2017). The allocation of surface water resources to the agricultural, hydropower generation, industrial, and domestic sectors is primarily determined by regional hydrological tendencies (Todmal, 2020). The potential and demand for water resources and their products in Ethiopia are still in their infancy; factors hindering the development can be grouped into four main streams: natural, technical, economic, and institutional (Dessu et al. 2019). The most significant issue is determining when and how much to irrigate a specific crop using different irrigation systems; gaps in soil suitability for surface irrigation play a vital role in the nation's effort to manage water resources (Halefom & Ulsido, 2020; Berhanu et al. 2013; Thiemig et al. 2012).

One of the effective solutions to the problem of food insecurity is irrigation; approximately 66% of the country's land may be used for agriculture (Fikadie et al. 2022). The government, investors, and farmers are all participating in the irrigation land project (Seyedmohammadi et al. 2016; Rising, 2020). According to the literature review, social pressure and a fast-rising population drive and cause the size of irrigable regions (Dau et al. 2021). Moreover, the cause of the damaged cropland, according to Ethiopia's Productive Safety Net Program, is unsustainable agriculture methods (Solomon et al. 2016). During Kiremt (winter season) 2019, floods affected 22,996 people around Gambella, Gambella town, Dima, Abobo, Gog, and Jor in the Agnuak zone; Itang special Woreda; and Wanthowa, Jikawo, Akobo, Lare, and Makoy in Nuer zone (GoE, 2015; Batisha, 2015; Ghoreishi et al. 2022).

1.3 Surface water availability

Water scarcity has evolved in several sections of the country due to uneven rainfall distribution, rising demand, and the incidence of droughts (Woldegebriel et al. 2022; Hailu et al. 2019). Because the majority of Ethiopia's rivers are transboundary; 97% of the country's annual streamflow flows out of the country, with only 3% remaining within the country (Ouda et al. 2013). The number of models employed in water, energy, and food nexus analysis is quickly expanding; water availability is being utilized for irrigation water demand to investigate future possibilities (Çetinkaya et al. 2022; Rising, 2020; Ostojski,

2013). However, precipitation patterns are incredibly valuable and have been studied in a wide range of fields (Varouchakis et al. 2018). In vast River Basins, hydrological modeling is an essential component of water resource study and management (Johnston and Smakhtin, 2014). Specifically, integrated surface irrigation water management required accurate information on the components of the water balance equation (Rajosoa et al. 2021; Nesru et al. 2020). However, the limited availability of water and continuous up-to-date ground stream flow data is one of the main constraints for large-scale basin forecasting models (Ekka et al. 2020; Revilla et al. 2016). Moreover, data on hydrology and water demand, as well as projecting the effects of various management systems under climate change, remain a difficulty (Höllermann et al. 2010).

1.4 Surface water management

In nations like Ethiopia, a detailed assessment of a River Basin's surface water potential irrigation water productivity is critical for the future growth of any water-related project (Kemal and Adeba, 2021). A review of Baro Akobo River, when compared to the values predicted in the river basin's master plan, the estimated surface water potential has been reduced by about 3.6 Bm³ (Deneke et al. 2023). Water resources developments are not short-payable investments, securing finance for projects from either lenders or private investors is challenging (Shannak et al. 2018). But, hydrological components, such as ET to water resource research are mainly restricted to the model and less analysis has been undertaken (Touseef et al. 2021). The enormous variation in crop yields around the world, however, has recently been brought to light by several articles; which have also identified mechanisms that can potentially increase crop yields (Brauman et al. 2013). This demand is kept high by the expanding human population because there is a lack of both land and water (Ibarrola et al. 2017). Crop Water Productivity (CWP) has become more well-known as a gauge of agricultural performance in recent years (Gebrehiwot & Gebrewahid, 2016). Besides, a huge gap between water supply and demand concerning per capita consumption among different dwellers (Kemal & Adeba, 2021; Touseef et al. 2021; Town, 2019; Hussen et al. 2018). The enormous variation in crop yields around the world, however, has recently been brought to light by several articles; which have also identified mechanisms that can potentially increase crop yields (Brauman et al. 2013).

1.5 Surface water hydrological modeling

The choice of the models may depend on the availability of data input requirements, climatic situations land use, topographic nature, soil type, morphological characteristics of a watershed, and other related factors (Adane et al. 2021). However, hydrologic models can be lumped, distributed, and semi-distributed; on the other hand, hydrologic models, such as Hydrologic Engineering Center's (HEC), River Analysis System (HEC RAS), Hydrologiska Byråns Vattenbalansavdelning (HBV), and Soil and Water Assessment Tool (SWAT) others are tested and largely approved for use in Ethiopia's numerous River Basins (Dile et al. 2016; Che & Mays, 2015; Creutzfeldt et al. 2010). Considering the water sector holistically, rapid urbanization, population growth, and ever-increasing demand from the irrigation sector should be taken into account (Abera et al. 2020; Irfan et al. 2018). Watershed hydrology is impacted by the land cover (LC) both spatially and temporally across the short- and long-term (Kafy et al. 2021); including, land productivity, geomorphological, hydrological, and related water resource systems in watersheds (Kotir and Ogundeji, 2020). The study demonstrates that the hydrological behavior in close-by catchments is comparable; nevertheless, while it works well when utilizing a dense network of gauging stations, it may result in erroneous representations of rainfall-runoff behavior in regions with different climatic and geomorphological characteristics (Baez et al. 2021).

1.6 Land cover change and soil erodibility

Ethiopia's highlands have lost over 1.5 billion tonnes of topsoil due to erosion, which might have resulted in a 1.5 million tonne boost in the country's grain production (Jemal, 2021). Because runoff generation is influenced by rainfall intensity, most study models concentrate on stormwater episodes and disregard smaller rainfall events (Timm et al. 2018). In Ethiopia, there are few studies on the topic, as well as fewer location-specific LC studies or soil erodibility assessments. Direct sowing and tillage that is perpendicular to the gradient slope are two agricultural practices that avoid runoff and limit the ability of the soil to be eroded by amorphous aluminium and iron (Atougour et al. 2019; Tilahun, 2018). A new product named LULC 2020 Environmental Systems Research Institute (ESRI) was released by the ESRI in June 2021. It was created by classifying Sentinel-2 satellite data at a 10-meter resolution using artificial intelligence; information on land use, such as forestry, crops, water, and urban areas is crucial and must be updated. Half of all erosion on a worldwide scale is estimated to be caused by water (Szporak et al. 2022);

one of the most significant environmental issues in the world, with both local and global effects, is soil erosion (Panagos et al. 2022). There is a need to understand how the LC change would affect the major river basins in the nation's flow regime, particularly in regions with seasonal water supplies (Mohaideen and Varija, 2018). The key factor contributing to the upper Baro basin's detrimental anthropogenic deterioration is large-scale agricultural expansion, which induces LC change and maintains the sustainable flow of water to the lower Baro watershed (Basin, 2021; Wu et al. 2014). The enormous variation in crop yields around the world, however, has recently been brought to light by several articles; which have also identified mechanisms that can potentially increase crop yields (Brauman et al. 2013). This demand is kept high by the expanding human population because there is a lack of both land and water (Ibarrola et al. 2017). Crop Water Productivity (CWP) has become more well-known as a gauge of agricultural performance in recent years (Gebrehiwot & Gebrewahid, 2016). Besides, a huge gap between water supply and demand concerning per capita consumption among different dwellers (Kemal & Adeba, 2021; Touseef et al. 2021; Town, 2019; Hussien et al. 2018).

1.7 Remote sensing water productivity

Currently, remote sensing technology allows for high spatial and temporal resolution measures of agricultural performance (Ferrant et al. 2014). Remote sensing (RS) makes it possible to keep track of a wide range of factors that have an impact on agricultural output (Salem et al. 2022). Water is a limited natural resource that is vital to life and is crucial for the development of human civilization; it is an essential part of agricultural production systems that produce fiber and food (Ndeketeya & Dundu, 2022; Safavi et al. 2015).

The Sustainable Development Goals (SDGs) of the United Nations (UN) call for drastically improving water consumption efficiency and doubling the agricultural productivity of SDG2.3 and SDG6.4 by 2030 (Moisa et al. 2022; Kotir et al. 2020; Eshete et al.2020). But lately, the rate of gain from more irrigation has slowed; increased warming will likely make it difficult to increase yield improvements through irrigation expansion (Zaveri and B. Lobell, 2019). The Ethiopian irrigation projects will cover 2.05 Mha by gravity (Gebul, 2021); 2.05 Mha by gravity, and 0.04 Mha by pressurised irrigation will be covered by 2050 (Multsch et al. 2017).

The present government has irrigated approximately 190,000 ha, with plans to enhance this figure (Mesfin et al. 2020). The statistics show that 86.5% of irrigation systems are functioning, 74.1% of the command area is under cultivation, and only 46.8% of the expected beneficiaries have benefited from irrigation (Awulachew and Ayana, 2011). To ensure the sustainability of agriculture in areas with limited surface water resources; particularly for crops with high water requirements, irrigation performance must be improved (Mandal et al. 2020; Haj et al. 2018; Teshome et al. 2018). Vegetables and sugarcane received less attention than cereal crops in the majority of yield gap analysis research (Van Loon et al. 2018; Chapagain & Hoekstra, 2011).

Food and Agriculture Organization (FAO) portal to monitor Water Productivity Open-access Portal Database (WaPOR) performance indicators play a crucial role in improving water use efficiency, assisting performance-oriented management, identifying constraints, and comparing system performance with other products (Multsch et al. 2017). Land productivity is estimated at spatial scales ranging from 100 to 250 m with a 10-day temporal resolution, depending on the site (Sawadogo et al. 2020). For applications in agriculture, there are no standardized accuracy standards for remotely sensed information (Karimi et al. 2019). Although projections for sugarcane for the next ten years indicate a slowdown in the increase of global sugar consumption. The pace of growth is still anticipated, and narrow scope and greater detail refer to a study's limited spatial coverage, single-crop emphasis, and extensive use of detail in determining the root causes of the yield discrepancy (Van Oort et al. 2017).

In sub-Saharan Africa, where 70% of the small landholder farmers are women, the target is to increase the yield gaps of crops by a factor of two to four (Giller et al. 2021). Investigation of the main elements restricting and reducing crop production in farmer's fields using yield gap analysis at the regional level is helpful (Silva et al. 2021). Global sugar consumption is expected to continue increasing, albeit at a slower pace, by 2027 (Van Oort et al. 2017). Water productivity potential (WPP), water productivity actual (WPA), yield potential (Yp), actual yield (Ya), and water-limited yield (Yw) are affected by topography and water availability. These measurements are based on benchmark rainfed crops, but determine the appropriate inference domain for specific WPP, WPA, YP, and

YW yield gap estimates can be challenging and require translating knowledge into action (Giller et al. 2021). The discrepancy between potential and water-limited production indicates a yield gap that can be filled with rainfed crops and more irrigation (Van Oort et al. 2017). Table 1.1 shows the potential irrigable and actual irrigated area of the main drainage basins, of Ethiopia.

Table 1.1 Potential irrigable and actual irrigated area of the main drainage basins of Ethiopia (MoWIE)

Basin	Potential Irrigable Area (ha)	Actual Irrigated Area (ha)	% Utilised
Abay (Blue Nile)	977,915	21,010	2.1
ReftValley (Lake)	122,300	12,270	10.0
Awash	204,400	69,900	34.2
Omo Ghibe	450,120	27,310	6.1
Genale Dawa	435,300	80	0.02
Wabi Shebelle	237,905	20,290	9.9
Baro Akobo	748,500	350	0.05
Tekeze	312,700	1,800	0.57
Afar	3000	-	-
Merebe	37,560	8000	21.3
Total	3,495, 795	161,010	4.0

1.8 Statement of the problem

Currently, there is an increasing demand for irrigation and hydropower development in Ethiopia. The country is experiencing several problems such as rapid population growth, limited surface water resources, environmental degradation, and yield reduction in lower Baro Ethiopia. Surface water resource managers in many large watersheds face three major challenges. Namely an increase in water demand, the impacts of climate change effect on water availability, and the land cover change implication to hydrological variables of soil erodibility. In contrast to other hydrological components in the hydrological cycle, the percentage of water in soil moisture is lower. Nevertheless, it is essential to many agricultural and hydrological investigations. Developing ways to improve water application, yields, and high-quality crops requires an accurate assessment of ETc as a critical first step.

Although trend analyses of hydro-meteorological variables are widespread in Ethiopia, earlier research solely looked at rainfall and temperature. They haven't given all the details of the watershed's hydrology (Ketema & Dwarakish, 2020). So, the science question makes estimating the hydrological extremes by a single method challenging. The combined hydrological modeling, remote sensing, and observation are the best complete picture. Understanding the components of water balance and how they affect the system's ecohydrological conditions and water productivity over the short and long term is crucial. Because there are fewer instruments available to analyze irrigation systems in such detail, this is the bottleneck, especially at the regional scale.

Traditionally, field studies are carried out to quantify and assess different approaches to surface water management to increase water productivity. Researchers have worked hard in recent years to create physical simulation models that can examine environmental and water consumption issues. Among the twelve River Basins in Ethiopia, the Baro Akobo Basin has abundant surface water resources, which up to now are less developed to any significant level. However, agriculture is affected by several causes, but the most common problems are pests, uneven rainfall distribution, waterlogging in wetland areas, salt-affected arid, semi-arid regions, and acidity in high-rainfall areas. As a result, of the over-exploitation of natural resources a wide range of problems priority has been given to address these challenges.

The creation of new technology and collection process of spatial data, particularly GIS and RS, represent a chance to overcome some of these obstacles; by providing fresh approaches and options for the collection and management of data, particularly on a more accurate spatial and temporal scale. Thus, the main task is to better understand the dynamics of soil erodibility on crop water productivity in challenging climatic conditions. Moreover, understanding the effects of scaling up surface water productivity innovations watershed levels are useful for catchment tributaries. The severity of the problems needs surface water hydrological modeling techniques and tools to investigate the surface water potential and irrigation water demand. Investigations with land use and land cover change on the hydrologic responses relating to the surface runoff at the watershed. Due to climate change, rainfall is very unpredictable in terms of timing, frequency, and volume.

However, population growth is the cause of the strain on the limited water resources (water, soil, and land); a dry spell typically occurs frequently and hinders CWP. As a result, the area's population occasionally has food shortages and insufficient access to domestic water; even the animals suffer severe starvation owing to limited pasture. Therefore, there is only seasonal food production in the study area, which has a high population density. The enhancement of surface water accessibility is necessary for the creation of small-scale, medium-scale, and large-scale irrigation systems at the watershed scale.

1.9 Objectives of the study

This study aims to integrate GIS and RS to estimate the surface potential and irrigation water productivity at the spatial and temporal distribution of water availability, increase the surface water productivity, water use efficiency (WUE), and system water use efficiency (sWUE) for agriculture in Ethiopia's lower Baro watershed. The following are the study's specific objectives:

1. To review the land cover change and its implication for hydrological variables, soil erodibility, and yield reduction
2. To explore statistical and trend analysis of hydro-meteorological data
3. To quantify the surface water potential and irrigation water demand of lower Baro watershed tributaries
4. To investigate the satellite ET-based irrigation performance: strategies to increase rainfed crops production in the lower Baro watershed tributaries

1.10 Organization of the study

The remaining chapters are organised as follows

Chapter Two a systematic literature review is presented, starting from the land cover change implication to hydrological process and soil erodibility and yield gap closing for food security and sustainable surface water management. Literature gaps have been identified to accomplish research objectives. The first objective of the study is discussed in this chapter.

Chapter Three provides a detailed methodology framed to complete the research work. It also provides a brief account of surface irrigation and yield gap evaluation techniques.

The reason behind choosing the study area and a detailed account is also given along with the data used in this chapter.

Chapter Four discusses the statistical and trend analysis of historical hydro-meteorological data obtained for the lower Baro catchment tributaries. Monthly and annual averages of rainfall, air temperature, and streamflow are subjected to trend analysis. Also, the statistical Easy Fit probability density function relating to rainfall goodness of fit is discussed and a conclusion is made.

Chapter Five presents the strategy adopted for the application of the WEAP model to assess and integrate surface water modeling with irrigation productivity in the lower Baro catchment tributaries. Results concerning catchment responses; especially streamflow, soil moisture, and evapotranspiration, to changes in LC hydrological process and LC climate variability, are discussed.

Chapter Six discusses the satellite ET-based irrigation performance: strategies to increase rainfed crop production in the lower Baro, Ethiopia. The strategy adopted, therefore Cropwat8.0 modeling for the irrigation schedule to increase the crop yield.

Chapter Seven Lastly summarises, concludes, and recommend the finding of this research work. Moreover, the limitations of the study and future scope are presented.

The next chapter reviews the literature relevant to the objectives of this research work

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This review of literature provides an overview of integrated surface water modeling of the satellite ET-based irrigation performance indicators as well as the yield gap targets for rainfed and crop water productivity in the lower Baro catchment tributaries. WEAP hydrologic model is used to explore the effects of external influences such as soil-water relationship, rainfall pattern, climate variability, and land use/land cover change in the lower Baro watershed. The review of the article is categorized into the following themes

- ♣ Trend Analysis of Hydro-Meteorological Variables in Crop Production;
- ♣ Selection of Surface Water Hydrological Modeling
- ♣ Irrigation Potential of Ethiopian River Basins
- ♣ Challenges of Surface Water Resources Development in Ethiopia
- ♣ Comparative Studies Using Surface Soil Moisture Models
- ♣ Surface Water Management at Regional Level (East Africa)
- ♣ Surface Water Resources at the National Level (Ethiopia)
- ♣ Surface Water Resources at Local level (Regional States)
- ♣ Climate Change Impact Studies on Surface Water Resources of Ethiopia
- ♣ Causes of Variation of Water Productivity
- ♣ Remote Sensing satellite real-time water productivity

Irrigating the land and improving the management of existing irrigation infrastructure may accomplish a lot; water resources should be developed responsibly to aid in the reduction of poverty and advance economic growth (Hamza & Getahun, 2022). The interactions between the Earth's atmosphere and land systems can be seen as the primary drivers of climate change (Kumilachew & Hatiye, 2022; Van der et al., 2018; Dau et al., 2021; Bekele et al., 2019; Hasanuzzaman, 2019; Asghar et al., 2019). The two variables that regulate ET are soil moisture and vapor pressure deficit, both of which are impacted by global climate change (Yao et al., 2023). When water moves from an area with high free energy to one with reduced free energy, this is known as the water potential (Woldegebriel et al., 2022). The potential and demand in the water sector development are still very less; with factors

hindering natural, technical, economic, and institutional (Dessau et al., 2019). The allocation of water resources is primarily determined by regional hydrological tendencies (Rajosoa et al., 2021; Todmal, 2020; Al-Faraj et al., 2016). Water scarcity has evolved in several sections of the country as a result of uneven rainfall distribution, rising demand, and the incidence of droughts (Ouda et al., 2013). Land-use changes are altering the hydrologic system and have potentially large impacts on surface water resources (Belay and Mengistu, 2021). Numerous regional studies have been performed worldwide to examine the effects of past land-use changes on water availability; in particular, in areas with limited water resources, land-use changes may make water more scarce and worsen living circumstances (Wagner et al. 2013). Based on the year-by-year correlation between rainfall and discharge suggests that the changes in land use/cover in the study area may have an impact on surface water resources (Tilahun et al. 2018). Although it has a huge surface water capacity, it is still unclear how successfully it will be able to supply the watershed's irrigation needs (Engdaw, 2016). However, the growth in the population, energy production, and land use are further contributing variables (Asitatikie & Gebeyehu, 2021). A gap between freshwater supply and demand will probably exist in many places of the world due to a changing climate (Salem et al., 2022; Sahukhal & Bajracharya, 2019; Varouchakis et al., 2018; Aramburu et al., 2015).

2.2 Trend analysis of hydro-meteorological variables and crop production variability

The primary water user that contributes to water scarcity in many river basins is irrigated agriculture (Mmbando, 2015). Studies indicated that 40% of the world's food comes from 17% of the world's cropland is irrigated which consumes more than two-thirds of the world's developed water supplies (Khatri et al. 2013). (Wichelns, (2017) emphasized at Bonn Conference, many distinguished speakers promoted the water-energy-food nexus as a novel and meaningful depiction of interactions involving water, energy, and food security (Dessu et al. 2019). Regional and local hydrological regimes are significantly vulnerable to global climate change which threaten the water resources and food security of nations (Bekele et al. 2019).

2.3 Selection of surface water hydrological modeling

Ancil et al. (2003) clearly explained in various publications, a model is a simplified representation of a real-world system; consists of a set of logical operations contained within a computer program. Models are set up for possibilities to include observed rainfall and streamflow data for different purposes mainly calibration (Kauffeldt et al. 2016). In the modeling world, with the applicability to basins for different purposes, there exists no universal hydrological model (Thi Thanh Hang, 2019). The Baro River overflows, along with a local tributary and the wetland itself, are primarily responsible for creating the Machar Marshes. The majority of studies focus on stormwater events and neglect smaller rainfall events; since the generation of runoff depends on rainfall intensities (Timm et al. 2018). Studies should advise a potential effect into account when parameterizing WEAP modeling for future scenario analysis (Abdi and Ayenew, 2022). The spatial and temporal pattern of the precipitation estimate resembles accurately gauged data where better temporal quality and areal extents are also critical for efficient prediction of the water balance components and hydrologic variability of the watershed tributaries (Shawul & Chakma, 2020).

2.4 Irrigation potential of Ethiopian river basins

In Ethiopia, surface water resource management for agriculture includes both support for sustainable production in rain-fed and irrigated areas. A total of 500,000 acres in 12 river basins are cultivated by 5 million farmers in regions with variable rainfall; irrigation water demand volume of around 6000 m³ per ha and a potential of 6.5 km³ (Belachew et al., 2022). The impact of various rainfall patterns on soil erosion can be estimated; high intensity with short-duration rainfall events influences soil erosion processes; the FAO reported that 25 to 40 billion tons of topsoil are degraded each year; affecting soil properties and crop yield (Maurya et al. 2021; Tigray, 2017). In 2007, the Central Statistics Agency of Ethiopia (CSA) reported that the LC change increased by +4.15% per year with the average landholding size per family of 1.4 ha; this is below the standard of FAO of 2 ha.

2.5 Challenges of surface water resources development in Ethiopia

Countries like Ethiopia must take a sensible approach to address the ecological, social, and economic problems associated with watershed development (Alemu, 2016). Obtaining funding for water resources projects from lenders or private investors is difficult because they are by their very nature non-short-payable investments. Only 40% of the country is covered by the approximately 470 functioning hydrological gauging stations, which is extremely few by any measure (Melesse et al. 2013; Lee et al. 2020).

2.6 Comparative studies using surface soil moisture models

Statistical learning theory approaches are used to handle the complicated nature of soil moisture. The capacity of tools to spatially assess scattered soil moisture at a single farm has been explored for years (Rai et al. 2019). Also necessary for figuring out hydrological processes, such as interactions between the land and the atmosphere, rainfall-runoff responses, and erosion processes (Shein et al. 2021; Adimassu et al. 2018). Buckingham is the first to present the idea of the soil water's potential dependency of water potential on water content (Wang & Yang, 2014). The short-term depletion storage due to soil water moisture is depleted by either evaporation or outflow away from the storage location (Drisya & Sathish Kumar, 2022; Mohaideen & Varija, 2018). Due to a higher water demand for ETo from crops and other natural vegetation brought on by a rise in temperature, the amount of soil moisture will be depleted more quickly (Mohaideen & Varija, 2018). Irrigation water is crucial to water availability in arid and semiarid areas (Han et al. 2014). A comprehensive strategy for managing water resources today supports the development and management of water, land, and related resources (Loukas et al. 2007; Joseph et al. 2020). Moreover, sufficient temperature to derive ET during the dry season, the saturation point shall not be satisfied to form precipitation due to lack of moisture. The hydropower reservoir location and annual ETo across Ethiopia as shown in Figure 2.1.

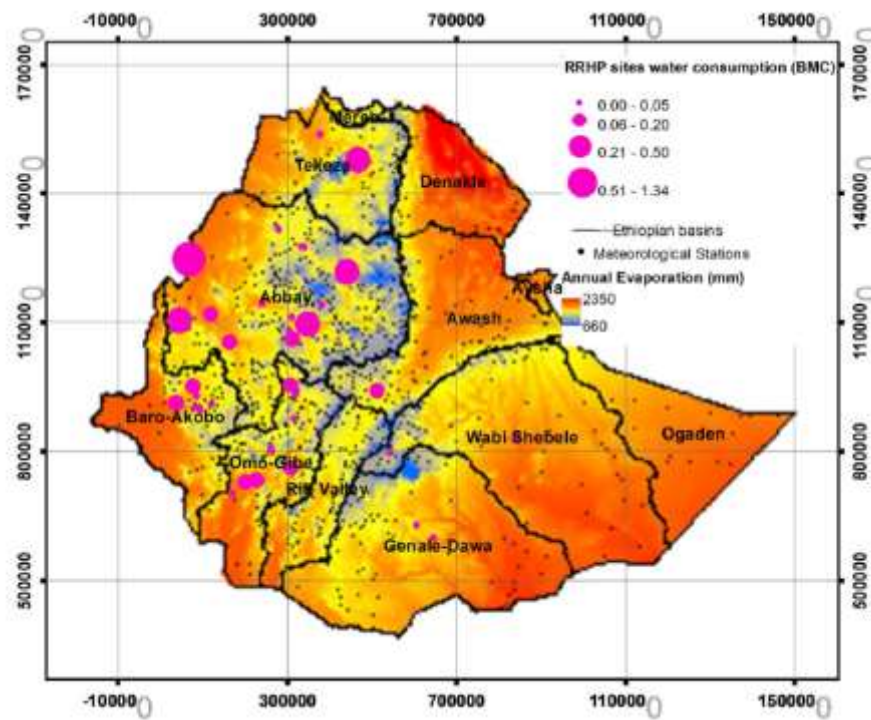


Figure 2.1 Hydropower reservoir location and the annual ETo across Ethiopia

Table 2.1 Summary of various hydrological studies

S No	Types of models	Hydrological processes simulated
1.	SWAT	Physically based, distributed watershed-scale models are intended to predict how changing land use will affect sediment, hydrology, and pollutant transport in significant, ungauged basins. When simulating HRU over an extended period, it is helpful.
2.	WEAP	A generic computer program that works well for modeling water management. It creates a model to support long-term planning, supply and demand, yield, dependability, risks, and related expenses.
3.	APEX	A flexible, dynamic framework is needed to model the consequences of land use and management for large farms and small water basins. Additionally, it can mimic the effects of different nutrient management techniques, cultivation methods, water and soil conservation measures, alternative farming practices, and more.
4.	HEC-HMS	Hydrological modeling offers a variety of techniques for simulating different aspects of the hydrologic cycle, both continuously and event-based.
5.	HBV	The most recent version of the HBV model is known as HBV-light, which makes use of a time when the temperature is pleasant, where physical factors are given suitable values for each parameter, and meteorological information.
6.	MIKE-SHE	This model is a deterministic, geographically distributed process-based model that can replicate the fundamental hydrological cycle processes at the land level.
7.	TOPMODEL	A portion of the semi-distributed model uses topographic information related to run-off generation. This model's main objective is to determine the depth of the groundwater table or the local storage deficit at each point for each time step.
8.	AnnAGNPS	A basin-scale, batch-process model was created to enable the assessment of ongoing hydrological and water quality data for agronomic activities. It combines GIS with a physical description of water basins to produce simulation possibilities for ungauged sites.
9.	HYPE	Information about the DEM, the kind of soil, the use of the land, the daily precipitation, and the daily air temperature; application techniques for agricultural and extra nutrient loads (rural homes, enterprises, wastewater treatment plants, and air deposition).
10.	PRMS	Runoff on overland and channel for storm mode (Kinematic wave equation using finite difference approximation), Evapotranspiration, Channel routing (Reservoir routing method), Reservoir routing (Linear storage routing (Modified-Plus routing)).

2.7 Surface water resources at the national level (Ethiopia)

Ouda et al. (2013) reported that 99.3% of Ethiopia is covered by land, and the remaining 0.7% is covered by water bodies. When water moves from an area with high free energy to one with reduced free energy, this is known as the water potential (Woldegebriel and Garg, 2022). Several studies indicate an increase in the mean rainfall trend, while others predict a decrease in rainfall in the basin (Gebul, 2021; Varouchakis et al., 2018; Aramburu et al., 2015). Moreover, data on hydrology and irrigation water demand, as well as projecting the effects of various management systems under climate change, remain a difficulty (De Oliveira et al., 2022; Kafy et al., 2021; Walker et al., 2015; Höllermann et al., 2010; Salem et al., 2022; Sahukhal & Bajracharya, 2019).

2.8 Surface water resources local level (Regional States)

The environment has suffered over the past few decades due to increased demand for fuelwood, wood for construction, and removing land for expanded agricultural and irrigation projects (Yohannes et al. 2018). The substantial potential for hydropower generation along the escarpment would further impact the downstream hydrological system (Wood et al. 2016). The MoWE twenty-two, large-scale potential irrigation sites in the Baro-Akobo basin are identified with an irrigable area of 101,9523 ha (Belachew et al. 2022). The Baro River is thought to enter the marshy bog at a rate of 2.3 to 5.0 km³/year (Abdelkader et al. 2023). Currently, large-scale private farms are established in the lower Baro watershed cultivating rice, oilseeds, palm oil, and sugarcane like Saudi Stars Plc and Karuturi Global Ltd; except for the Alwero dam built in 1992; there is fewer major water resources development that took place before these new large-scale private commercial farms (Kebede, 2013; Geremew, 2013).

2.9 Climate change impact studies of surface water resources in Ethiopia

The interactions between the Earth, atmosphere, and land systems can be seen as the primary drivers of climate change (Kumilachew & Hatiye, 2022; Van der et al., 2018; Dau et al., 2021; Bekele et al., 2019; Hasanuzzaman, 2019; Asghar et al., 2019). In Ethiopia, rainfed agriculture yields 30% of our expected production; substantially expanded

commercial irrigation to mitigate this and paved its way; regional hydrological tendencies primarily determine water resource allocation (Rajosoa et al., 2021; Todmal, 2020; Al-Faraj et al., 2016; Dessau et al., 2019). This suggests that some portions of the basin may experience water stress, while the other areas struggle with issues associated with local flooding (Mikhak et al. 2022). In Ethiopia, there is currently compelling evidence that greenhouse gas emissions are causing the Earth's surface to warm up on average, which may have an impact on the hydrological cycle and water balance (Chaemiso et al. 2016). However, land use also influences the climate along with temperature; thus, any change in land use could affect predictions of future climatic conditions (Cooper, 2010).

Climate change increases variability in rainfall and ET patterns; it is estimated that by the year 2050, all of Ethiopia's watersheds will face water scarcity. A general decrease in the amount of accessible runoff. However, climate change contributes to an increase in the frequency, severity, and size of extreme weather events, which give rise to surface water-related problems. Drought negatively impacts the economy, culture, and environment and ultimately has a significant impact on people's quality of life (Bryan et al., 2020); by affecting things like irrigation surface water availability (Woldegebriel & Garg, 2022). The surface water resources are under a great deal of stress resulting in increased land use caused by deforestation, industrialization, intensive agricultural methods, and expansion of agriculture to fulfill the needs of the growing population (Santos et al. 2010).

Freshwater availability for crop water consumption and irrigation in the future is progressively being called into doubt as the climate is having effects (Siebert et al. 2015). More emerging nations than wealthy ones will experience an increase in water consumption. However, the average yearly demand for water across all applications has increased by 600% in the last 100 years, and by 2050, it will have risen by 20 to 30% (Boretti & Rosa, 2019). Many uncertain elements impact how climate change affects crop water use efficiency (WUE). In this regard, edaphic characteristics like lingering soil moisture are a concern; a more accurate impact of climate change on agricultural production might limit the influence of these ambiguous and unknown elements. The crop WUE is determined using the ratio of agricultural production to ET, a more thorough understanding of the soil surface environmental functioning, and the resilience of the ecosystem (Giller et al. 2021).

However, comprehending how climatic and agronomic factors affect crop WUE to design sustainable water management methods to mitigate and adapt to future climate change (Tesfaye et al. 2021); increased WUE variability under different management scenarios can contribute to a more accurate assessment of the impact of climate change on WUE at the size of regional watersheds. The yield (land productivity) obtained from a certain amount of water is called water productivity. When crops have higher CWP, they can produce the same amount of food with fewer resources or more with the same amount of water (Santos et al. 2010). For smallholder farming systems, agricultural droughts and dry spells present the biggest hurdle to increase yields. Agricultural droughts last between three and five weeks during the growing season and, adequately managed, could help the performance of the final harvest. Water production can be raised even in semi-arid environments, available water can be directed towards beneficial uses. Therefore, increasing CWP under the given challenges is useful.

2.10 Causes of variation in water productivity

Generally speaking, the incidence of poverty is higher, the more agriculture contributes to the gross domestic product. A large watershed level of socioeconomic development substantially impacts agriculture in addition to biophysical factors. For the lower Baro watersheds, the water stress is a limiting factor. Due to competition from other industries' demands, water scarcity has become increasingly severe over time and is predicted to continue in this manner.

2.11 Remote sensing and hydrological modeling

The current modeling practice recognizes the necessity for high spatial and temporal resolution, but data availability still has to be enhanced (Salvadore et al. 2015). Precipitation reaches the surface of the earth in the form of rainfall, some parts will percolate and recharge the aquifer; some features will be evaporated into the atmosphere, and the remaining become flow as surface runoff (Kumilachew and Hatiye, 2022). Thiemig et al. (2012) excessive precipitation has been linked to flooding and droughts and has the potential to cause a negative economic impact on rain-fed agriculture, in particular. These problems can be solved through the valuable information from satellite hydrological data (Wang & Yang, 2014; Andersson et al. 2009); since it is key for water resource planning and management (Tilahun et al. 2018).

2.12 Water evaluation and planning (WEAP) model

The scenario approach makes it useful in evaluating the surface water resources in different climate changes, water pollution, and policy changes (Teklu et al., 2020). WEAP may link up with other models and Software such as MODFLOW, MODPATH, PEST, Excel, and WEAP can read and write text files similar to SWAT, SWAP, Mike11, HEC-HMS, HEC-RAS, and GEO-SFM (Talila et al. 2018; Arnold et al. 2015). Water, energy, and food nexus analysis are quickly expanding, and water availability is being utilized to research the surface water potential and irrigation water demand to investigate future possibilities (Çetinkaya et al., 2022; Johnston & Smakhtin, 2014; Ostojski, 2013; Harma et al., 2012). Moreover, the model has evolved as a powerful tool for decision support (Salar et al., 2020).

When considering the water sector holistically, population growth, and ever-increasing irrigation water demand from the sector, including rainfed agriculture, should all be taken into account (Naghdyzadegan et al., 2022; Kemal & Adeba, 2021; Nesru et al., 2020; Kotir & Ogundeji, 2020; Irfan et al., 2018; Shannak et al., 2018; Okada et al., 2018; El-Gafy, 2017; Rockström & Barron, 2007; Wen et al., 2007; Wen et al., 2004). To prepare for anticipated water shortages, it is crucial to regulate water storage in reservoirs (Karamouz et al., 2017; Song et al., 2016; Safavi et al., 2015; Venot et al., 2010). The agroecosystems also provide regulation and maintenance services like water and climate control (Bethwell et al., 2021; Waldron et al., 2020). Further, to surface irrigation potential and the crop water demand a greater understanding of water resources as well as novel techniques for agricultural water management are required (Hadri et al., 2022; Muleta, 2021; Tessema et al., 2020; Kemal & Adeba, 2021; Karamouz et al., 2017). A summary of the literature is shown in Table 2.2.

Table 2.2 Summary of literature review

Work done by	What was studied	What was found	Observations
(Hamed and Gachon 2009)	The trend of rainfall, temp streamflow	A significant change was observed in lower Baro	Due to climate change variability
(Awulachew and Ayana 2011)	Major water resources development	Surface water Irrigation improvement	Dependent on Rainfed agriculture
(Multsch et al. 2017)	SPARE: WATER irrigation water demands FAO56 Crop irrigation guidelines	Improving the irrigation efficiency	The challenge in balancing the increasing irrigation water demand
(De Niel et al. 2020)	Land cover changes at hydrological extremes are investigated using a conceptual model (lumped)	Parsimonious hydrological models to simulate the impact of land cover changes	Well-calibrated lumped conceptual hydrological model top-down disaggregation approach
(Kemal and Adebaba 2021)	Climate change scenarios	Changing surface water demand & potential	Lack of integrated surface water management
(Negewo & Sarma, 2021)	Estimation of water yield	Climate variability	Future prediction of yield
(Szporak et al. 2022)	LC change soil erodibility	The spatial and temporal implication	Influencing the land productivity
(Abdelkade et al. 2023)	Evaluation of the effects of planned water resources	Forecast future development initiatives on Baro Akobo	Reduction in flow irrigated agriculture and hydropower development
(Getahun et al. 2023)	Surface irrigation potential assessment Chacha River upper Blue Nile	GIS tool and multicriteria analysis	Enhance agricultural productivity
(Sukma & Hiroki, 2023)	Indigenous knowledge	Ecosystem and environment	Sustainability of natural resources
(Raghavendra Prasad et al. 2023).	The hydrological cycle, significantly affected by spatiotemporal variability	Annual and seasonal trends in actual evapotranspiration	Irrigation and cropland expansion on actual ET trends and precipitation
(Wubneh, Worku, & Chekol, 2023)	Changing climate on water resource availability in watersheds	Surface water stress	Adoption of water-stress crops

2.13 Research gap

The literature review shows that hydro-geomorphological surface water potential and demand assessment information play an important role. Moreover, extremely useful to increase the yield gap of water productivity. To understand the problem, an outstanding and structured development in investigating hydrological models using RS techniques is critical. Regional surface water planning & development, surface water management, and many fields use hydrological data extensively. However, studies on integrated surface water potential and irrigation water demand for increasing water, land, soil, and crop productivity use modeling are almost very few. The use of compressive water balance-based model calibration and the validation of hydrological surface water demand and potential data and tools are required as part of this study.

2.14 Land cover change and its implication to hydrological variables and soil erodibility in the lower Baro watershed

LC change on surface runoff, river discharges, and low flow revealed a complex interplay between trees and water in soil erodibility and LC on watershed hydrology (Hassen, 2022). While the human population increased by 2% yearly, forest cover declined by 1% yearly (Guzha et al. 2018). Due to this, the impact of LC change on hydrological variables and soil erodibility is critical for assessing and understanding regional changes. Soils comprise agricultural practices such as direct sowing and tillage oriented perpendicular to the gradient slope to prevent runoff. In the hydrological process the two elements especially Amorphous Aluminium and Iron limit soil erodibility (Rafiei et al., 2020). Hydrological behavior in neighboring catchments is comparable; when utilizing a dense network of gauging stations; it may result in inaccurate portrayals of rainfall-runoff behavior in regions with different climates and geomorphological characteristics (Baez et al. 2021). Geremew's, (2013) empirical evidence, LC changes, and socio-economic dynamics have a strong relationship; as the population grows, the need for cultivated land, grazing land, and fuelwood grow; settlement areas grow to meet the growing demand for food and energy and livestock population. Ethiopia's cultivable land area estimates vary between 30 and 70 Mha, but 112 Mha land (Eshete et al. 2020).

The sector's contribution to the national economy may be easier to manage; it comprises river basins, Rocky Mountains, and flat-topped plateaus with deep gorges. Erosion, volcanic eruptions, and tectonic movements have influenced the country's terrain; the lowest elevation is 120 meters below sea level, while the highest is 4,620 meters above sea level. Copernicus Global Land Service's 2015 land cover map of Ethiopia is shown in Figure 2.2.

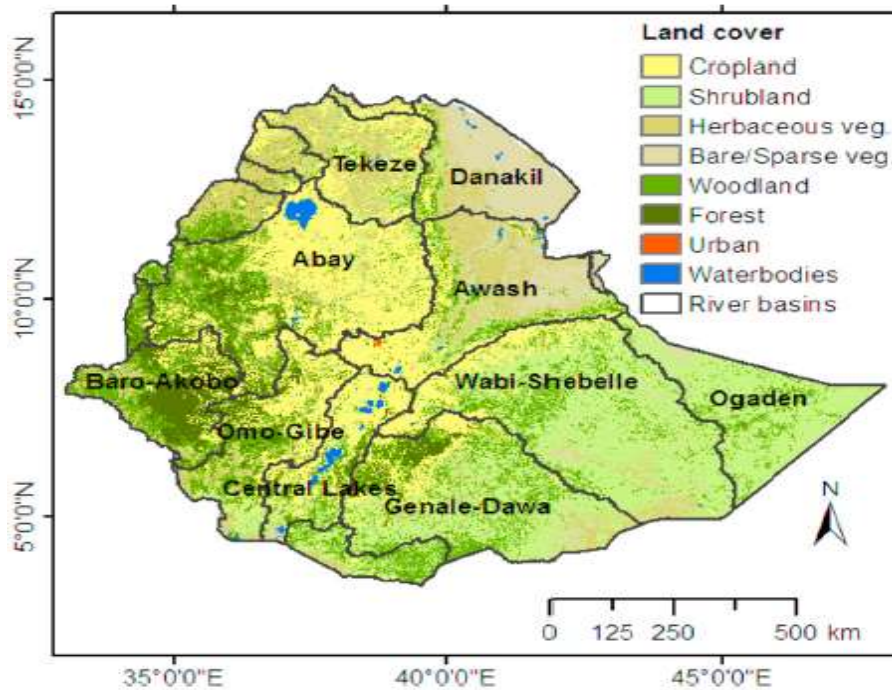


Figure 1.2 According to the Copernicus global land service's 2015 land cover map, the main forms of land cover in Ethiopia (<https://land.copernicus.eu/global/>)

It is becoming more and more practical to assess catchment water yield and the consequences of different management practices at watershed levels before suggesting treatments for watershed degradation (Negewo & Sarma, 2023). Since agriculture is Ethiopia's primary income source, productivity declines brought on by soil degradation may complicate efforts to achieve food security (Fenta et al., 2021). Given the limitations on protecting all places undergoing soil loss, focusing resources on erosion-prone areas with substantial soil loss is a realistic option. Moreover, soil loss reduction (%) using agroecology-specific land management techniques in regions with moderate to severe soil loss rates >10 t/ha/yr as shown in Figure 2.3.

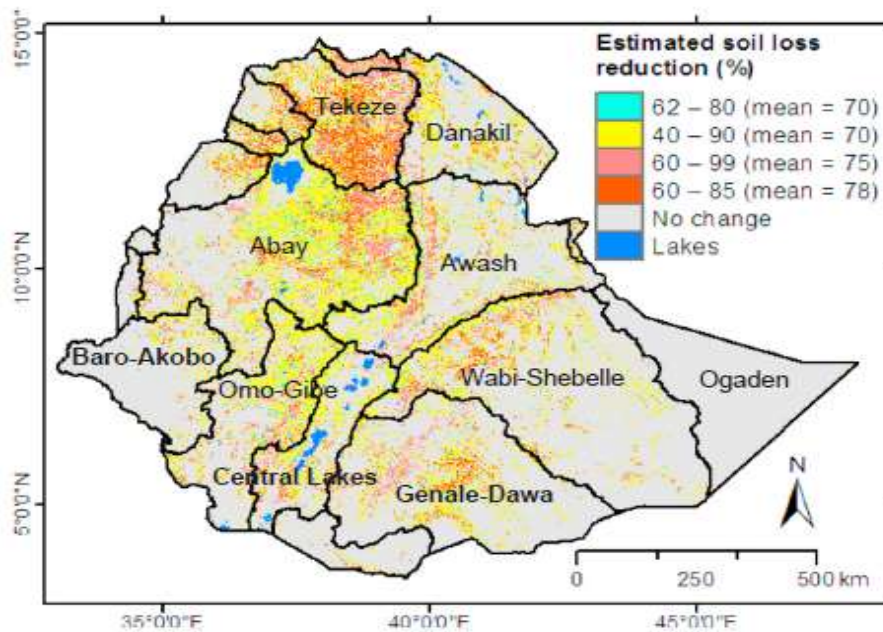


Figure 2.3 Estimated soil loss reduction (%) as a result of using agroecology-specific land management techniques in regions with moderate to severe soil loss rates >10 t/ha/yr

In this study, two percent of the review on LC change soil erodibility and hydrological variables were screened and ultimately included. Geomorphology plays a key role in the flow and storage of groundwater as it transforms rainfall into runoff (Mallick, 2016). In the 1960s, Wischmeier and Smith proposed the Universal Soil Loss Equation (USLE) for the first time. However, soil loss, which lowers soil fertility and promotes topsoil loss, is a major problem in agricultural output (Adimassu et al. 2018). Agricultural soil loss is the worst, with 8.5 t/ha, followed by settlement area at 60 t/ha, bare soil at 45 t/ha, and woods at 6.5 t/ha (Chuma et al. 2022). According to the study done by Gizaw et al. (2017), the Baro sub-basin is still mostly in its natural state, with forests covering roughly half of the territory and arable land covering the rest. Planners can use it to extrapolate sparse information regarding erosion to various locations and circumstances. Erodibility is not a single quantitative metric since it encompasses all static and dynamic soil parameters that influence some sub-processes that influence soil erodibility (Panagos et al. 2022). A soil organic content, primary particle sizes and stability, permeability, water retention forces, porosity, exchangeable ions, and infiltration rate are all crucial; regarding the direct and indirect interactions with precipitation, which result in ponding water in surface runoff and soil surface depressions (Ekka et al. 2020). The soil erodibility is now expressed in USLE as shown in equations 2.1 and 2.2.

2.19 Universal soil loss equation (USLE)

$$A = R * K * L * S * C * P \quad (2.1)$$

A = soil loss in t/ha/year; R = rainfall erosivity factor in MJ·mm·ha⁻¹·H⁻¹·year⁻¹; K = soil erodibility factor in t·h·MJ⁻¹·mm⁻¹; L = slope length in m; S = slope steepness in %; C = vegetation cover factor or land-use factor; and P = erosion control practices factor.

2.20 R-factor is mathematically defined as

$$R = \frac{1}{n} \sum_{j=1}^n \left[\sum_{k=1}^m [E_k (I_{30})_k] \right]_j \quad (2.2)$$

The RUSLE is an erosion model that, like its predecessor, is designed to estimate long-term average yearly soil loss from specific fields; slopes in specified land-use and management regimes that is crops, rangeland, and recreational areas.; where E is the total storm kinetic energy (MJ/ha), 730 mm/h is the maximum I₃₀ min rainfall intensity, j is an index of the number of years used to produce the average, k is an index of the number of storms in each year, n is the number of years used to obtain the average R, and m is the number of storms in each year. Erodibility indicates the soil response to rainfall and runoff erosivity. Soil erodibility can be classified into two large groups, one corresponding to soils in warm and cool climates. Based on their soil types and agro-climatic zones, FAO soil types are categorized into 59 soil-hydrological groups; Ethiopian soils are categorized as sand, silt, clay, and gravel by the harmonized soil database. In the lower Baro, the majority of the soil is relatively high in silt content, between 15 and 35%, and in the developed area is relatively high in clay content, between 30 and 45%; heavy soil or high clay content soil is usually better suited to paddy rice than lighter sandy soil (Nell and Africa, 2017).

2.21 K- factors using William's (1995) equation and FAO Soil

All the factors of soil; sand, clay, silt, and organic carbon were represented in the topsoil cover of the watershed because it is affected directly by the raindrop energy. K- Factors Using William's (1995) Equation and FAO soil are as shown in equations 2.3-2.7.

$$k_{USLE} = f_{csand} \cdot f_{cl-si} \cdot f_{orgc} \cdot f_{hisand} \quad (2.3)$$

$$f_{csand} = \left(0.2 + 0.3 \cdot \exp \left[-0.256 \cdot m_s \cdot \left(1 - \frac{m_{silt}}{100} \right) \right] \right) \quad (2.4)$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}} \right)^{0.3} \quad (2.5)$$

$$f_{orgc} = \left(1 - \frac{0.0256 \text{orgC}}{\text{orgC} + \exp[3.72 - 2.95 \cdot \text{orgC}]} \right) \quad (2.6)$$

$$f_{hisand} = \left(1 - \frac{0.7 \left(1 - \frac{m_s}{100} \right)}{\left(1 - \frac{m_s}{100} \right) + \exp \left[-5.51 + 22.9 \left(1 - \frac{m_s}{100} \right) \right]} \right) \quad (2.7)$$

Where f_{csand} is a factor that gives low soil erodibility factors for soil with high coarse sand contents and high values for soils with little sand, f_{cl-sil} is a factor that gives low soil erodibility factors for soils with high clay and silt ratios, f_{orgc} is a factor that reduces soil erodibility for soils with high organic carbon contents, this is the factor that reduces soil erodibility for soils with highly sand contents, f_{hisand} is a factor that reduces soil erodibility for soils with extremely high sand contents, m_{ssand} is the percentage of clay contents 0.05-2 mm diameter particles, and m_c is the percentage of clay content (< 0.002 mm diameter particles and OrgC is the percentage of organic carbon contents of the layer percentage. The number of research articles on the hydrological mechanism, and climate have all changed drastically throughout time, as seen in Figure 2.4 (a) there was very little variation from 2007-2013, and from 2013-2015, both fell. Moreover, from 2015 to 2019 both have been on the rise; Figure 2.4 (b) from 2007-2012, there was little variation. In contrast to the hydrological process, LC increased from 2012-2015 both have to rise and fluctuating pattern from 2015-2018. The broad range of factors affecting and notifying the hydrological process is the primary desire of the researcher (Yadete & Amba, 2021). In this study, between 2007-2022 the research articles on hydrological processes in the lower Baro rivers slowed as climate change accelerated (Deneke et al. 2023). Therefore, the impact of climate change on the region's hydrological systems is becoming more evident.

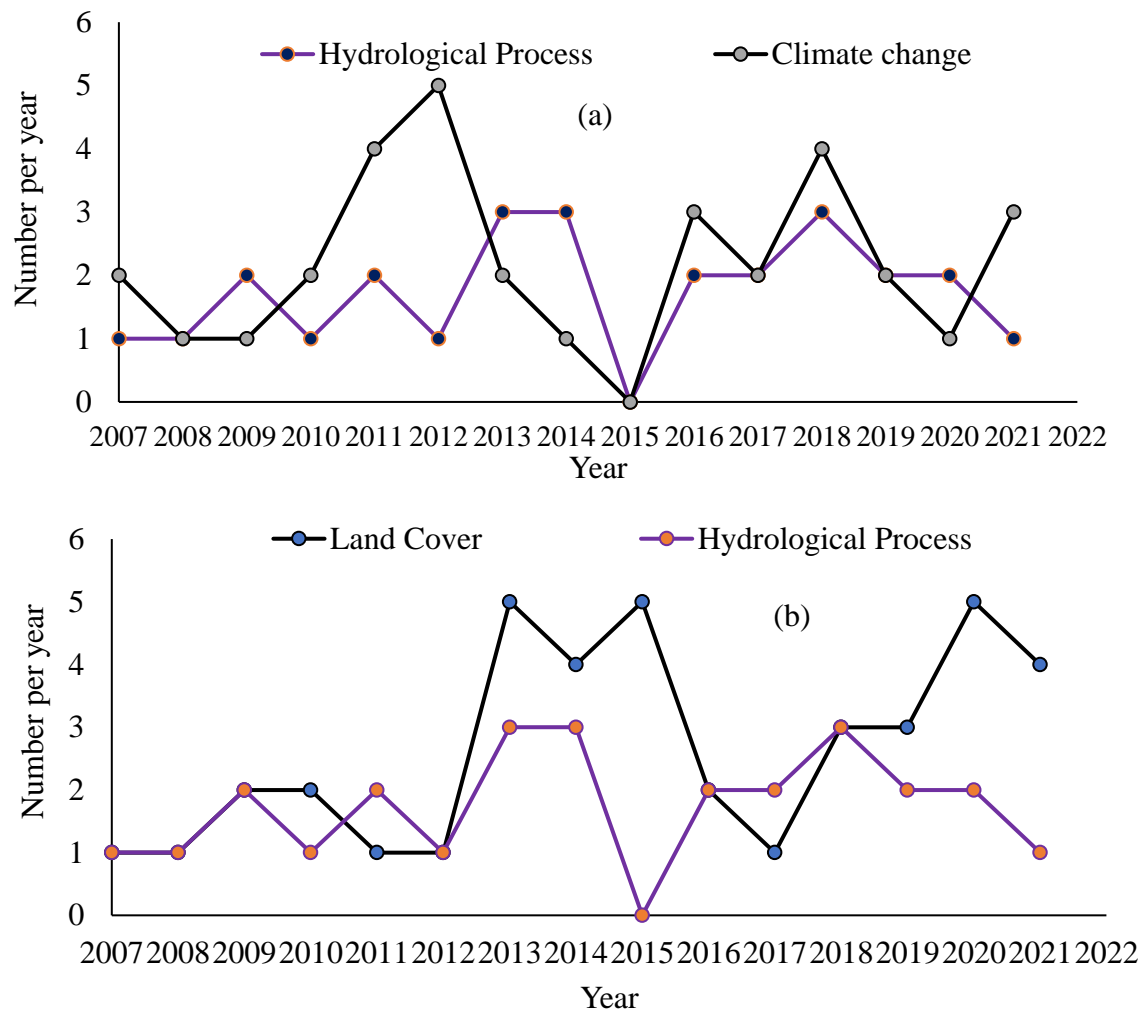


Figure 2.4 Frequency of refereed articles publications on land cover and hydrological process, and climate change utilized

Correlating LC activities at the appropriate temporal and spatial scales is thus a critical issue (Degife et al. 2018; Kassawmar et al. 2018). The upper Baro basin is detrimental to anthropogenic degradation mainly due to the large-scale expansion of agriculture, which leads to LC change over the lower Baro (Basin, 2021). Studies on the impacts of climate change on crop production fully address the three major cereal crops rice, wheat, and maize; other studies concentrate on the response and adaptation of crop cultivation to interactions between food production and climate change, which is a complex issue that necessitates a multi-dimensional, temporally and spatially precise analysis (Wu et al. 2014). Erodibility is the resistance of the soil to both detachment and transportation; the K-factor for Europe is evaluated using 22,000 soil samples gathered around Europe (Wang et al. 2016). In Ethiopia, cropland, around 15% of the area covered, is responsible for 2/3 of the overall soil loss in Baro-Akobo (Fenta et al., 2021).

They discovered that the USLE of the K-factor has a SI unit mean of 0.04 t hr/MJ/mm and a range of 0.01 to 0.08 t hr/MJ/mm. Averaging 0.03 in the SI unit, the K-factor values in China range between 0.02 and 0.04 t hr/MJ/mm. However, the K-factor for the Tikur Wuha watershed in Ethiopia is comparable to other results from different sources; studies in Ethiopia show that the K-factor value is significantly lower (Ketema & Dwarakish, 2020). As a result, lower Baro, based on William's (1995) equation and FAO soil, the chromic vertisols, humic cambisols, eutric cambisols, and eutric nitosols of the K factors of each soil type are 0.31, 0.23, 0.14, and 0.07 respectively as shown in Table 2.3.

Table 2.3 K- factors using William's (1995) equation and FAO Soil

Soil types	Sand (%) topsoil	Silt (%) topsoil	Clay (%) topsoil	OrgC (%) topsoil	f_{cssand}	f_{cl-si}	f_{orgc}	f_{hisand}	K factors
Humic Cambisols	55.2	21	23.8	3.86	0.20	0.80	0.97	0.15	0.23
Eutric Nitosols	68.4	10.5	21.2	0.60	0.20	0.72	1.00	0.52	0.07
Chromic Vertisols	22.4	24.5	53	0.69	0.20	0.71	1.00	0.21	0.31
Eutric Cambisols	36.4	37.2	26.4	1.07	0.20	0.85	0.99	0.85	0.14

According to several studies, soil physical qualities such as soil depth and compaction have a negative impact. Nevertheless, soil loss is a subset of land degradation processes that immediately impact soil. According to the soil texture map, four texture classes, silt loam 30, loam 14, clay 24, and sandy clay 29%, occupy over 97% of the land. In contrast, other textural classes comprise about 2% of the territory, and water occupies the remaining 1% (Woldegebriel & Garg, 2022). However, soil erodibility parameters are mainly carried out by nomograph for the selected samples (Wang et al. 2016). In a scientific study, it is crucial to evaluate correlations and interactions of soil among variables understandably. The resilience to weathering and the renewal of soil particles are additional important sustainability factors. The primary FAO soil types of the Baro River as shown in Figure 2.5.

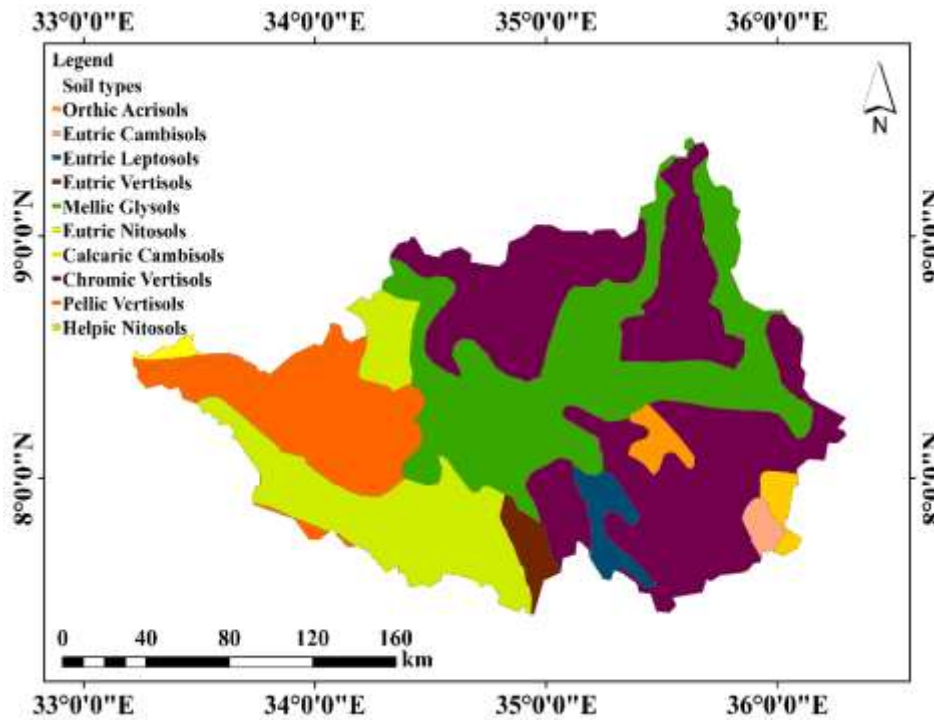


Figure 2.5 Major soil types of the Baro watershed (FAO, 2015)

2.22 Soil Erodibility related to surface water resources potential

Cropland soil loss was 2-15 times higher than non-cropland soil loss, meaning that agriculture covers around 23% of Ethiopia's total land area (Mihretie et al. 2022). This is due to the traditional crop production strategy exacerbating soil loss from agricultural regions (Tadesse & Zewdie 2022; Akram et al. 2019). In high land area cropland, humid sites lose more soil than semi-arid sites (Ebabu et al. 2023). But in low land, Baro is impacted by rapid soil erosion, soil quality, and agricultural output (Berhe et al. 2022; Embaye et al. 2020). The watershed is above the maximum allowable level are 36.64%; while 63.36% of the catchment's average annual rate of soil loss is 33.3 t/ha/yr (Kebede & Fufa, 2023). Additionally, this suggests that in areas where cropping occurs, careful consideration must be given to soil erosion conservation planning (Yimere & Assefa, 2022; Tadesse & Zewdie, 2022; Mandal et al. 2020). Almost all of the country's rivers originate in the highlands and high-rainfall zones, which have a considerable surface water potential of $124 \times 10^9 \text{ m}^3$, consequently known as East Africa's "Water Tower (Almaw et al. 2021). Soil erodibility is a valuable index for determining the soil's sensitivity to erosion and a critical component in understanding the mechanism of soil erosion. Despite the different

climate change scenarios, there is a variance in the rainfall change among various models due to a need for future climate change scenario-based data (Muleta, 2021). Surface water is generated by either infiltration excess or saturated excess mechanisms and is routed into the channels as sheet overland flow (Hatiye et al. 2017). This is related to seasonal fluctuations in precipitation volume, temperature, and ET rate in the study region. Rainfall is one of the critical inputs into the runoff process, and river discharge is understood to reflect an integrated response of the watershed (Chathuranika et al. 2022; Chintalacheruvu et al. 2022; Chandrashekar & Shetty, 2018). Ethiopia's annual wet flow has increased by 39%, while its average dry flow has decreased by 46% (Gashaw et al. 2018). In the region, large-scale commercial farms are also quickly expanding; there has been a loss in regional infiltration, tree clearing, flat ground, poorly managed drainage infrastructure, and atypical floods have become increasingly common; however, to maintain agricultural output, it is to reduce runoff, soil erosion, and nutrient loss (Rai et al. 2019).

2.23 Land cover change assessment

For decades, LC change has been a helpful parameter that has been the focus of extensive research in academic circles. LC change is not uniform worldwide; tropical forests are decreasing by 12 Mha/yr, and biodiversity loss in Ethiopia (Muluneh, 2021). The effects of LC changes on local hydrology in the lower Baro watershed need to be better understood due to large-scale agricultural LC dynamism. Additionally, the impact of these changes and the conversion of LC to irrigation land and dam construction may enhance crop output during the dry season, hence improving the quality of life for the community living near the research locations (Basin et al. 2021). Assessing the historical, current, and future anticipated LC dynamics is helpful (Land et al. 2021). Due to anthropogenic influence, the LC change on the Baro River from 1984 to 2010 up and down was noticed; in addition, the basin surface runoff potential is boosted from 37-49% (Kasaye, 2015); as we reviewed articles on Ethiopian river basin, built-up/ settlement, agricultural land, water body, bare/ outcrop, and commercial farm, all increased by around +195, +48, +35, 35, and +1%, respectively as shown in Figure 2.6. On the other hand, Range land, Shrub, forest and grazing land, and wetland decreased by 2, 4, 10, and 20%, respectively.

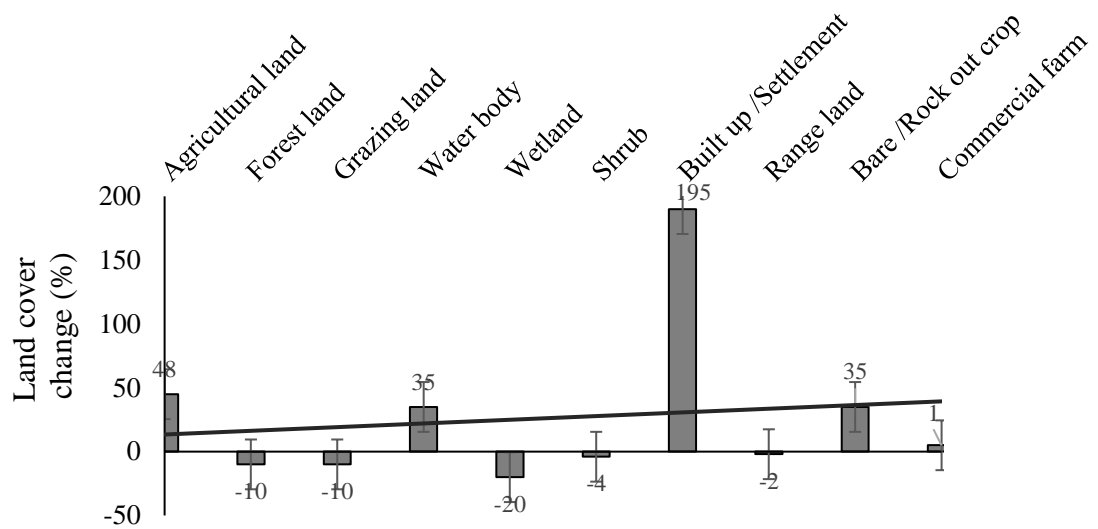


Figure 2.6 Land cover change percentage of lower Baro from 2007-2022

LC interacts with the climate in addition to temperature, and any change in the LC may result in alternative estimates of future climatic conditions; primary cereal crop production has increased at the national level, partly due to increased application of fertilizers and modern seeds, but significant global climatic events caused droughts and rain failures, as small changes in such climatic elements negatively affect the food security condition of both consumers and producers. Furthermore, rainfall-runoff erodibility and LC change predict soil erosion, while other variables, such as soil type and topography, are constant.

2.24 Soil and water conservation practices

To effectively execute preventive measures in the lower Baro, it is necessary to determine the soil erodibility potential in agricultural lands (Berteni, 2020). It aids in the protection of natural resources and watersheds, as well as the restoration of plant and wildlife habitats, water quality improvement, and soil health improvement. Extremely useful to find the optimum approach to utilize surface water resources without compromising any other features of the land's suitability for agricultural productivity. The degree of accuracy loss varies by category, ranging from minor to slight and moderate to severe.

2.25 Techniques for enhancing water use efficiency

The key strategies for enhancing water use efficiency (WUE) at crop, farm, and watershed levels are:

- Improving agricultural water productivity through the use of contemporary tools and methods such as geographic information systems, remote sensing, integrating water surface water resource planning, and district irrigation plans.
- Promotion of rainwater harvesting and artificial recharging of groundwater.
- Promotion of water recycling and reuse.
- Promotion of multiple uses of water through the integration of water harvesting with efficient irrigation techniques in different farming systems.
- Enhancing crop productivity through integrated watershed management.
- Use of weather forecasting and ICTs for efficient use of water.
- Promotion of awareness of government schemes about the conservation of surface water resources.
- Development of a user-friendly decision support system (DSS) for irrigation scheduling on a real-time basis.
- Reducing the gap between the irrigation potential created and utilized.
- Increasing the marketable yield of the crop per unit of evapotranspiration.
- Using efficient water-saving technologies like gravity-fed micro-irrigation systems, a system of rice intensification (SRI), raised bed planting systems, laser land leveling, direct-seeded rice (DSR), conservation agriculture, precision irrigation techniques, etc.
- Development of an automated irrigation system for enhancing water productivity.
- Development of site-specific irrigation and fertigation schedules to enhance water and nutrient use efficiency simultaneously.

2.26 Summary and conclusion of the LC change review

According to the prediction inquiry, LC is vital for monitoring the water balance. Using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) technique, the authors analyzed 85 previous studies on LC implications, hydrological parameters, and soil erodibility in Ethiopia's lower Baro watershed, a Single-article LC monitoring explained in various ways, with various outcomes. Only 2% of abstracts considered for review were from 2007-2022. The review study looked at the factors, features, estimates, and influence of the LC shift on hydrological variables, soil erodibility, as well as the relationship between the hydrological process with LC, hydrological process with climate change, potential ET, and rainfall in the lower Baro watershed.

The severity of accuracy loss varies by category, ranging from slight to moderate and moderate to severe. The analysis showed that the FAO soil data for lower Baro K factors are 0.31, 0.23, 0.14, and 0.07 for chromic vertisols, Humic Cambisols, Eutric Cambisols, and Eutric Nitosols. As a result, built-up/ settlement, agricultural land, water body, bare/ outcrop, and commercial farm all rose by roughly +195, +48, +35, +35, and +1% in lower Baro, respectively. Contrarily, Range land, Shrub, forest and grazing land, and wetland decreased by 24, 10, and 20%, respectively. The runoff hydrological process is influenced by ET, radiation intensity, wind speed, precipitation, soil water content, and temperature, among other factors. SWC techniques are critical for reducing soil erodibility in the lower Baro. Direct sowing and tillage procedures perpendicular to the gradient slope prevent regional runoff. Without adequate surface water resource management for irrigation expansion activities, urbanization and land clearing radically transformed the environment. In the future time series, increases in the C-factor, P-factor, and R-factor all climb rapidly. Soil fertility is an available nutrient representing an adequate amount and suitable proportion. The nutrients present, nitrogen, phosphate, potassium, and organic matter, are removed, that the reason for the reduction of soil fertility.

The gradual depletion in soil fertility and reduction in soil organic matter is highly related to the soil's physical, chemical, and biological properties of the soil. Soil conserves micro selectivity increased because of more aeration. Over irrigation and heavy rainfall of heterogeneous landscapes exhibit the nutrient moved into percolating water, which is leaching, and this nutrient became unavailable to the plant. Based on the findings of the review studies, the RUSLE is a promising option for assessing soil erodibility. For consistent outcomes in lower Baro, it will be essential to agree on regional LC change, soil erodibility, the possibilities criteria of a river watershed strategy in the future, and land suitability for irrigation productivity, as shown in Table 2.4.

Table 2.4 Criteria for major crops and land suitability for surface irrigation

Constraints	Criteria/Attributes	Points	Suitability class	Influence (%)
Elevation (m)	1,554-2,267	1	1 st degree	50%
	2,267-3,024	2	2 nd degree	
	3,024-3,215	3	3 rd degree	
	3,215-3,468	4	4 th degree	
	3,468-3,660	5	5 th degree	
Soil-adjusted vegetation index (SAVI)	>0.4	1	1 st degree	25%
	0.4-0.3	2	2 nd degree	
	0.3-0.2	3	3 rd degree	
	0.1-0.2	4	4 th degree	
	<0.1	5	5 th degree	
Normalized Difference Index (NDVI)	0.03-0.26	1	1 st degree	25%
	0-0.03	2	2 nd degree	
	-0.05-0	3	3 rd degree	
	0.1-0.2	4	4 th degree	
	<0.1	5	5 th degree	

The next chapter presents the study area, the data used, and the overall methodology of the research work.

CHAPTER 3 STUDY AREA AND RESEARCH METHODOLOGY

3.1 Introduction

There is a need to scientifically understand the drivers responsible for integrated surface water modeling and increasing irrigation productivity, particularly in the Ethiopian context of the lower Baro watershed tributaries. The objective of this chapter was to explain in brief the various steps that are involved in the execution of the objectives of this research and also briefly make a mention of the study area taken up for demonstration and the data used. Accordingly, this chapter is organized under the following headings.

- ♣ Salient features of the lower Baro River watershed as shown in Table 3.1
- ♣ Study Area
- ♣ Model selection and justification
- ♣ Data required for input parameters
- ♣ Running the modeling
- ♣ Calibration and validation of the model performance

Table 3.1 Salient feature of the lower Baro River watershed

Title	Description
Area	20,325 km ²
Uniqueness	The second-longest bridge in Ethiopia crosses the lower Baro, connecting two parts of the Gambella Region. This bridge is 305 m long
Biosphere	Majang Forest has also been listed as a new UNESCO Biosphere Reserve located in Gambella
State	SSNPR Gambella Regional State Ethiopia
Starting point	From the highest Nile Benishangul Gumuz
Ending point	Lower White Nile South Sudan
Length	306 km ² joining the Pivot River
Altitude	440 m and 500 m. a.m.s.l
Highest peak	2500 m down to Gambella
Rainfall	Annual 900 mm to 1500 mm
Temperature	Maximum exceeds 38 ^o C
Water Resources	Reaching the stream affording on an open waterway to White Nile
Soils	Marshy land vertisol with high erodibility

3.2 Location of the study area

The basin watershed is located in the Southwestern part of the country, between latitudes $8^{\circ} 28'40''$ N and longitudes $34^{\circ} 20'36''$ E, and covers an area of about 20,325 km². South Sudan borders it in the west. The eastern part of the basin consists of the hilly upland areas of a plateau. The basin is mountainous in altitude ranges below 500 to 3000 m.a.s.l, with 50% of the area falling below 1000 m.a.s.l and 42% between 1000 and 2000 m.a.s.l. The lower Baro watershed tributaries, as shown in Figure 3.1.

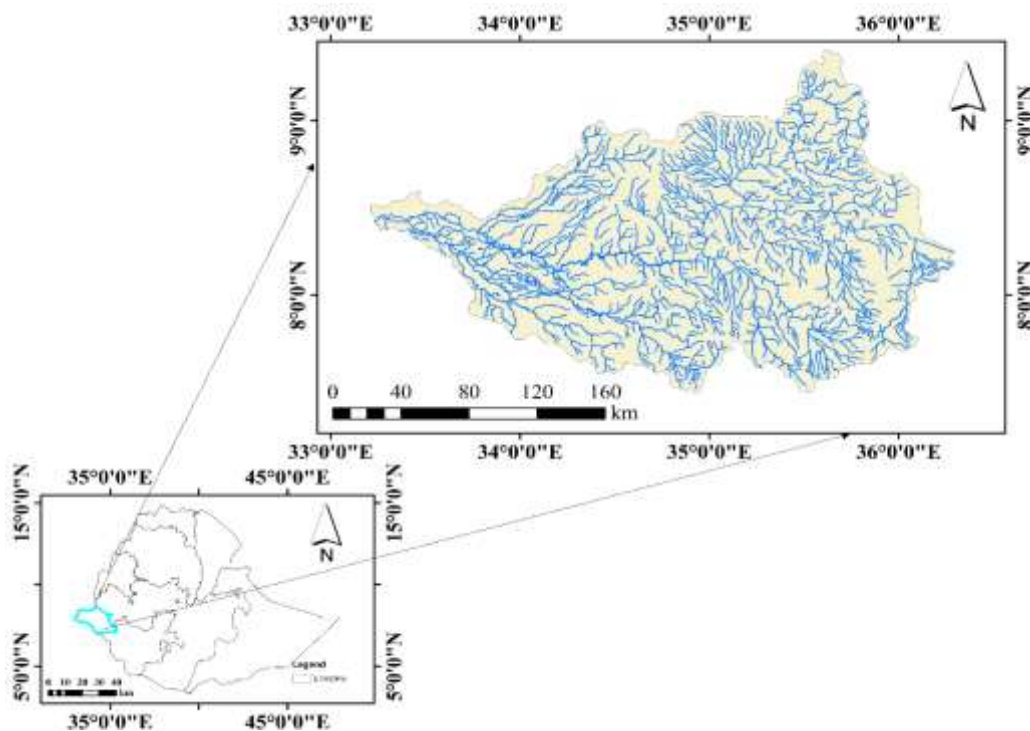


Figure 3.1 Main tributaries of the lower Baro watershed (2015-2018)

The eastern 2/3 of the basin area lies between 1000 to 2400 m.a.s.l, and the plain are gently sloping towards 400 to 500 m.a.s.l in the west. The limited surface water resources and low organic matter soils helped enhance the selected crop products and improve development conditions (Naghdyzadegan et al. 2022). However, the hydro-geologically basin watershed is dominated by mining, and less water resource development has occurred so far (Halefom & Ulsido, 2020; Worku Ayalew, 2018). Ethiopia is heterogeneous, so one climatic zone may not represent 100 km. The land use and annual average rainfall of the catchment were indicated based on Trewartha's classification using the data from Ethiopian National Meteorology Agency (ENMA), as shown in Table 3.2.

Table 3.2 Basic information on the river catchments (1986-2018) and the land use types of the lower Baro watershed

Catchment Name	Climatic Zone (Trewartha's classification)	Area (km ²)	Annual average rainfall (mm)	Area of land use types (ha)		
				Agricultural	Pastoral	Other
Alwero	Humid	4696	195.3	14,000	22,000	143,086
Gilo	Humid	1716.5	190.8	1,315	460	1000
Fugnido						
Birbir	Tropical	1563.0	104.4	634,415	8,115,000	14,280
Yibdo						
Gog	Humid	3,025	82	1,650	25000	29.3
Baro	Humid	2978.3	176	280,000	81,000	600,000
Gambella						
Baro Itang	Humid	325.25	173	1914.09	33.05	1499.22
Gumero	Tropical	1,249	208	25	3000	538
Gore						
Sor Metu	Tropical	1622	213	78	234	120

3.2 Digital elevation model (DEM)

The DEM data were used to create stream networks and delineate the watershed. Moreover, information on low flow is needed to estimate the amount of water available for surface water potential and irrigation water demand during the dry season. The DEM map of the lower Baro watershed tributaries is shown in Figure 3.2.

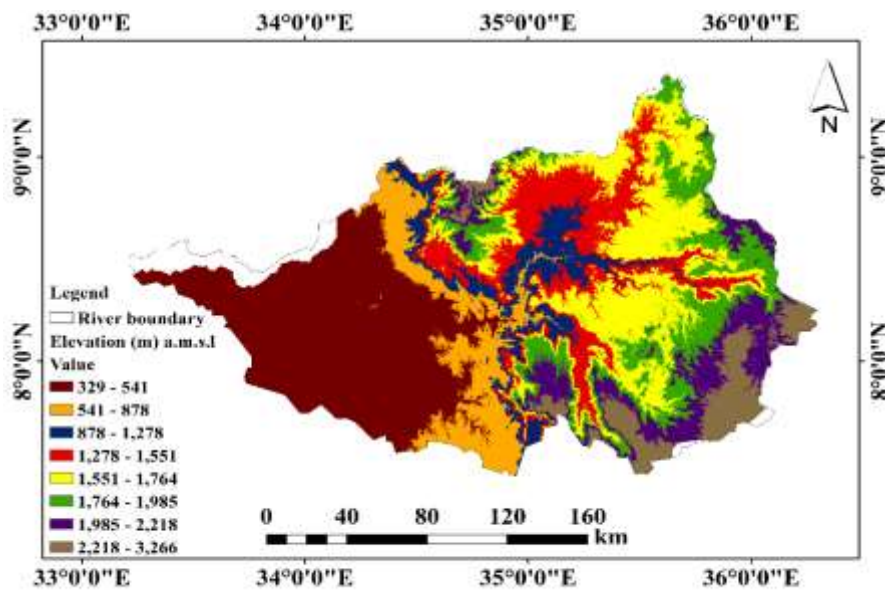


Figure 3.2 DEM of the lower Baro watershed tributaries

The difference between the water potentials of two liquids is known as the water potential gradient. The ability of water to move between two locations due to changes in pressure, dissolved solutes, and other factors is known as water potential (van Oort et al., 2017). The gradient of the water potential between two solutions directly affects the pace of osmosis; the more significant the gradient, the faster osmosis proceeds from higher to lower water potential. Water goes from an area with high water-free energy to one with low water-free energies; this idea helps rationalize how water can defy gravity and flow freely. Water potential shows how water moves through the tissues of plants by osmosis, capillary action, and defying gravity.

3.3 Surface water hydrology

Ethiopia is considered Africa's water tower due to its abundant surface water resources. Among the 12 river basins, the Nile basin, which produces 70% of the nation's renewable surface water, primarily through the Abay basin, includes the western Baro-Akobo, Mereb, Setit-Tekeze/Atbara, and Abay (Blue Nile) basins. These basins supply 86% of the yearly flow of the Nile as a whole. Over 20% of surface water resources in the central and northeastern Afar-Denakil, Awash, Omo-gibe, and rift valley basins cover much of East Africa. The southern Omo-gibe and rift valley basins have the greatest concentration of surface water resources. Moreover, the Awash Basin accounts for 4% of the country's supply, and the Afar-Denakil Basin in the far north needs water. The Awash Basin has a small pool, a high demand, and little yearly precipitation on average; 8% of Ethiopia's surface water is in the eastern Wabi-Shebelle and Genale-Dawa basins, a portion of the Shebelle-Juba basin.

3.4 Geology, slope, soils, and land use:

Some work on erosion and conservation measures in the part of the lowland of the Akobo Basin, an area dominated by flat to hilly grass-covered savannah terrain and soil studies (GSE, 2016). The slope of infiltrating surface has the most significant effect on surface runoff production when the soil is closer to field capacity and even saturation. One of the most critical factors determining soil quality and its appropriateness for agricultural production is soil texture (Mersha et al. 2018; Khalil, 2017). The geological map of the lower Baro watershed tributaries is shown in Figure 3.3.

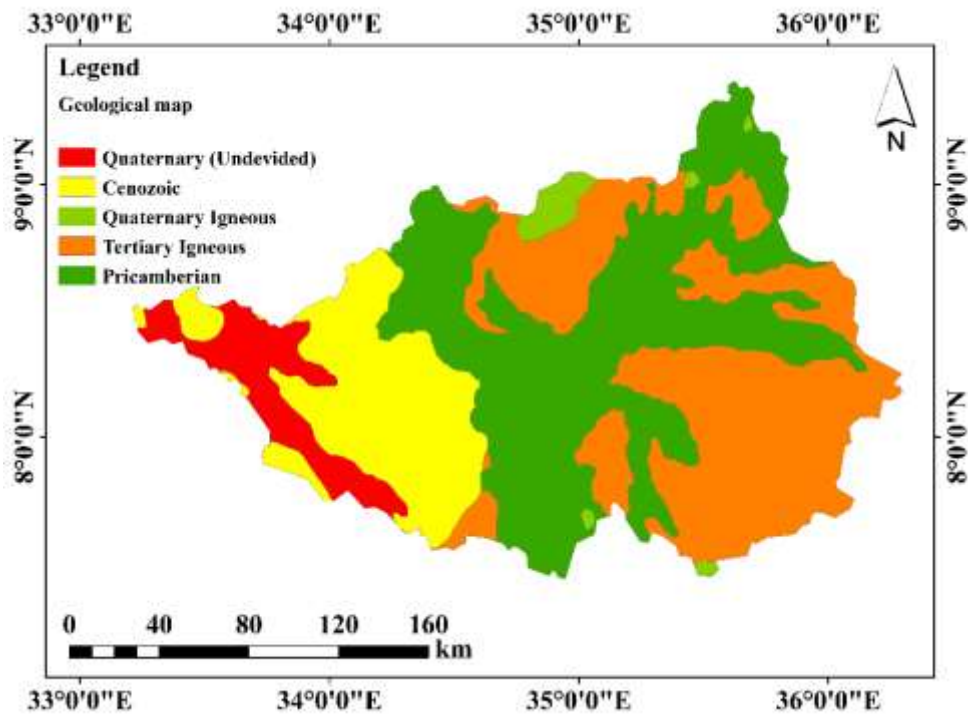


Figure 3.3 Geological map of lower Baro watershed tributaries

Land usage relates to how the land cover affects the hydrology, including water, grassland, and forests covering the Earth's surface; including built-up, recreational, and agricultural areas. Concern for its various environmental effects, or LU/LC change, has spread worldwide. Since several years ago, land use changes have significantly impacted global environmental variation (Kabite et al. 2020; Belay & Mengistu, 2021). Similarly, land use affects the irrigation water demand of crops grown in irrigated and rainfed systems (Wang & Yang, 2014). According to the literature review, social pressure and a fast-rising population drive and cause the size of irrigable regions (Dau et al. 2021). Many developing countries face different challenges in producing rice, sugarcane, maize, and vegetables, such as dependence on rainfall and inadequate water for irrigation purposes (Gebul, 2021; Embaye et al.2020). Agricultural productivity influences land use when water supplies are scarce (Fikadie et al. 2022). Land use Map of the Baro River watershed as shown in Figure 3.4.

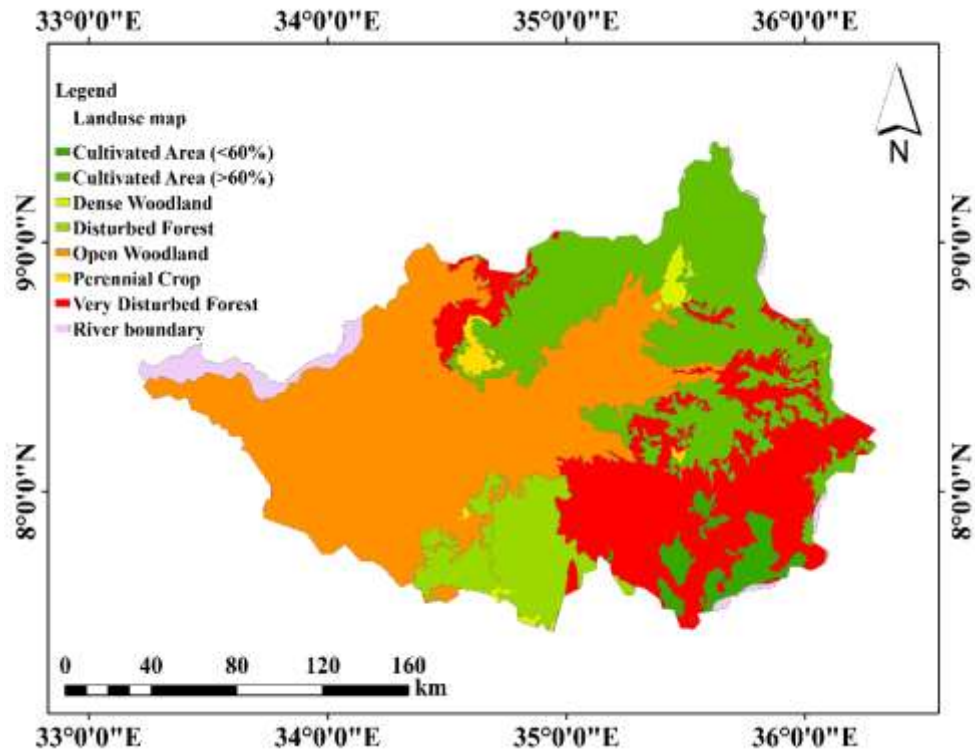


Figure 3.4 The land use map of the lower Baro watershed; source: own elaboration based on MoWE data from (2017-2020)

The mean temperature range in the area is about 27.5°C below 500 m on the flood plain to about 17.5°C at 2,500 m in the highland. The range in mean maximum temperature is 35 to 24°C and in mean minimum temperature from 20 to 10°C. Temperature peaks during 9 February and March on the flood plain, but high values extend into April in the highlands. Below about 700 m elevation, mean maximum temperature values exceed 38°C for two to three months, as shown in Figure 3.5. Ethiopia's agriculture sector plays a central role in the lives and livelihoods of most Ethiopians (Getnet & Dugasa, 2019). The average household needs roughly 2.5-2.8 hectares of land (Dc, 2015). Maize is one of the most widely grown cereals in the world and an important food crop for many countries worldwide (Hordofa et al. 2008). The climate of Ethiopia and its dependent territories varies greatly; however, temperate on the plateau and hot in the lowlands. The weather is usually sunny and dry, but the short (belg) rains occur from February to April, and the significant (Meher) rains are from mid-June to mid-September. The climate is very healthy and temperate over the more significant part of Ethiopia and the Oromia highlands, as shown in Figures 3.5 and 3.6.

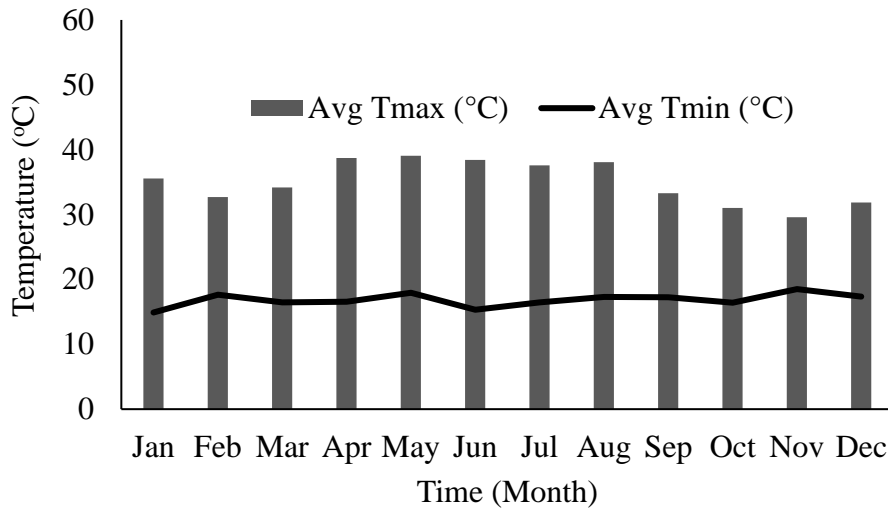


Figure 3.5 Average monthly maximum and minimum temperature over lower watershed (1986-2018)

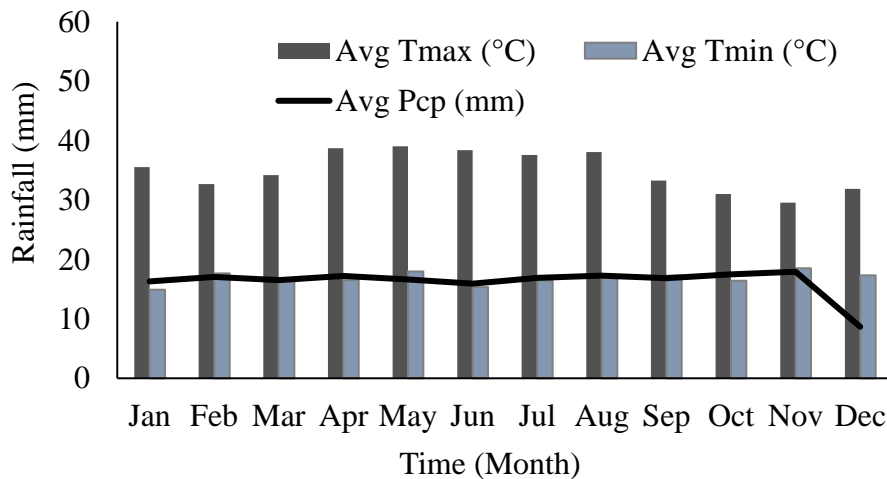
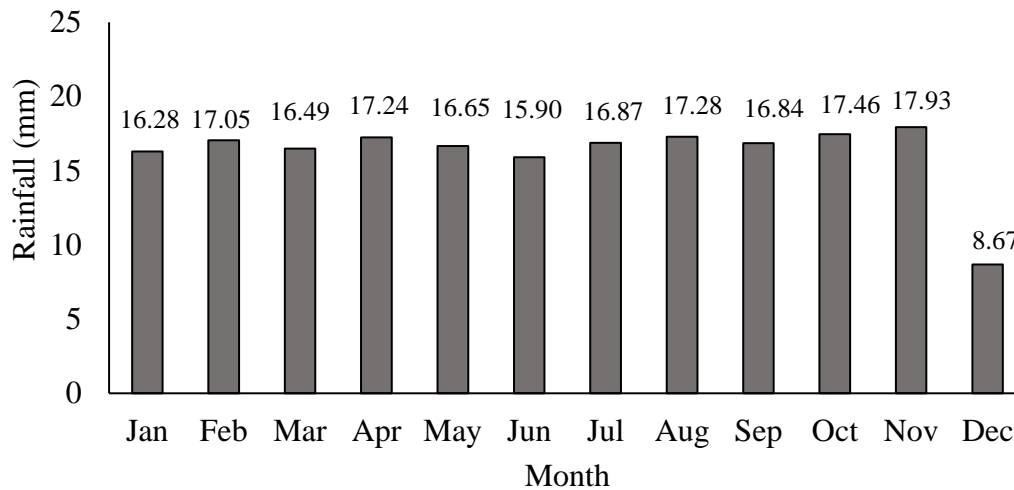


Figure 3.6 Average monthly maximum and minimum temperature and rainfall for the lower watershed (1986-2018)

The fate of rainfed crops, especially in sub mountain tracts without irrigation systems due to the hard subsoil surface water, is determined by rainfall, a crucial component of the soil water balance. As a result, its rapid quantification is crucial for identifying strained areas and rescheduling irrigation plans to increase the area's water and land output. The estimated rainfall is then utilized to calculate the rainfall water productivity. The study is expected to be beneficial to managing the surface water resources sufficient to ensure the long-term water supply for irrigation. The monthly average rainfall over the lower Baro watershed is shown in Figure 3.7.



**Figure 3.7 Average monthly rainfall for the lower Baro watershed
(ENMA, 1986 2018)**

3.5 Data collection and quality testing

The essential preliminary step in trend detection analysis is data quality assessment. In this study, particular emphasis to quality control and data set selection. Given that the strong trend of probability density function analysis needs comparatively long records, a first selection was made among all available stations before further control of data quality and homogeneity testing for consistency across the station network. The monthly and annual data collected from the Ethiopian Meteorological Agency from eight meteorological stations from 1986-2018 were subject to homogeneity tests. The list of the rainfall stations' names and their missing data (%) is in Table 3.4.

Table 3.4 Showing the rainfall stations and missing data (%)

Station Name	Missing data (%)
Alwero	0.05
Gilo Fugnido	0.02
Birbir Yubdo	0.01
Gog	0.04
Baro Gambella	0.01
Baro Itang	0.06
Gumero Gore	0.07
Sor Metu	0.03

The streamflow/discharge data and land cover data were acquired from the Ethiopian Ministry of Water Resources Irrigation and Energy (MoWE) Department of water resources and Hydrology. The population growth rate percentage of 2.7% was used based on the Central Statistical Agency of Ethiopia. With this growth rate, in 2049, the total population of Ethiopia become 200 million. The quality of the rainfall and streamflow missing data was filled in Excel stat 2019. The annual and monthly streamflow variation of 45-years data was performed using graph pad prism 9.4. All the climatic data were arranged as per the model's input requirements. Such as temperature maximum and minimum in ($^{\circ}\text{C}$), relative humidity (%), wind speed (km/day), and sunshine hour (hr). The streamflow data point of eight stations is compared with the recently published work. In the cropwat8.0 model, the crop water requirement and the daily climatic data were used. In this study, four crops were selected, namely rice, maize, sugarcane, and vegetable. Based on the selected criteria, three methods are used in the cropwat8.0 model to calculate the crop water requirements in the lower Baro watershed. These are fixed percentage, dependable rain (FAOAGLW), empirical formula, and United States Department of Agriculture (USDA). Moreover, the study considered pre-pudding irrigation at 0.5 m of soaking depth in the soil moisture condition to assess evapotranspiration. The crop ET_c in the Cropwat8.0 model is defined in (Eqn. 3.1).

$$\text{ET}_c = \text{ET}_o * \text{Kc} \quad (3.1)$$

Where Kc is based on the various crop types and their developmental stages

3.6 Method for calculating evapotranspiration

There are many indirect methods to estimate ET_o, but choosing the best given the data can take time. In this study, the FAO- 56 Penman Monthieth equation was used in the current investigation to estimate daily ET_o, as shown in (Eqn 3.2). The estimation of daily ET_o can be written as (Abera Abdi & Ayenew, 2021; Debnath et al. 2015).

$$\text{ET}_o = \frac{0.408\Delta.4_n - G) + \gamma \frac{900}{T_{\text{avg}} + 273} W_s (e_s - e_a)}{\Delta + \gamma(1 + 0.34W_s)} \quad (3.2)$$

E_{To} = Reference evapotranspiration (mm/day),
 R_n = Net radiation at the crop surface (MJ/m²day),
 G = Soil heat flux density (MJ/m²day),
 T_{avg} = Daily air temperature at 2 m height (°C),
 W_s = Wind speed at 2 m height (m/s),
 e_s = Saturation vapour pressure (kPa),
 e_a = Actual vapour pressure (kPa),
 $e_s - e_a$ = Saturation vapour pressure deficit (kPa),
 Δ = Slope vapour pressure curve (kPa/°C), and
 g = Psychrometric constant (kPa/°C).

3.7 WEAP model approach

WEAP applies to water demand systems, single catchments, and complicated transboundary river systems as the primary operational basis of a water balance (Arnold et al., 2015). WEAP may also deal with various topics, including sectorial demand studies, water conservation, water rights, allocation priorities, streamflow simulations, reservoir management, and hydropower generation (Dau et al., 2021). In the lower Baro WEAP model, the hydrological systems are represented as nodes and links. Specific to hydropower potential, irrigation water demand, livestock water demand, and surface water potential, since it is generic, the model is best applied to scenario-identifying demand assessment in irrigation (Mersha et al., 2018). The weighted LC, monthly observed rainfall, streamflow, and water use rate were all used to run the WEAP model. The key assumptions are the water use rate and the water consumption in soil moisture methods for estimating the scenario-based surface irrigation potential and crop water demand. Moreover, the reference scenarios in this study are rainfall and streamflow from 2000-2014 and 2020-2030. The assessment was carried out in the annual and monthly irrigable and rainfed areas of eight stations of the lower Baro. Setting the impact of minimum flow requirements on water demand, the model achieved the desired downstream outcome for the river basins (De Oliveira et al., 2022). This ensures the downstream biological integrity of most rivers by protecting streamflow to an average of 80% (Giri et al., 2018).

3.8 Surface water resource assessment

The WEAP model also helps to provide a system for maintaining supply information besides the simulation of demand and flows (Abdulwahd et al., 2020; Rousta & Araghinejad, 2015). They accounted for the soil moisture method on empirical functions describing ET, surface runoff, and percolation loss within the watershed. Besides, using the PEST routine from the WEAP system, the manual calibration and validation performance evaluation of the observed annual and monthly streamflow data were conducted in eight gauging stations. Namely, Alwero, Gilo Fugnido, Birbir Yibdo, Gog, Baro Gambella, Baro Itang, Gumero Gore, and Sor Mettu. Moreover, the trend of ET was related to surface irrigation potential in the study area.

The WEAP hydrological model used long-term average climate data such as rainfall, high and low temperatures, relative humidity, wind speed, natural recharge, storage capacity, monthly mean values of stream flow, catchment LULC, and average Kc value to determine the surface water demand and potential in the watershed (Kahlerras et al. 2018). The model parameters include water circulation between layers and each layer's water storage capacity (Negasa et al. 2019). By dividing a watershed unit into N fractional areas reflecting different land uses and soil types, the water balance of each fractional area j of N may be calculated. Each sub-climate catchment's water balance is computed assuming it is uniform, as shown in Eqn 3.4.

$$Rd_j \frac{dz_{1,j}}{t} = p_e t - PET(t)k_{c,j}(t) \left(\frac{5Z_{1,j} - 1 \cdot j^2 Z_{1,j}^2}{3} \right) - p_e(t) Z_{1,j}^{RRFj} - f_j k_{s,j} Z_{1,j}^2 (1 - f_j) k_{s,j} Z_{1,j}^2, \quad (3.4)$$

$Z_{1,j} = [1,0]$ represents relative storage as a function of total effective root zone storage (mm) for the fraction of land cover, j. p_e is the effective rainfall. It's taken for granted that it's zero. PET is potential evapotranspiration, and $k_{c,j}$ is the crop/plant coefficient for each fractional LC. The third term refers to surface runoff, with $RRFj$ denoting the land cover's runoff resistance factor. The storage factor, $k_{s,j}$ is ignored when an alluvial aquifer is added to the model and a runoff/infiltration link is created between the watershed unit and the groundwater node. Each sub-catchment surface and interflow runoff at time t is written in Eqn 3.5.

$$RT(t) = \sum_{j=1}^N A_j p_e(t) Z_{1,j}^{RRFj} + f_j k_{s,j} Z_{1,j}^2, \quad (3.5)$$

Where,

$RT(t)$ = the total surface and interflow runoff

A_j = the watershed unit contributing area

3.9 Creating a baseline scenario

In urban and rural locations, water usage and consumption patterns differ in any place of the region lower Baro. In comparison to rural areas, metropolitan areas use more water. People in rural areas rely on pools, tube wells, bore wells, and other sources of water, whereas city dwellers are completely reliant on municipal water supplies. Based on rainfall and streamflow scenarios for the next few years from December 2014-January 2030 are considered in the WEAP model to assess the surface water demand and supply side. Moreover, the temperature and precipitation were affected by climate change over the time frame. However, without considering future natural flows, evaporation, and groundwater recharge will all shift (Hamza & Getahun, 2022).

3.10 Calculating the soil moisture balance

One crucial area that needs attention is the computation of the soil water balance, and for aspiring scientists, in particular, a thorough understanding of their hydrometeorology underpinnings is essential. Additionally, consider how these can increase production potentials by changing ET water as possible to the transpiration components, giving plants access to more nutrients. Therefore, the estimation/calculative portion of the various soil moisture balance components must be distinguished.

3.11 Research methodology adopted

A broad research methodology was formulated to achieve this study's objectives. This dynamic trend analysis of the probability density function of hydroclimatic variables and the detailed analysis of the statistical Easy Fit model in lower Baro tributaries. In addition, the WEAP hydrological model integrates various input data within a GIS and RS framework and simulates the hydrologic impacts of likely change in LC implication soil edibility and climate change impact on surface water in the lower Baro watershed. Figure 3.8 depicts the flow of tasks performed in this study. Subsequent chapters of this thesis provide a detailed description of each task and a discussion of the results obtained.

Using satellite ET-based FAO WaPOR irrigation performance for Alwero irrigated area and the global yield gap atlas for rainfed agriculture was performed, unlike other studies. This study's subsequent chapters go into great depth about these undertake and a discussion of the outcomes. The quantification of surface water potential and irrigation demand scenario assessment in the study watershed is covered in the following chapter.

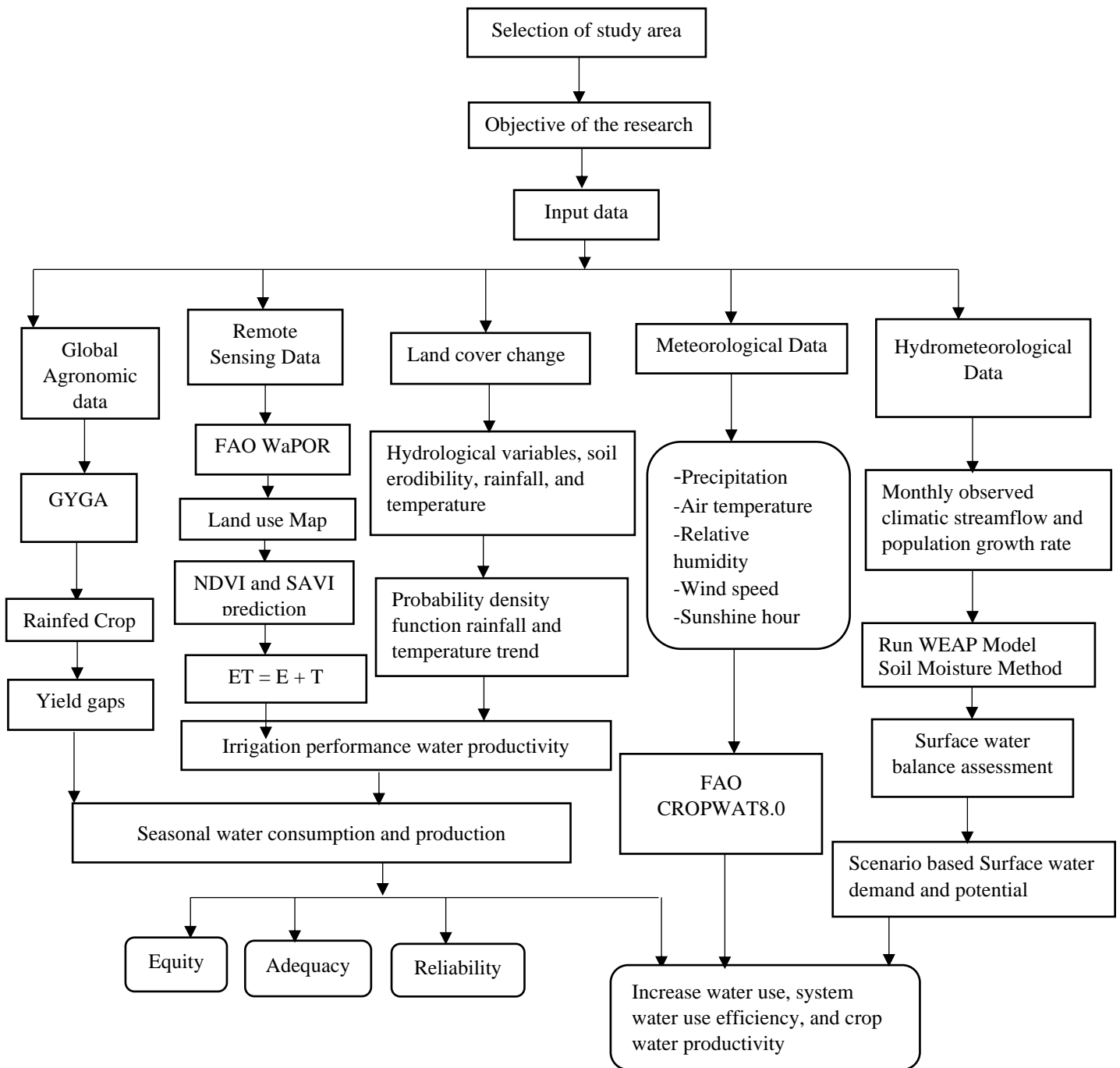


Figure 3.8 Research methodological framework of the Study

Table 3.5 Tools/platform and data used in this study

Tools/Platform	Purpose
ESRI, 2020	Land cover change extraction from 2017-2023
Arc GIS 10.3	Using the pixel value of the confusion matrix to visualize and evaluate geographic data
FAO WaPOR	Quantification of water productivity concerning irrigation performance
Easy Fit 3.0	Statistical analysis, the hydrometeorological data GOF tests:1) Kolmogorov-Smirnov, Anderson-Darling, and Chi-squared
Cropwat8.0	Irrigation Scheduling
CSA	No of holder including crop output, seed rate, and fertilizer application
NDVI and SAVI	Used to drought indicator and minimize soil brightness influences using a soil brightness correction factor
Graph pad prism 9.4	A statistical tool used in this study for streamflow variability

CHAPTER 4 STATISTICAL AND TREND ANALYSIS OF HYDRO METEOROLOGICAL DATA

4.1 Introduction

This chapter examines the hydro-meteorological trend changes in space and time that have taken place and whether or not they are significant. Hydro-meteorological time series almost always exhibit seasonality due to the periodicity of the weather. We need precipitation, temperatures, and discharge data to see the surface water potential trend variability and changes. River discharge reflects an integrated response of the basin, while rainfall is one of the significant inputs into the runoff process. The different reviews revealed that its potential impacts on the Eco-hydrological systems are an issue in the basin area using distributed hydrological models. For observed data showing high seasonality, methods to analyze trends should incorporate the seasonal component. The rainfall variability since rainwater is the primary source for the agriculture sector reported by Chandrashekar & Shetty, (2018). On the other hand, in Nepal Kulekhani hydropower project of 60 MW indicated that the impact of climate change on the hydrology of a basin and its resultant effects on electricity production is up to 30% (Shrestha et al. 2016; Gebrehiwot & Gebrewahid, 2016). Recent studies have found broad consensus that global surface water resource availability and management are impacted by climate change in both the present and the future (Abebe & Kebede, 2017).

Analyzing rainfall and streamflow trends provides valuable information for influential hydrological variables, water resource planning, and management systems. The variability analysis helps in understanding hydrological and climatic variables' performance and features over time. Given the rate at which the global average temperature has climbed over the last 36 years, the semi-dry zone of northern Ethiopia just have its highest temperature in the previous 40 years (Cherinet et al. 2019). The variability of rainfall brought on by climate change at various geographical and temporal scales has piqued the interest of the scholarly community. Recently, there has been much concern about how global warming affects the Earth's climate on different regional and temporal dimensions.

The continent of Africa's nearby water is experiencing rising air temperatures. However, The average annual maximum temperature has increased by roughly 0.10 °C every ten years. In contrast, the average annual lowest temperature has been rising by about 0.25 °C every ten years across the nation ENMA, 2007. Recently Ethiopia's temperature dropped to 23.35 °C in 2021 and from 23.38 °C in 2020. The vegetation ranges from Acacia seyal to Balanites aegyptiaca savanna forest in the east through grassland to seasonal marshes and swamps in the west, with rainfall in the highlands exceeding 2000 mm throughout a rainy season of 10 months, while it is only about 600 mm in the lowlands. Hydrologic variables such as ET, radiation intensity, wind speed, precipitation, soil water content, and temperature affect the runoff hydrological process (Malede et al. 2022; Li et al, 2020). Seasonal variations in the amount of precipitation, temperature, and the ET rate at the study region significantly impact the lower Baro watershed. Methods incorporating the seasonal component should be used to analyze trends for observed data exhibiting strong seasonality. In this chapter, the significance of the changes in hydro-meteorological trends that have taken place across time and space is examined.

4.2 Methodology

4.2.1 The goodness of fit tests

A preferred distribution information criteria approach measures the relative goodness of fit. However, they do not evaluate the model's goodness of fit when linking models together. This study used the Easy Fit program by Math ware technologies to fit the statistical distribution in the lower Baro watershed. It has several mathematical tools for the statistical analysis of extreme occurrences. All of the statistical probability distributions mentioned in these works, as well as a vast number of others, are supported. According to the movement, strength, and magnitude of the storm, rainfall events in the arid and semi-arid tropics exhibit spatial and temporal variability, leading to significant differences at local scales (Vargas et al. 2020). Convective rainfall contributes to rainfall's spatial and seasonal variability and is a crucial component of tropical and subtropical weather systems (Tessema et al. 2020). The dynamic behavior of convective rainfall in terms of volume, intensity, and peaking time affects the reactions of streamflow. The urgency of predicting rainfall's spatial and temporal variability is increasing due to global climate change (Mimikou and Baltas, 2013).

a) Kolmogorov Smirnov test

The maximum discrepancy is called the D-statistics (D_n) which is compared to the critical D-statistics (Yevjevich 1972), $f_n(x) = 1/n$ {number of observations $\leq x$ }, and $D_n = \text{maximum } (F_n(x) - f(x))$. The critical -D-statistic depends only on the sample size (n). Astafurov et al., (2017) provide a detailed table of critical distance values for a range of sample sizes. Since it was developed to confirm the data distribution, this test is regarded as a non-parametric test.

b) Anderson Darling test statistics

The test assumes that there are no parameters to be estimated in the distribution being tested, in which case the test and its set of critical values are distribution-free as shown in Eqn 4.1.

$$A^2 = -\frac{1}{n} \sum_{i=1}^n (2i-1) [(\ln)f(x_i) + \ln(1-f(x_{n-1} + 1))] \quad (4.1)$$

where n is the sample size and i is an index of the data set.

c) Chi-squared goodness of fit test

The statistical test establishes whether or not a variable is likely to come from a given distribution. It is frequently used to assess how well sampling data represents the entire streamflow data.

4.3 Temperature and precipitation affecting the yield

Crop water productivity, temperature, and precipitation are two climatic elements affecting yield gaps. Temperature and precipitation show meaningful, moderate-to-strong connections with yield for each crop. The temperature reaches the limiting factor, and irrigation is longer beneficial for improving yield (Degife et al., 2021; Sileet et al., 2013).

4.4 Results and discussion

4.4.1 Spatial and temporal analysis of meteorological data

The significance of the statistical probability density function distribution was the results of the temporal fluctuation of hydrometeorological variables at annual average values in this study.

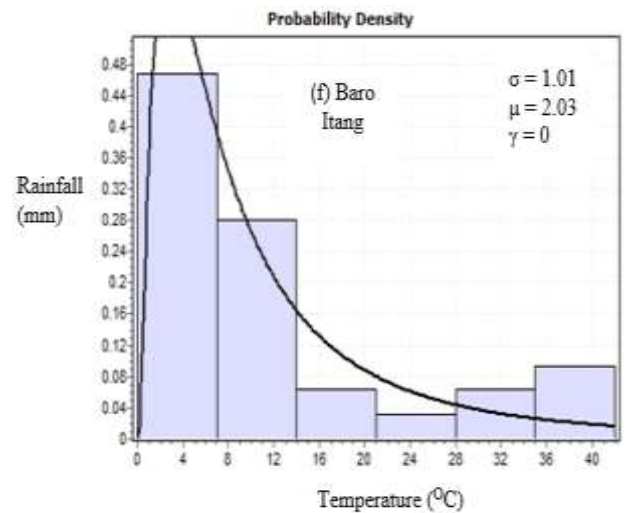
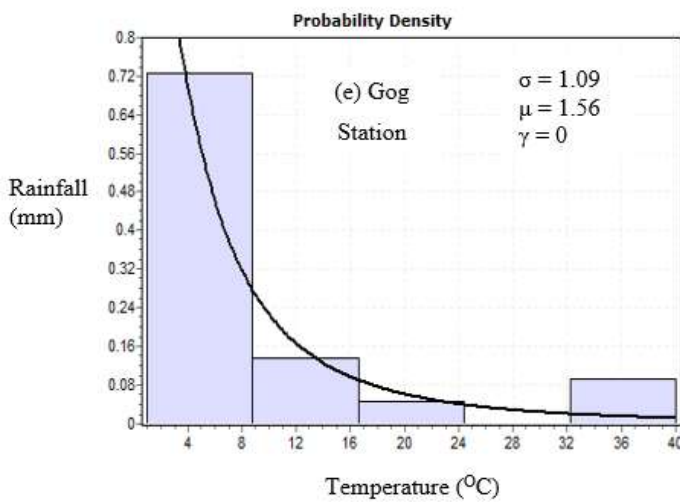
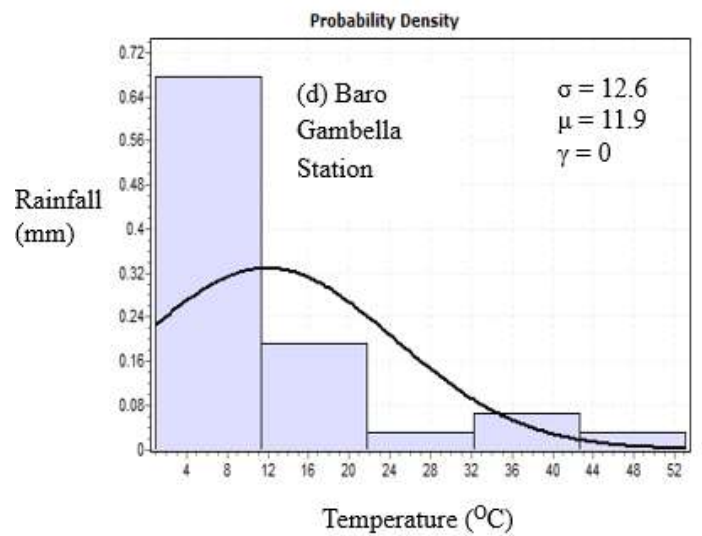
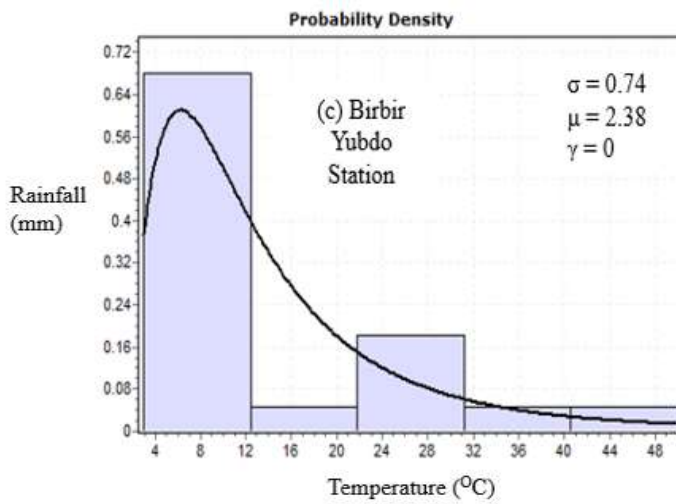
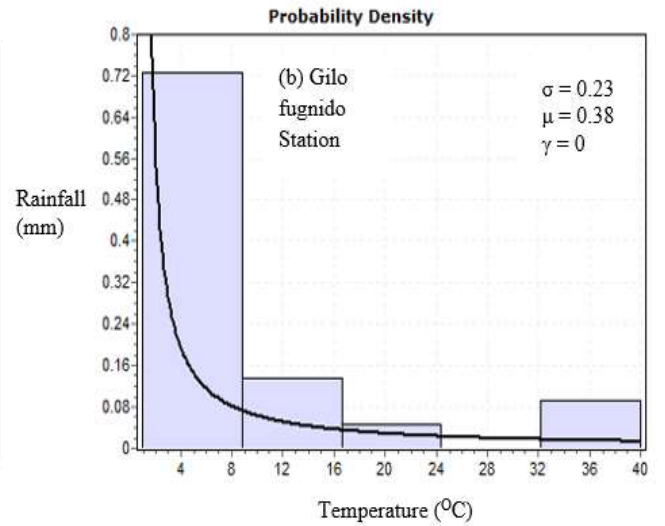
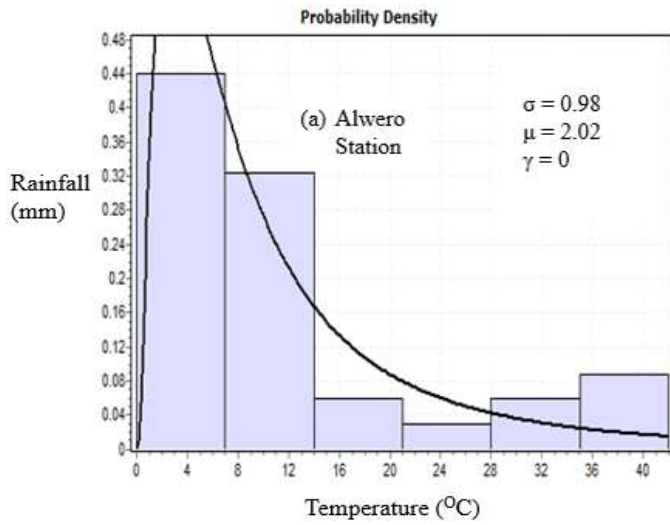
Moreover, the spatiotemporal variability of the analyses of hydrometeorological components provides a further understanding of the hydrological process and hydrometeorological modeling. In the past, the lower Baro watershed had relatively higher evapotranspiration than other watersheds, whereas the spatiotemporal temperature fluctuation was generally minimal.

4.4.2 Pattern and variability of rainfall and temperature

As a result, the Kolmogorov Smirnov test, Anderson Darling test statistics, and Chi-squared goodness of fit test show significant changes in the rainfall and temperature in the distribution being tested. The test set of maximum critical values observed in the Baro Gambella sub-catchment shows that $\sigma = 12.6$, $\mu = 11.9$, and $\gamma = 0$, and the corresponding lowest observed result found in the Sor Metu sub-catchment $\sigma = 0.80$, $\mu = 1.75$, and $\gamma = -0.03$. The lower Baro watershed is one of the tributaries of the White Nile in South Sudan, shows high spatial and temporal rainfall variability (annual and seasonal); rainfall tends to increase in the southern section of the watershed while tending to decrease in the northwest (Malede et al. 2022). According to Tola & Shetty (2023), extreme rainfall indices have a less than 20% overall variance over the upper Awash basin; although there is significant regional variability ($CV > 30\%$). This may be the result of topographical elements like climate change and rainfall and streamflow variability. Similar findings with Gebremicael et al. (2017) also stated that the monthly rainfall variation in the Tekeze Atbara basin is topographically determined (Malede et al. 2022). The correlation between rice, sugarcane, and vegetable yields is larger than the correlation between temperature and maize yields.

Numerous statistical probability distributions, such as those covered in these studies, have been supported (Mishra et al. 2013). Easy Fit supports the following GOF tests: 1) Kolmogorov-Smirnov, Anderson-Darling, and Chi-squared. The graph presents the distributions ranked by the GOF statistics, allowing one to choose one or more models that accurately represent the data. The statistical properties of several distributions, including scale and shape parameters, mean, variation, standard deviation, kurtosis, and skewness coefficient. One can quickly determine the chance of rainfall using the scale, shape, and other parameters (Mandal & Choudhury, 2015). Regional probability dependencies may arise from physical causes, such as large-scale meteorological occurrences.

In light of this, as previously said, the region should first be described to determine which statistical distribution best explains the anticipated temperature and rainfall events. The variability in temperature and rainfall over time in eight stations is shown in Figure 4.1.



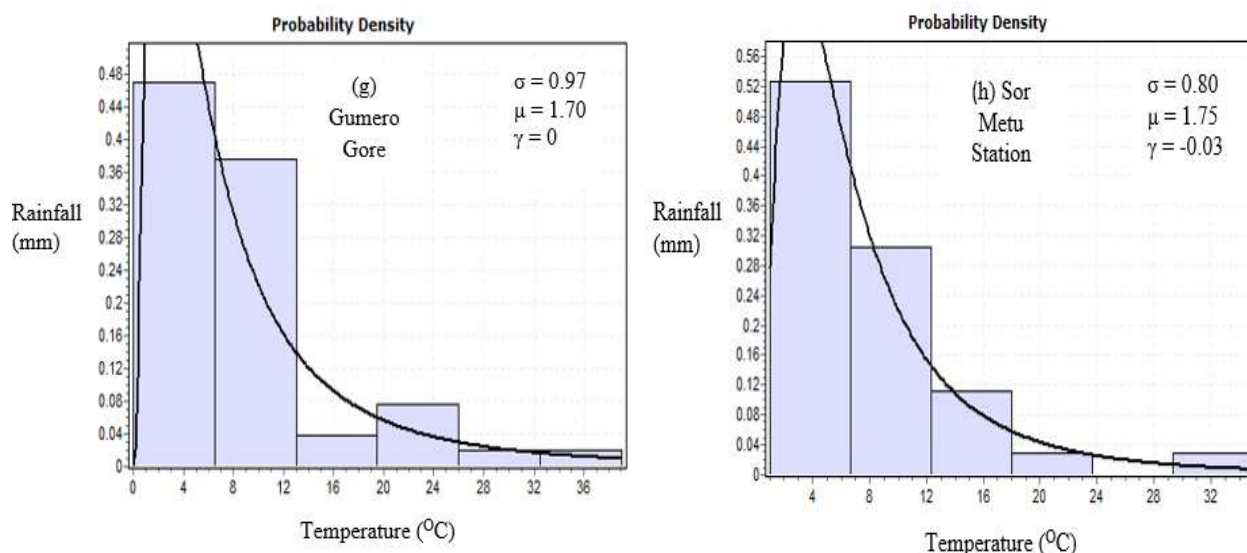


Figure 4.1 Variability in temperature and rainfall over lower Baro tributaries

4.5 Streamflow variability in the kiremt (rainy season) in eight sub-catchments of Baro River

Streamflow tends to rise towards the downstream region in watersheds with low elevation. The functional relationship between the yearly average streamflow and elevation explains the spatial variability of the water availability in the watershed. According to Table 4.1, the lower Baro Alwero station minimum streamflow coefficient of variation (CV) changes between 0.34 in 2009 and 0.71 in 2019. Streamflow may be better understood because of the surface water and ocean topography mission, which is launched in December 2022; with three products, to monitor almost 200,000 rivers with a width of over 100 m, with overpasses occurring every 21 days (Lodge et al. 2023). However, the year is divided into three seasons namely Kiremt (the "major rains" season, June-September), Bega (the dry season, October-February), and Belg the "little rains" season, March-May (Muleta 2021). Moreover, the analysis for the Bega (dry season, October to February) and Belg ('little rains' season, March to May) was not conducted due to various obstructions in the lower stream portion of the Baro River. Long-term kiremt season streamflow trend variability (June-September) was examined using the eight streamflow gauging station data.

Table 4.1 Alwero average annual streamflow station

Date	Annual Average Discharge (m³/s)	Mean	STD	CV
2009	3	3	1	0.34
2010	3	3	1	0.35
2011	2	3	1	0.37
2012	2	3	1	0.38
2012	2	3	1	0.40
2014	2	3	1	0.42
2015	2	3	1	0.43
2016	3	3	2	0.45
2017	3	3	2	0.50
2018	3	3	2	0.58
2019	3	3	2	0.71

One of the most frequent changes humans make to a flowing water system is a long-term or permanent change in the amount of water that flows through the river or stream channel. Streamflow normally increases in the basin's downstream area, where the elevation is low (Molla & Abdisa, 2018; Muleta, 2021). The annual average streamflow with elevation is used to explain the spatial variability of streamflow. At the lower Baro Gilo Fugnido station, the CV of the lowest streamflow varies from 0.7 in 1990 to 0.3 from 1977-1983, as shown in Table 4.2.

Table 4.2 Gilo Fugnido average annual streamflow station

Date	Annual Average Discharge (m³/s)	Mean	STD	CV
1977	102	89	26	0.3
1978	110	88	27	0.3
1979	103	87	26	0.3
1980	95	85	27	0.3
1981	96	84	27	0.3
1982	99	83	28	0.3
1983	85	81	28	0.3
1984	66	80	30	0.4
1985	77	82	32	0.4
1986	79	83	35	0.4
1987	80	85	39	0.5
1988	78	86	44	0.5
1989	99	90	53	0.6
1990	81	81	58	0.7

During the dry season, the monthly river flow was low, and it began to rise throughout the rainy season in Birbir Yubdo station. As a result, the CV of minimum streamflow varies by 0.3 from 1977-1982 and a maximum of 0.7 in the year 1990, as indicated in Table 4.3. This meant a finite amount of water accessible during the dry season when irrigation is required and more in the wet season when hardly any irrigation is needed (Yimere & Assefa, 2022). Air temperature, whether precipitation falls as rain, and the timing of precipitation are all climate factors that influence streamflow (Kumilachew & Hatiye, 2022; Bekele et al., 2019). However, human management of land and water resources during the previous three decades has impacted streamflow variability more than fluctuation in climate has over the same time (Tilahun et al., 2018; Ibarrola et al. 2017), including population expansion, water scarcity, and climate-related effects like droughts and extreme weather.

Table 4.3 Birbir Yubdo average annual streamflow station

Date	Annual Average Discharge (m³/s)	Mean	STD	CV
1977	36	36	10	0.3
1978	35	36	11	0.3
1979	37	36	11	0.3
1980	37	36	11	0.3
1981	38	36	12	0.3
1982	38	36	12	0.3
1983	39	36	13	0.4
1984	32	35	14	0.4
1985	32	36	15	0.4
1986	31	37	16	0.4
1987	33	38	18	0.5
1988	34	40	21	0.5
1989	37	42	25	0.6
1990	48	48	34	0.7

The results indicated that the highest discharge on annual average value was 0.26 in 1991, 1994, and 1995 at Gog station of the lower Baro watershed. Whereas the lowest value on the annual average value of 0.15 was found in 2002. The mean maximum was 0.22 in 1990 and a minimum of 0.16 in 2006, Std was 0.11 maximum in 2006 and a minimum of 0.06 in

1990-1992, and the CV minimum was 0.29 in 1990, the maximum was 0.71 in 2006 as determined that had the highest river flow variability as shown in Table 4.4. The catchment Gog station water balance may be seen by the streamflow variability in mean, Std, and CV. Furthermore, the surface runoff, baseflow, and interflow comprise streamflow (Eshete et al. 2022); while the basin watershed produced is contributing during the monsoon season (Todmal 2020). Therefore, the soil moisture would present more resistance when the flow occurs below the earth's surface (Zhang et al. 2021).

Table 4.4 Gog average annual streamflow station

Date	Annual Average Discharge (m³/s)	Mean	STD	CV
1990	0.24	0.22	0.06	0.29
1991	0.26	0.21	0.06	0.30
1992	0.23	0.21	0.06	0.30
1993	0.23	0.21	0.07	0.31
1994	0.26	0.21	0.07	0.32
1995	0.26	0.20	0.07	0.33
1996	0.24	0.20	0.07	0.34
1997	0.24	0.19	0.07	0.34
1998	0.24	0.19	0.07	0.36
1999	0.23	0.18	0.07	0.37
2000	0.19	0.18	0.07	0.37
2001	0.17	0.17	0.07	0.40
2002	0.15	0.18	0.08	0.43
2003	0.17	0.18	0.08	0.47
2004	0.22	0.19	0.10	0.52
2005	0.17	0.17	0.10	0.58
2006	0.16	0.16	0.11	0.71

As a result, in this study, the lowland Baro Gambella station had the maximum and minimum streamflow annual variability in terms of the mean of 1.65 maximum and 0.19 minimum in 1988 to 1992, an STD maximum of 0.6 in 1988-1992, and a minimum of 0.1 in 1988 to 1992, and the CV maximum of 3.16 in 1988 and minimum 0.06 in 2004 as shown in Table 4.5. Because of the controlled flow pattern, the hydropower scenario increased the flow arriving at Aswan by an average of 1.3 km³/year; in contrast, the irrigation scenario decreased the flow by an average of 4.4 km³/year (Abdelkader et al. 2023). With endemic drought and flood occurrences, Ethiopia has extremely challenging hydrology that fluctuates over time and area (Gebrehiwot et al. 2014).

For 57 gauging stations dispersed throughout the Ethiopian highlands, studies have looked at trends in streamflow parameters between 1975 and 2010 (Degefu et al., 2019). Over 70% of the 513 test cases showed rising signals, and 32% of the tests were generally field significant at 0.05 (Degefu et al., 2019).

Table 4.5 Baro Gambella average annual streamflow station

Date	Annual Average Discharge (m³/s)	Mean	STD	CV
1988	1.6	0.19	0.6	3.16
1989	1.5	0.36	0.6	1.67
1990	1.5	0.38	0.6	1.58
1991	1.4	0.39	0.6	1.54
1992	1.5	0.41	0.6	1.46
1993	1.5	0.43	0.5	1.16
1994	3.2	0.46	0.5	1.09
1995	2.8	0.47	0.4	0.85
1996	2.6	0.49	0.4	0.82
1997	2.6	0.52	0.4	0.77
1998	2.5	0.56	0.4	0.71
1999	2.5	0.60	0.4	0.67
2000	2.5	0.67	0.4	0.60
2001	1.7	0.75	0.1	0.13
2002	1.7	0.90	0.1	0.11
2003	1.7	1.15	0.1	0.09
2004	1.8	1.65	0.1	0.06

The maximum and minimum mean annual streamflow were 413.9 & 441.5, the STD were 102.9 and 308.7, and the CV of 0.2 & 0.7. In contrast to streamflow variability in Baro Itang, the minimum streamflow showed a CV of 0.2 in 1990, 1991, and 1992 a corresponding maximum of 0.7 in 2008. Deforestation for agricultural expansion, settlement growth, water extraction, and rain-fed and irrigated farming are among human activities that affect streamflow availability. Several studies indicated that Ethiopia is one of the emerging nations that have been harmed by hydrometeorological variability (Asitatie & Gebeyehu, 2021; Malede et al., 2022). The literature still needs to thoroughly investigate the relative effects of different climate variabilities on streamflow at the daily, monthly, annual, and mean annual scales. Streamflow is affected by the temporal variation of precipitation and potential ET on a daily to long-term period (Yao et al. 2020). The CV of simulated annual streamflow is another indicator of the influence of climate variability (Malede et al. 2022).

A decrease in streamflow would impede further socioeconomic development and put ecosystems in peril because streamflow is highly responsive to human activities (Malede et al., 2022). More than 65% of the drop in streamflow may be attributed to human activity, while less than 35% can be attributed to climate change (Zhong et al. 2021). As a result, huge significant implications for surface water potential and demand of the streamflow variability in Baro Itang station, as shown in Table 4.6.

Table 4.6 Baro Itang average annual streamflow station

Date	Annual Average Discharge (m ³ /s)	Mean	STD	CV
1990	475	434.1	102.9	0.2
1991	483	431.8	104.7	0.2
1992	484	428.8	106.1	0.2
1993	481	425.4	107.5	0.3
1994	476	421.7	108.9	0.3
1995	469	417.8	110.5	0.3
1996	407	413.9	112.4	0.3
1997	385	414.4	116.8	0.3
1998	387	417.2	122.0	0.3
1999	387	420.2	128.0	0.3
2000	397	423.8	134.9	0.3
2001	416	427.2	142.9	0.3
2002	414	428.8	152.1	0.4
2003	426	431.2	163.4	0.4
2004	420	432.3	176.9	0.4
2005	417	435.5	195.1	0.4
2006	451	441.5	220.9	0.5
2007	437	436.6	252.1	0.6
2008	437	436.6	308.7	0.7

As a result, in Ethiopia's tropical Gumero Gore station, the maximum and minimum variability in the mean STD and CV 500 & 394 in the years 1974 and 1978, 287 & 197 in the years 1980 and 1978, and 0.7 in the years 1980 & 0.4 from the year 1974-1976 as shown in Table 4.7. The spatial-temporal changes in surface water and how they related to the climate and the difference were influenced mainly by temperature and precipitation, with ET having little effect. One of Malaysia's major tropical rivers, the Selangor River, has experienced long-term fluctuations in its annual streamflow regime over 50 years, from 1961 to 2010; Using the Pearson correlation coefficient and Shapiro-Wilk and Pettitt's tests, the results showed that the annual streamflow and variations in the yearly duration are both high and low (Seyam and Othman, 2015).

Table 4.7 Gumero Gore average annual streamflow station

Date	Annual Average Discharge (m³/s)	Mean	STD	CV
1974	647	500	201	0.4
1975	561	475	197	0.4
1976	559	458	203	0.4
1977	550	433	205	0.5
1978	385	394	197	0.5
1979	390	398	230	0.6
1980	406	406	287	0.7

In Sor Metu the streamflow shows that precipitation had a significant impact on streamflow dynamics, as it accounts for almost 85% of the variation of annual streamflow in the Mean, maximum and minimum were 53.6, & 41.8, where as the STD were 12.7 & 29.6, and the CV value of 0.2 & 0.7 as shown in Table 4.8. Both inter & intra annual precipitation and streamflow are highly erratic (Mandal & Choudhury, 2015; Mishra et al. 2013). As a result, the response of hydrological variability, ecological, and biophysical variability was due to the heterogeneity of the land surface at the watershed scale. Stepping back from the land surface, one of the significant phenomena of societal and scientific interest was the hydrological extremes, in this study was flood and drought in the summer and winter seasons. The lower Baro hydrological cycle is greatly influenced by the time of rainfall (Kedir, 2021). In light of this, there is a strong link between yearly streamflow and total precipitation. In other words, streamflow decreases as a result of variations in precipitation (Panagos et al., 2022; Malede et al., 2022). Although they have changed throughout the study, the relationships between regional precipitation and discharge remain. A considerable decrease in precipitation, especially during the rainy season, can have a significant influence on the hydrological cycle and the availability of water for ecosystems and humanity; in reality, variations in precipitation quantity alter runoff rates, affecting the local population's access to water (Kedir, 2021). Regarding agricultural demand, a soil moisture deficit brought on by reduced precipitation may affect both rainfed crops and irrigated plants (Vargas-Pineda et al., 2020; Rai et al. 2019).

Table 4.8 Sor Metu average annual streamflow station

Date	Annual Average Discharge (m³/s)	Mean	STD	CV
2000	55	53.6	12.7	0.2
2001	56	53.5	13.0	0.2
2002	56	53.3	13.3	0.3
2003	55	53.2	13.7	0.3
2004	59	53.1	14.1	0.3
2005	62	52.7	14.4	0.3
2006	49	52.0	14.5	0.3
2007	56	52.3	15.1	0.3
2008	56	52.0	15.6	0.3
2009	53	51.6	16.1	0.3
2010	53	51.4	16.8	0.3
2011	53	51.2	17.7	0.3
2012	53	51.0	18.6	0.4
2013	48	50.6	19.8	0.4
2014	50	51.1	21.5	0.4
2015	51	51.4	23.7	0.5
2016	58	51.4	26.6	0.5
2017	55	48.2	28.6	0.6
2018	42	41.8	29.6	0.7

As a result, in this study, the gross biomass water productivity of the Alwero sub-catchment ranges from 1.8-2.8 kg/m³ in the annual time series bases from 01/07/2010 to 01/07/2022 as shown in Figure 4.2. In a recent study on remote sensing data products as an input, the result was that WaPOR for wheat ranged from 0.2 to 1.8 kg/m³ of harvestable wheat per cubic meter of water consumed (Chukalla et al. 2022). Because water has become scarcer and there is more competition in agriculture and other industries, water productivity in this agricultural system needs to be significantly improved to satisfy future demands. Comparing fields with high-performance (bright spots) and low-performance (hotspots) areas reveals differences in water productivity. Since these stages are the most stressful sensitivity periods for their respective crops, water stress should occur throughout the most sensitive growth phases (Steduto et al., 2007). These suggest a need for more effective irrigation planning, more significant moisture conservation, or more sensible water distribution during the crop growth phase.

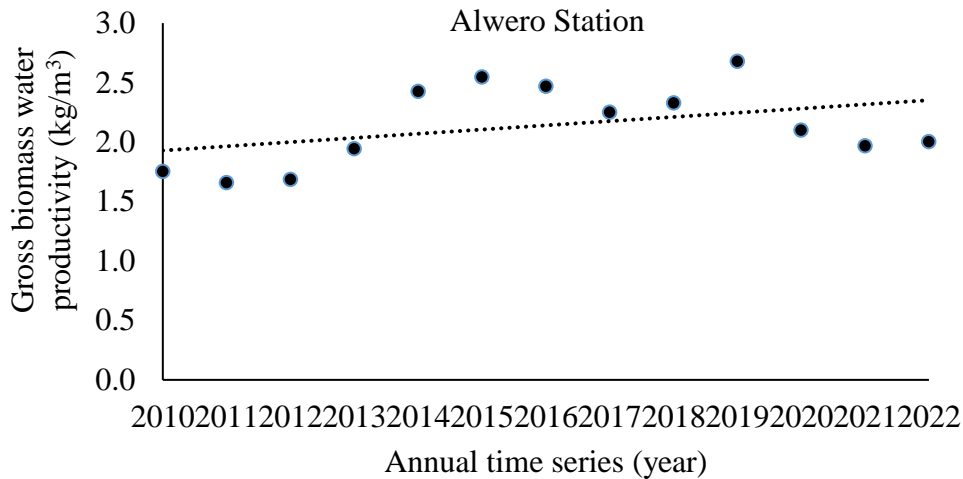


Figure 4.2 Alwero annual time series vs the gross biomass water productivity in kg/m³

As found by this study, the Gilo Fugnido sub-catchments gross biomass water productivity ranges from 0.7 to 1.3 kg/m³ in the yearly time series ranging from 01/07/2010 to 01/07/2022 as indicated in Figure 4.3. The methods implicitly aim for different formulations of water productivity: the first track focuses on increasing yield per unit of water used. In contrast, the second track concentrates on increasing water productivity in terms of surface water productivity to achieve sustainability for future generations. However, these demonstrate the potential for increased water productivity, regardless of whether such productivity gains, as measured by greater yields per unit of water consumed in crops or irrigation systems, would also lead to higher production at the watershed scale.

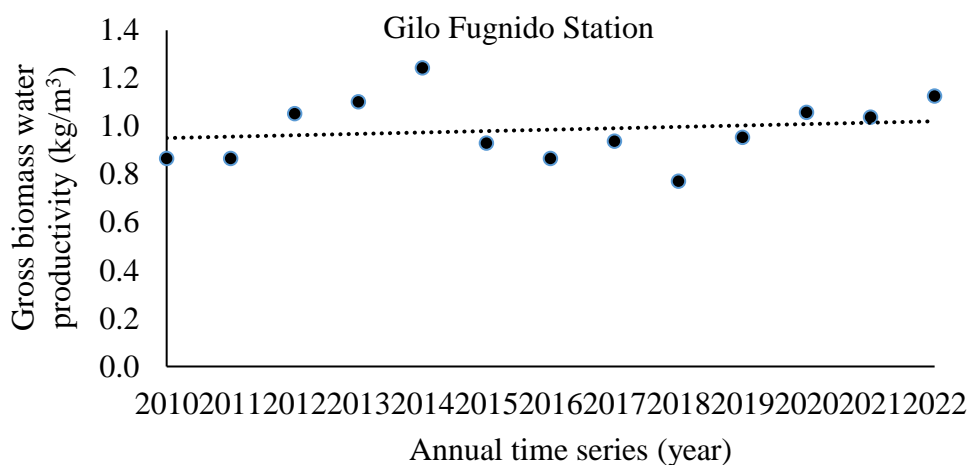


Figure 4.3 Gilo Fugnido annual time series versus the gross biomass water productivity in kg/m³

The gross biomass water productivity of the Birbir Yubdo sub-catchment, as determined by this study, varies from 1.7 to 2.6 kg/m³ in the annual time series from 01/07/2010 to 01/07/2022 as mentioned in Figure 4.4. The related study applied two types of interventions; more expensive technologies like a sprinkler, drip, and other micro-irrigation techniques, and agronomic practices, including field leveling and zero tillage. Numerous research has found ways to prevent non-beneficial depletion. However, a common theme is the need to consider scale, hydrology, and the environment when interpreting and possibly applying the results. For instance, it was common knowledge that biological techniques would consume less water than surface irrigation.

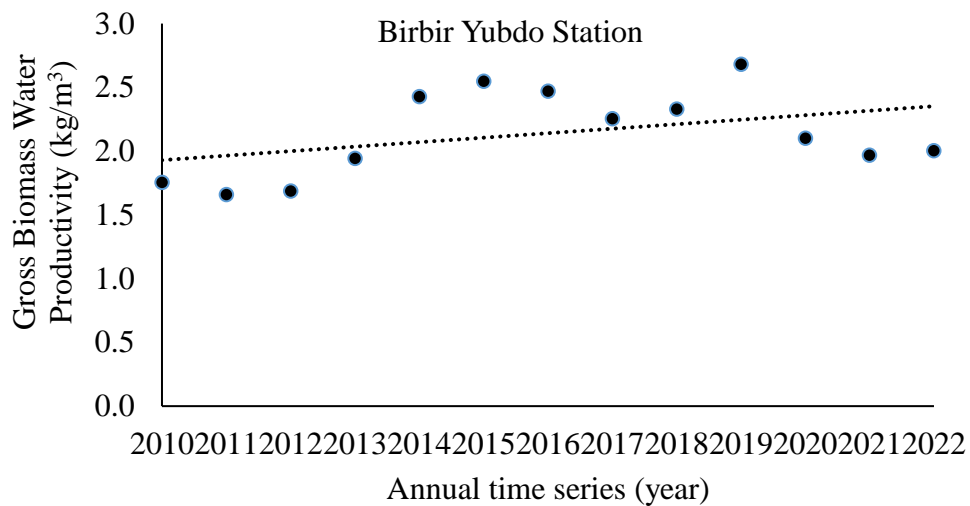


Figure 4.4 Birbir Yubdo annual time series versus the gross biomass water productivity in kg/m³

According to this study, the Gog sub-catchment gross biomass water production ranges from 0.7 to 1.3 kg/m³ annually from 01/07/2010 to 01/07/2022, as shown in Figure 4.5. Water stress decreased, and more general socioeconomic objectives by shifting water use from agriculture to other sectors. It was acknowledged as a pillar of water demand management since it maximizes current resources instead of expanding supplies. By 2050, developing nations will need 158 kg/person/per year of grain food from Ethiopia (Silva et al. 2021). However, increasing irrigation efficiency can liberate significant water for reallocation to other more valuable purposes.

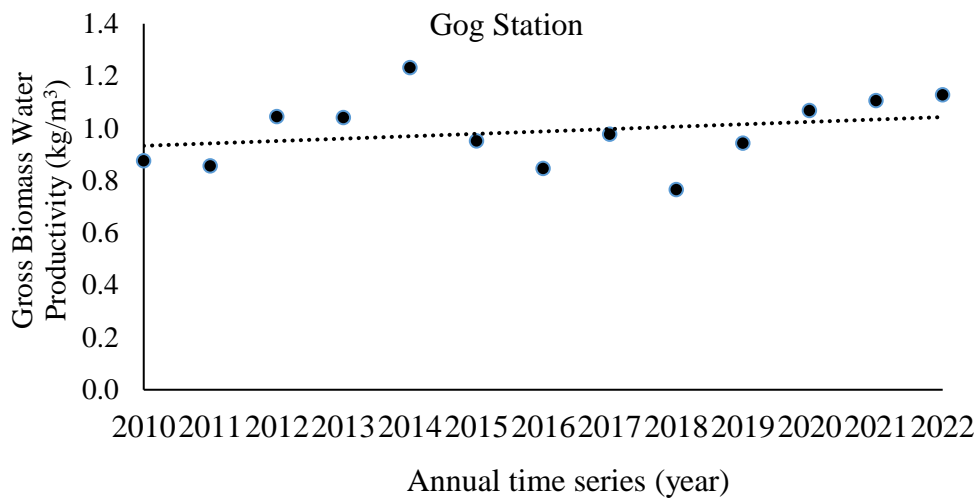


Figure 4.5 Gog annual time series versus the gross biomass water productivity in kg/m³

The Baro Gambella sub-catchments gross biomass water productivity, as a consequence of this study, varies from 0.8 to 1.2 kg/m³ during an annual time series from January 1, 2010, to January 1, 2022, as shown in Figure 4.6. Appropriate geographical and temporal scales and the particular hydrological environment are crucial to ascertain where and how productivity increases and actual water savings. Developing and applying various approaches from adjacent domains may lead to new insights and chances for improving water production and efficiency assessments.

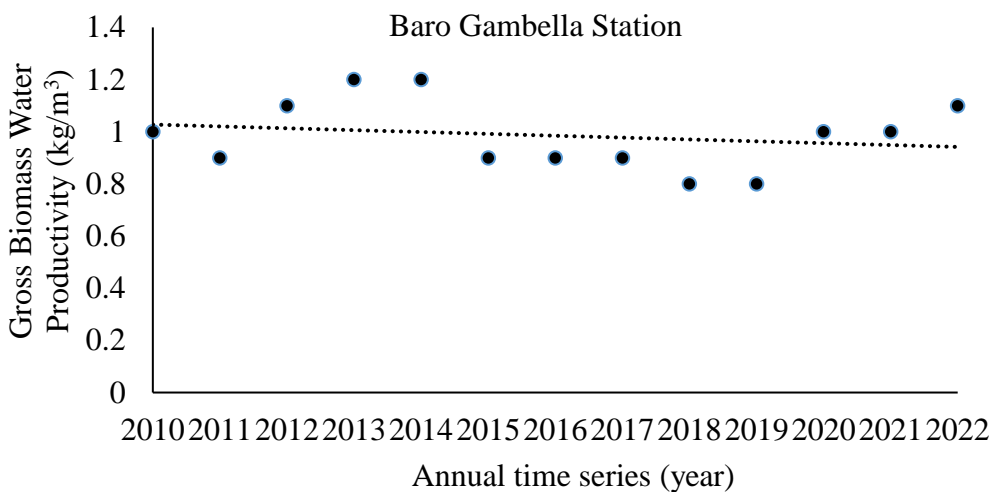


Figure 4.6 Baro Gambella annual time series versus the gross biomass water productivity in kg/m³

The Baro Itang sub-catchment gross biomass water production as a consequence of this study ranges from 1.6 to 2.6 kg/m³ annually from 01/07/2010 to 01/07/2022, mentioned in Figure 4.7. However, it can take some time before the benefits of farm productivity become apparent. As a result of this study, on drip and sprinkler irrigation technologies in the Ethiopia Gambella regional states, irrigations recovered their initial investment in one to three years.

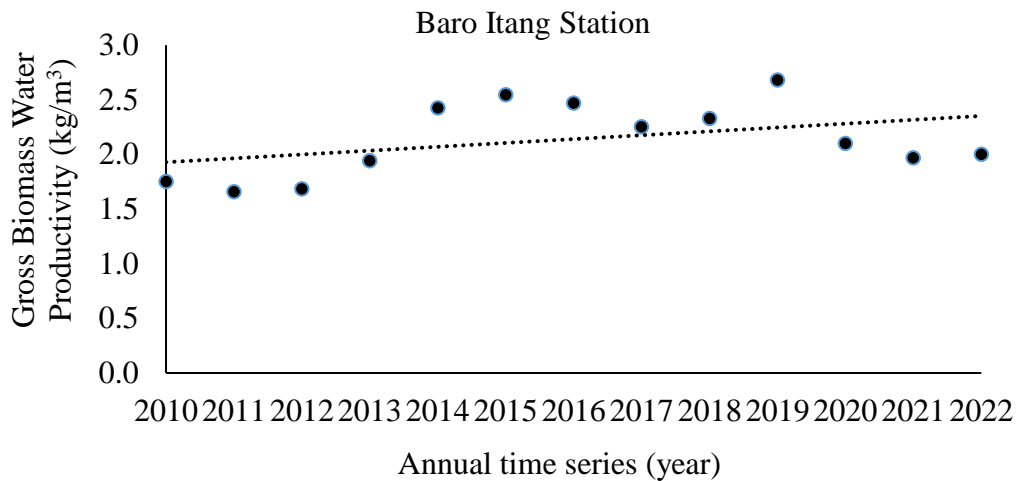


Figure 4.7 Baro Itang annual time series versus the gross biomass water productivity in kg/m³

As a result, in Figure 4.8 of this study, the gross biomass water productivity of the Gumero Gore sub-catchment ranges from 0.7 to 1.3 kg/m³ throughout an annual time series from 01/07/ 2010 to 01/07/2022. The cost of production at the watershed scale was decreased while the measured units of applied water and other agricultural inputs increased as a result of the recovery of the gross biomass water productivity.

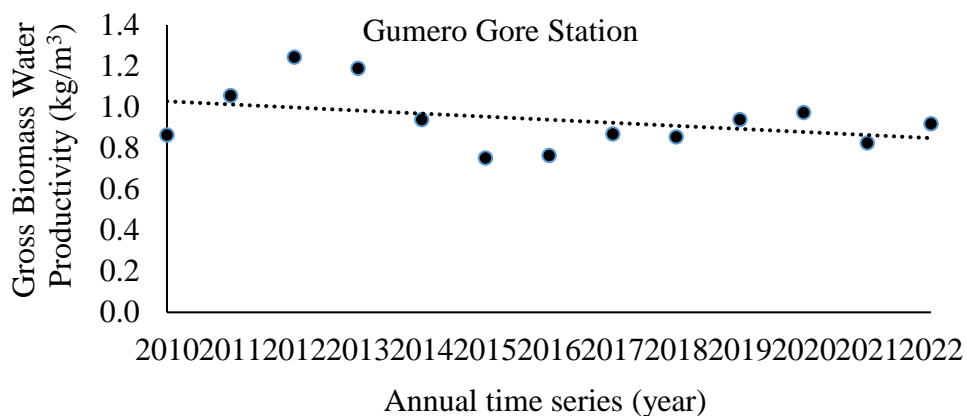


Figure 4.8 Gumero Gore annual time series versus the gross biomass water productivity in kg/m³

As a result, of this study stated in Figure 4.9, the gross biomass water productivity of the Sor Metu sub-catchment ranges from 1.4 to 1.9 kg/m³ throughout an annual time series from 01/07/ 2010- 01/07/2022. Nevertheless, the links between water and agricultural productivity might be made more evident. While the contributions of water and other elements to agricultural yields have been identified and quantified with significant effectiveness, the magnitude of each element's contributions vary greatly depending on the region, the accompanying hydrologic and climatic environment, and other factors. The WaPOR offers good sugarcane results; however, the remote sensing-based forecasts connect the biomass gap (Blatchford et al., 2020). In this study, the HI indicates how much biomass production contributes to the harvestable fraction of a crop yield. The management techniques for bettering the timeliness of water supplies utilizing supplemental or deficit irrigation. In studies on this pathway as a potential intervention. The crucial issue restricting agricultural productivity is moisture availability in dry places, especially during vital times.

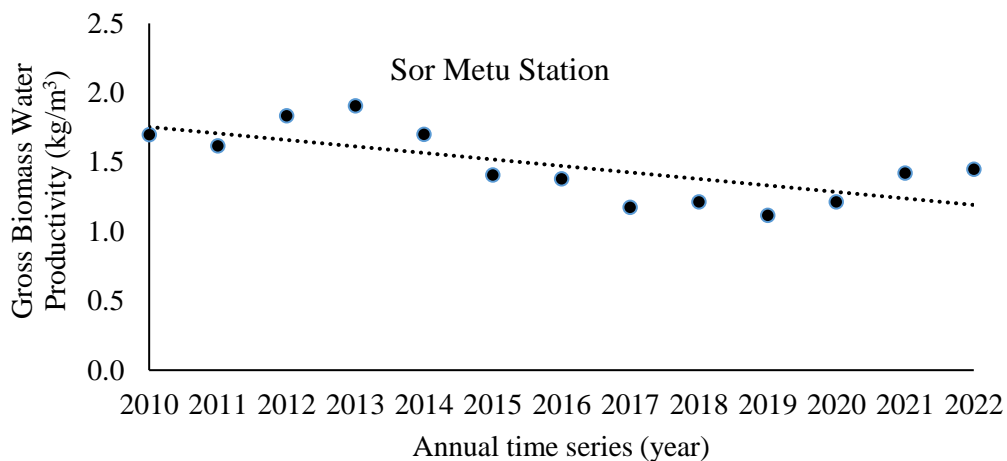


Figure 4.9 Sor Metu annual time series versus the gross biomass water productivity in kg/m³

4.6 Conclusions

The streamflow variability, characterized by the coefficient of variation (CV), and the region revealed substantial fluctuations in surface water demand and streamflow potential, followed by modest variability. In addition, Penman Monthieth FAO56 was to analyze the ETo trend. The highest predicted monthly hydropower potential, irrigation water demand,

livestock water demand, and surface water potential were 60.3 Mm³ inflow due to the water balance produced from the WEAP hydrological model. The corresponding outflow value was 52.4 Mm³. The total predicted mean annual surface runoff that departs the basin for each station, as determined by the model, was 462.06 Mm³. The FAO gross water productivity average annual and monthly ET trend changed over time, and the variation in monthly streamflow of the box plot for each station across 43 years of streamflow data showed significant variability over the lower Baro watershed. Additionally, using the mathematical tool EasyFit explored the normal distribution's probability density in the eight gauging stations. The underlying trend of temperature increase and extreme temperature variability may aid ET. Finally, the total annual streamflow indicates that the model's efficiency between the observed and simulated flow utilized to represent the watershed is quite good. Much effort is required to bring the sustainability challenge to the lower Baro watershed. The region has enough resources to meet all the demands. However, the gap increases the strain on water supplies. To limit adverse effects on their livelihoods, stakeholders should be aware of surface water demand and potentially use it in water management, water conservation, and irrigation methods. Additionally, it is essential to develop effective agricultural methods and rainwater collection in the research area. Despite a substantial record of time series for the basin, the attribution of large-scale surface water demand and potential to long-term changes in climatic factors still needs to be investigated; it will bring sustainability in terms of surface water management.

The next chapters discuss the detailed analysis of surface water irrigation potential and crop water requirement in the lower Baro watershed.

CHAPTER 5 SURFACE WATER POTENTIAL AND IRRIGATION WATER DEMAND OF LOWER BARO WATERSHED TRIBUTARIES

5.1 Introduction

As introduced in chapter one of this thesis, it might be possible to be more explicit about the links between water and agricultural output. The levels of each factor's contributions vary substantially depending on the region, the accompanying hydrologic and climatic environment, and other factors, even though it has successfully identified and quantified the contributions of water and other elements to crop yields (Yidana et al. 2011). The methods used to comprehend the entire hydrological process in this study was an integrated approach to surface water potential and irrigation demand in the current chapter. The WEAP hydrological model explores the critical hydrological processes in the lower Baro tributaries. Finally, develop possible current and future surface irrigation potential and crop water requirements within the lower Baro Gambella catchment. Moreover, it devoted me to thoroughly explaining the WEAP hydrological model, data inputs, application methods, and findings obtained.

5.2 Selection criteria of the hydrological model

There are several factors to consider when deciding which hydrological model best suits a particular circumstance. The standards vary on the region of interest because each site has different requirements. Some criteria are also arbitrary and dependent on the application. Four universal and crucial selection criteria must always be considered among the several field-dependent ones.

- The required model output that must be predicted by the model since it is necessary to the project (Does the model forecast the variables needed by the project, such as the long-term sequence of flow?);
- Hydrologic processes that must be represented to accurately estimate the intended outputs (Can the model simulate a single event or continuous processes?);
- Accessibility of input data (Can the project's time and budget allotments and all the inputs needed by the model be provided?), and
- Cost (Does the investment appear to be worthwhile given the project's goal?).

5.3 The reasons for choosing the WEAP hydrological model

The model is free and easily accessible to users, replicates the main hydrological processes in the catchment, has good literature, a well-organized database, and the GIS interface; in numerous circumstances and locations around the world, the model was used to analyze surface water potential and irrigation crop water need. A significant limitation to large-area hydrologic modeling using WEAP is the spatial detail required to simulate hydrological processes correctly. Another area for improvement is that data files can be challenging to manipulate and contain several missing records.

5.4 Surface soil moisture and irrigation productivity

Concerning crop water needs and the potential for surface irrigation in the lower Baro watershed, this study sought to identify possible scenarios. Soil moisture is critical in classifying rainfall into infiltration and runoff; it significantly impacts runoff modeling and flood predictions (Brocca et al. 2017). The hydrological modeling is superior to the original soil moisture estimation in the downscaled products (Dau et al. 2021; Zhuo & Han, 2016). Several studies used in situ soil moisture monitoring to improve flood modeling using data assimilation techniques and the calibration of hydrological models (Zhang et al. 2021). However, moisture reserves are highly dynamic, and the rainfall dramatically changes the moisture reserves in the agro soils of the landscape (Shein et al. 2021).

Other research mostly focused on classical calibration, which was ineffectual at accurately projecting streamflow's seasonal and long-term variability; the soil moisture technique utilized hydrological modeling in this particular watershed (Ingol-Blanco & McKinney, 2013). They calibrate the watershed rainfall-runoff model in WEAP to replicate its historical runoff characteristics precisely. However, instead to create a good approximation of the current streamflow that could be used as a baseline for climate change research (Oti et al. 2020). A study on the Baro watershed showed that the mean annual actual ET is 30.8 Bm^3 and the percolation loss of 2.4 Bm^3 (Engdaw, 2016; Tadesse et al. 2018).

5.5 Results and discussion

The average monthly ET fluctuates, the availability of seasonal vegetation cover, and rainfall availability, ranging from roughly 27.8 mm/month in February to July and August, a maximum of 66.5 and 64.9 mm/month, as shown in Figure 5.1.

The wet winter (kiremt) season accounts for around 55% of ET, with the remaining 45% occurring during the summer (dry) season (Gebrehiwot, 2013). As a result, of this study, there was little vegetation cover and less rain during the summer (dry) season in lower Baro watershed. Also, ET shows how quickly the soil is becoming dried out. However, high temperatures may impact plant productivity and crop yields even if crop water consumption decreases as harvest seasons (Hadri et al. 2022). According to Abebe & Kebede, (2017), a study demonstrated that climate change has an impact on how water resources are managed today and in the future. Because irrigation-induced local changes in ET demand impact crop and irrigation water requirements. However, various irrigation scenarios should consider these changes when planning and predicting agricultural water consumption (Zhang et al. 2021).

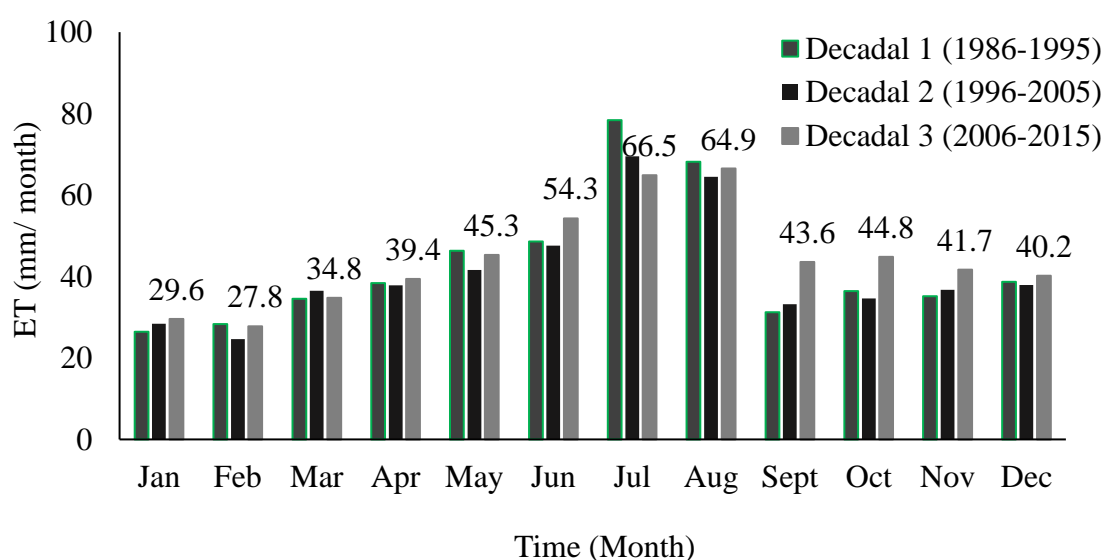


Figure 5.1 Temporal variation of average monthly ET of different decades

Many irrigators have discovered that due to these modifications, they have greater control over the water used on their farms. And could get more use out of irrigation scheduling. The streamflow gauge stations variability over 45 years as shown in Figure 5.2. The amount of water that would evaporate if energy were the only limitation (i.e., moisture availability does not limit the evaporation (Burn & Hesch, 2007).

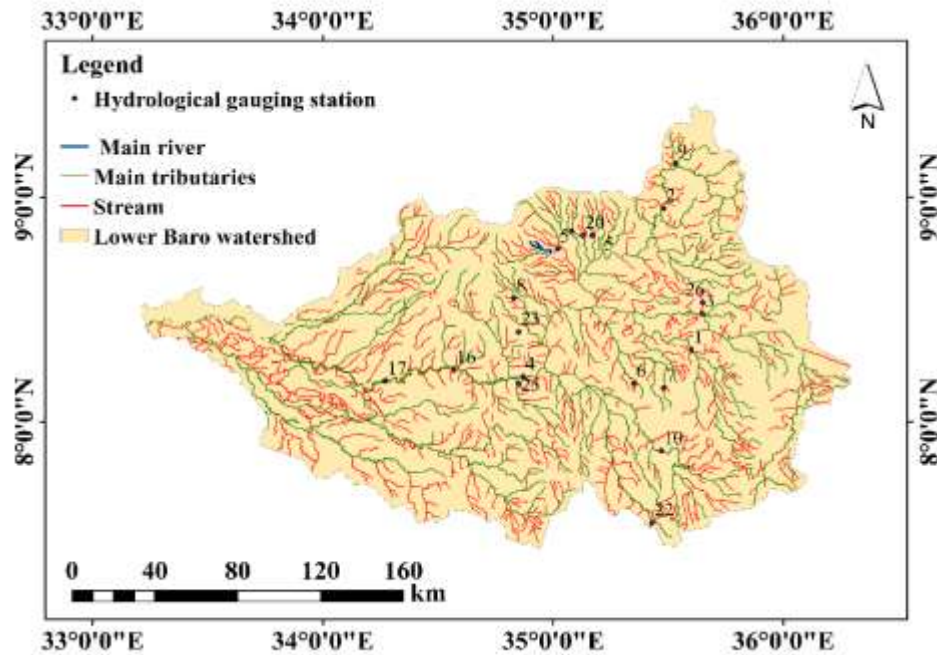


Figure 5.2 Lower Baro stream gauging stations

Similarly, ET values in this study were calculated as a principal value at eight stations in the lower Baro watershed by FAO56 Penman Montieth from the reference ET_0 as compared with ET. The ET_0 necessity of an environment free of crop variety, crop growth, and management activities is demonstrated by Penman Montieth, which incorporates 4-5.8 mm having various climatic impacts (Islam & Alam, 2021). In a prior study, the uncertainty of ET_0 dropped from April to October, with an average overestimate of 0.11 mm/day throughout the year, in contrast, the average overestimation of ET_0 is only 0.02 mm/day, and the uncertainty of ET_0 reached its lowest value in July (Xingming Hao et al. 2018). As a result, in this study, in the Baro Itang, the maximum ET_0 was 7.01 mm, whereas the minimum ET_0 was 5.49 mm was found in the Gilo Fugnido as compared to the six sub-catchments. This is help Irrigators can utilize information to plan more precise irrigations to help in producing maximum harvests and increase water productivity (Nesru et al. 2022). The time of routine sprinkler irrigation treatments can be determined to maximize water productivity using a method similar to that used for surface irrigation (Fikadie et al. 2022; Bwambale et al. 2022). The crop needs irrigation water for deep percolation and transpiration, solar radiation, air temperature, wind speed, and relative humidity values all have an impact on ET as shown in Table 5.1.

Table 5.1 Station-based evapotranspiration estimate using fao56 Penman Montith average monthly climatic data over Baro river tributaries (1986-2018)

Stations	T _{min} (°C)	T _{max}	T _{dry}	T _{wet}	T _{mean}	Dewpoint	Wind Speed	Ra	e°(Tmin)	e°(Tmax)	e°(Twet)	es	ea	es - ea	Rso	Rs	Rns	Rnl	Rn	U ₂	ETo (FAO56)	ET (mm)
Alwero	27.9	43.8	1.8	23.7	35.9	25.9	2.00	31.94	3.76	9.0	2.93	6.38	4.33	2.05	23.96	23.74	18.28	2.16	16.12	1.50	6.43	6.41
Gilo Fugnido	22.8	42.1	1.3	22.6	32.4	20.8	1.33	33.84	2.77	8.23	2.73	5.50	4.09	1.41	25.38	22.57	17.38	2.08	15.29	1.00	5.49	7.00
Birbir Yibdo	27.5	44.9	2.1	18.9	36.2	25.5	2.09	36.25	3.66	9.53	2.18	6.60	3.26	3.34	27.19	18.94	14.58	2.32	12.26	1.57	6.13	7.67
Gog	28.0	43.5	2.2	20.2	35.7	26.0	2.21	37.73	3.77	8.85	2.36	6.31	3.51	2.80	28.30	20.19	15.55	2.13	13.41	1.65	6.22	7.46
Baro Gambella	28.7	41.6	3.0	23.6	35.2	26.7	3.03	37.54	3.95	8.02	2.90	5.98	4.21	1.77	28.15	23.56	18.14	1.82	16.32	2.27	6.65	6.68
Baro Itang	29.1	43.5	3.0	22.9	36.3	27.1	3.01	36.67	4.03	8.87	2.79	6.45	4.06	2.39	27.50	22.90	17.63	2.02	15.61	2.25	7.01	7.06
Gumero Gore	28.9	40.7	3.5	23.7	34.8	26.9	3.46	36.43	3.99	7.68	2.92	5.83	4.21	1.62	27.32	23.65	18.21	1.91	16.30	2.59	6.62	6.19
Sor Metu	29.8	40.3	2.3	23.2	35.0	27.8	2.33	37.02	4.18	7.49	2.84	5.84	4.17	1.67	27.76	23.19	17.86	1.86	16.00	1.74	6.23	5.96

5.6 Analysis using precipitation time series

The monthly maximum ET was 125 mm/month in Gumero Gore, whereas the minimum ET was 75 mm/month in terms of the CV in the catchment of Sor Metu among the eight tributaries. According to the study, ETo efficiency values are principal in the rainfall trend (Lambe and Kundapura, 2021); however, hydrologists are interested in time series forecasting; they do not necessarily follow forecasting principles (Papacharalampous et al. 2018). One key reason for studying ET in a reservoir and River basin water balance analyses is to bring sustainability to the water stress area. Nevertheless, changes in LULC on watershed hydrological responses, especially forest cover, impact ETo (Mohaideen & Varija, 2018; Yan et al. 2013). The monthly trend of each station varies with the ET value, as indicated in Figure 5.3.

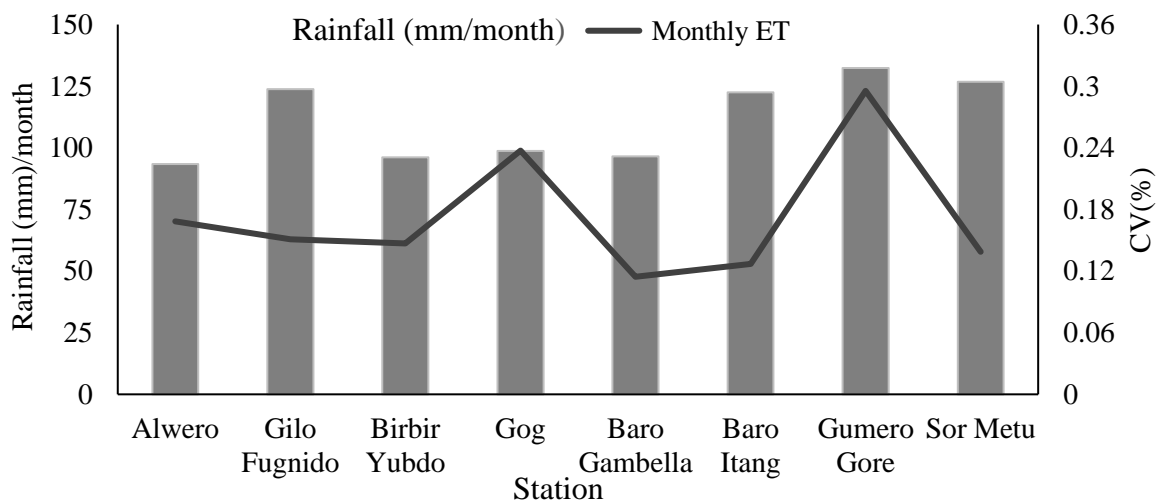


Figure 5.3 Station-based evapotranspiration estimate over the lower Baro watershed

5.7 Station-based variability of river discharge

As a result, the water balance generated by the model, the most significant estimated total monthly inflow hydropower potential, the irrigation water demand, livestock water demand, and surface water potential were 60.3 Mm³, and the corresponding total outflow value of 52.4 Mm³. Water was accumulated in the ground, which raises river levels, surface runoff, and discharge. Figures 5.4 (a) and (b) show the water balance inflow and outflow.

Many agricultural impact studies and future irrigation plans are imposed without taking variations in irrigation water availability into account (Okada et al. 2018). In this study, precipitation exceeds ET during wet winter (kiremt) seasons, which results in an excess of water. The longer the period, the more adaptable the model will be to changing hydrological conditions; the fundamental assumption, on the other hand, is that the model structure accurately depicts the catchment's operations (Romanowicz et al. 2013).

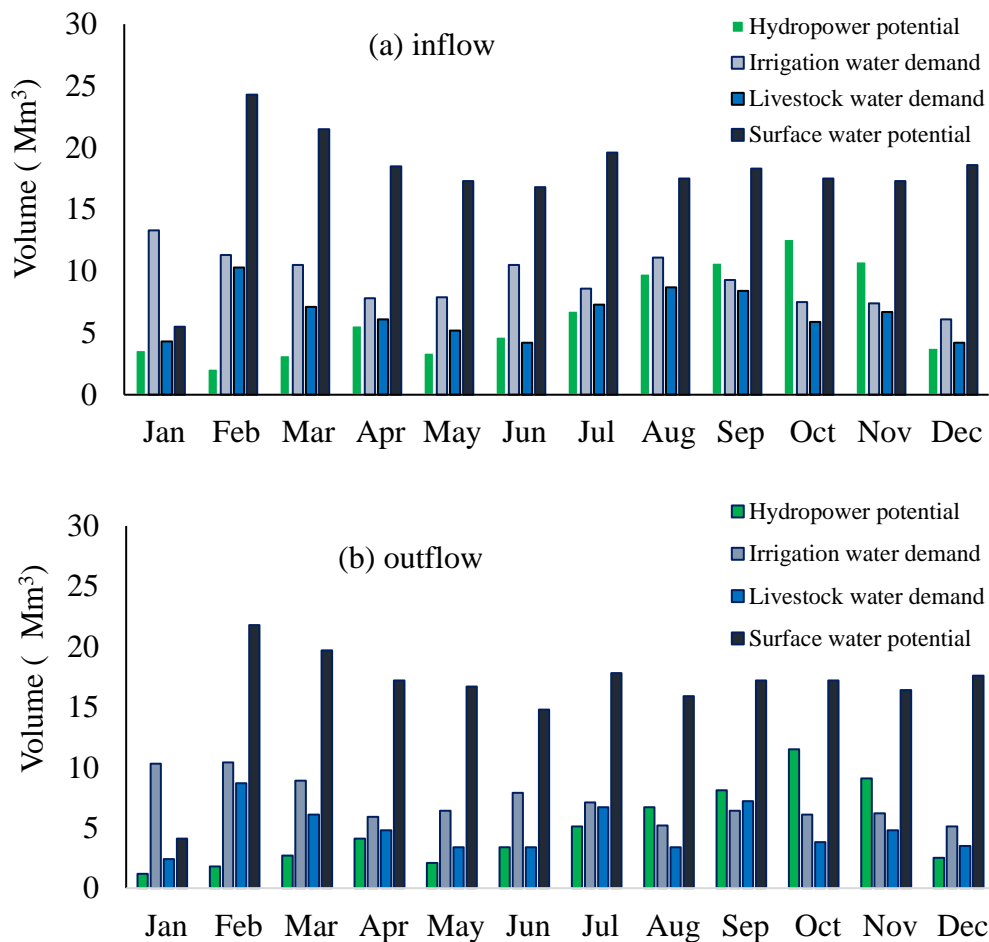


Figure 5.4 Monthly inflow (a) and outflow (b) over the lower Baro watershed

In this study, the total estimated mean annual surface runoff that leaves the basin for Sor Metu, Baro Itang, Birbir Yubdo, Baro Gambella, Alwero, Gumero Gore, Gog, and Gilo Fugnido was 462.06 Mm³ as shown in Table 5.2. Higher temperatures, less precipitation, and increased water demand should be balanced; failing to do so will likely result in a major reduction in long-term runoff and water availability, especially during the summer (Todmal, 2020).

Several studies mentioned that the significant additional cropland growth at the watershed could put water security at risk. However, under climate change and lead to unstable agricultural output (Fu et al., 2022). The hydro climate and biophysical conditions may be negatively impacted by the expansion of irrigated agriculture (Karthikeyan et al., 2020). However, water savings brought on by irrigation technology are sufficient to support the increase in agriculture (Hadri et al., 2022). Because rainfall intensity and duration vary from location to location horizontally, the amount of rain at each meteorological station records should weigh appropriately for the region it represents (Belay & Mengistu, 2021). Agricultural land increased from 21.8-39.8% and annually increased ET by 12%, surface runoff decreased by 42%, and land use decreased by 24% (Mengistu et al. 2022). Moreover, according to a previous study, annual surface runoff in the Baro Akobo River basin is 23.6 Bm³ (Degefu et al., 2015).

Table 5.2 Station-based annual average maximum, minimum flow, and surface runoff (1986-2018)

Station	Maximum flow (Mm³)	Minimum flow (Mm³)	Surface Runoff (Mm³)
Alwero	5.69	3.48	46.51
Gilo Fugnido	150.56	60.70	25.73
Gog	162.4	74.2	28.79
Birbir Yibdo	55.91	19.18	51.76
Baro Gambella	539.75	300.75	46.54
Baro Itang	838.9	458.47	68.74
Gumero Gore	2.44	0.91	37.72
Sor Metu	62.90	33.75	76.96

Based on the result of Figure 5.5 illustrates, the supply requirement, including the losses from 2000-2014 was 90-100 Mm³; due to this, a 20% loss rate was observed in the network of the study region. Due to increased population and water consumption, climate change was predicted to worsen critical water stress situations before 2025; by the 2020s and 2050s, the population that has been impacted is predicted to reach between 350 and 600 M respectively (Wang & Yang, 2014). In the WEAP model, the projected population for the Gambella region under the high population growth rate scenario of 2.7% per year was about 306 916.

In this situation, the examined scenarios come into play, activity levels, losses, and consumption would be necessary to meet the demand (Okungu, 2017). This instance shows how the water demand and the amount released from the watershed are incompatible due to expanding irrigation areas and population growth, water shortages, and rising demand in the future worsened.

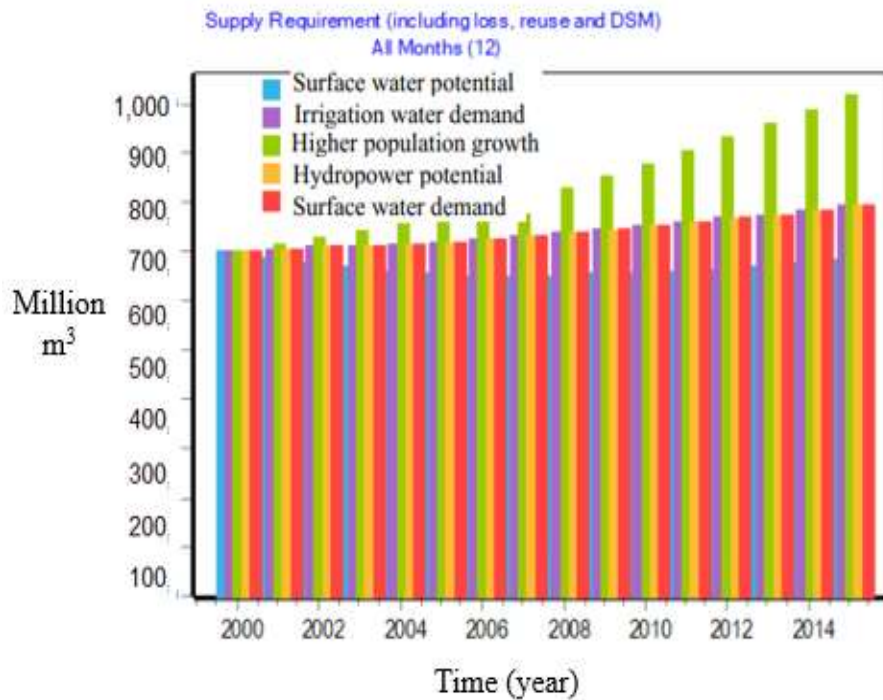


Figure 5.5 Lower Baro watershed supply requirements including loss

This study's surface water potential and the irrigation demand vary from 20 Mm³ to a maximum of 140 Mm³; from 2000-2014, the water shortage increased from 50 to 400 Mm³, as shown in Figure 5.6. Upgrading irrigation and on-farm supply systems have also increased interest; the irrigation demand sites the surface water potential and forecast scenario from 2014-2030 of the water availability under high population growth would cause much more insufficient water in some sub-cities of the region Gambella (Degife et al. 2021; Kahlerras et al. 2018). However, the eastern Nile River basin Baro Akobo is a west-flowing river with an annual water availability of roughly 3432 m³ (Adeba et al. 2016). However, for instance, for the hydropower construction in the country river Basins, recently, the government of Ethiopia was looking at Mega projects under the construction of Genale Dawa 3 Dam, Koysha, and the Great Renaissance Dam. The rest still need more effort to bring the water resource safe and equitable (Van et al. 2018).

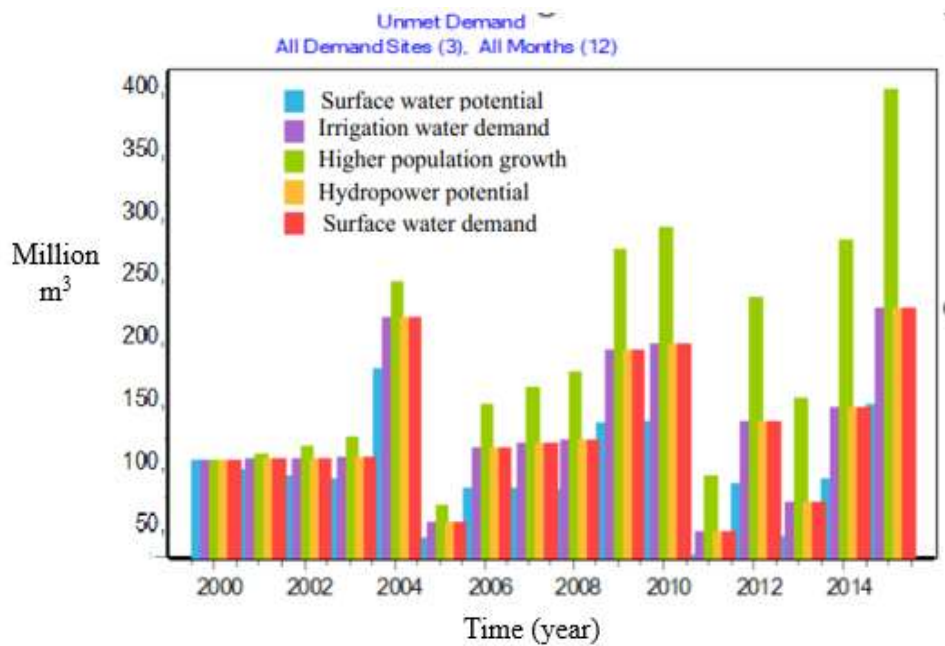


Figure 5.6 Unmet water demand of lower Baro watershed

The water scarcity during the specified time range, the total irrigation demand was 25.4 thousand m^3 more than the surface water potential of 16.3 thousand m^3 for the limited water resources. The anticipated winter (kiremt) rainy and summer (bega) dry weather alarms the current water conservation measures more beneficial (Ahn & Kang, 2014). In the Baro Akobo basin, the water needed more quantity and quality for livestock husbandry (Adeba et al. 2016). The growth of the population, as well as modifications to energy production and land use, are further contributing variables (Asitatie & Gebeyehu, 2021). If the impending dry and rainy circumstances are not managed well, the selected scenarios could eventually face significant water shortages as shown in Figure 5.7.

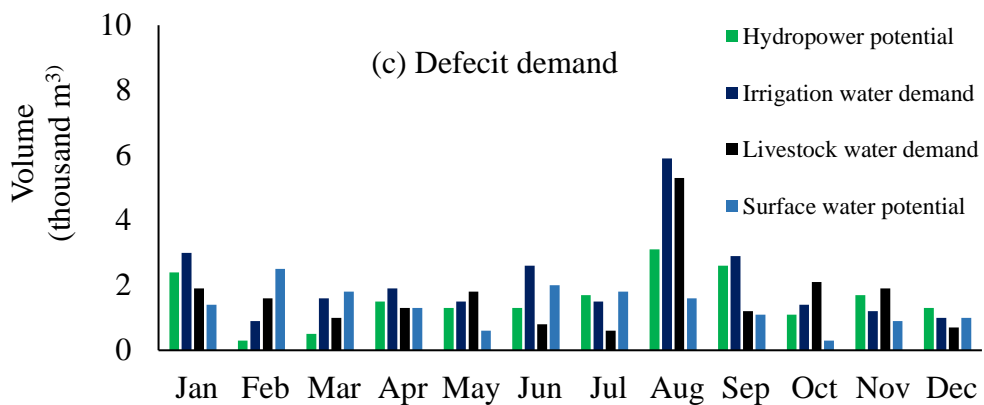


Figure 5.7 Water shortage in the lower Baro watershed

The annual maximum surface water demand from 2020-2030 was $16 \cdot 10^3 \text{ Mm}^3$; this showed that the demand increased with possible deviation from 2020-2030 for the lower Baro watershed. Previous studies of the surface water potential of Baro River is 21.5%, and the annual surface runoff is 19 Bm^3 (Engdaw, 2016). Since annual rainfall is the region's main source of water supply due to the lower Baro limited water resources, unmet water demand must follow the trend (Agarwal et al. 2019). The demand and potential prediction in the eight tributaries, as shown in Figure 5.8.

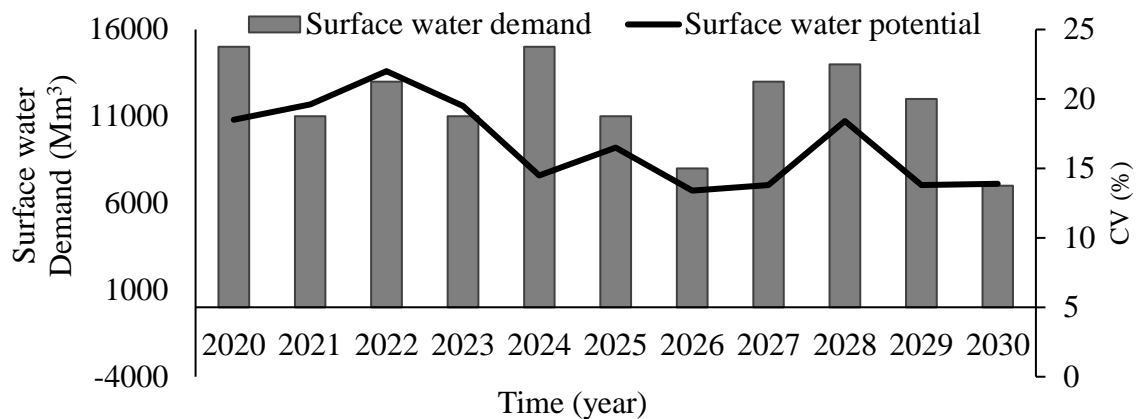
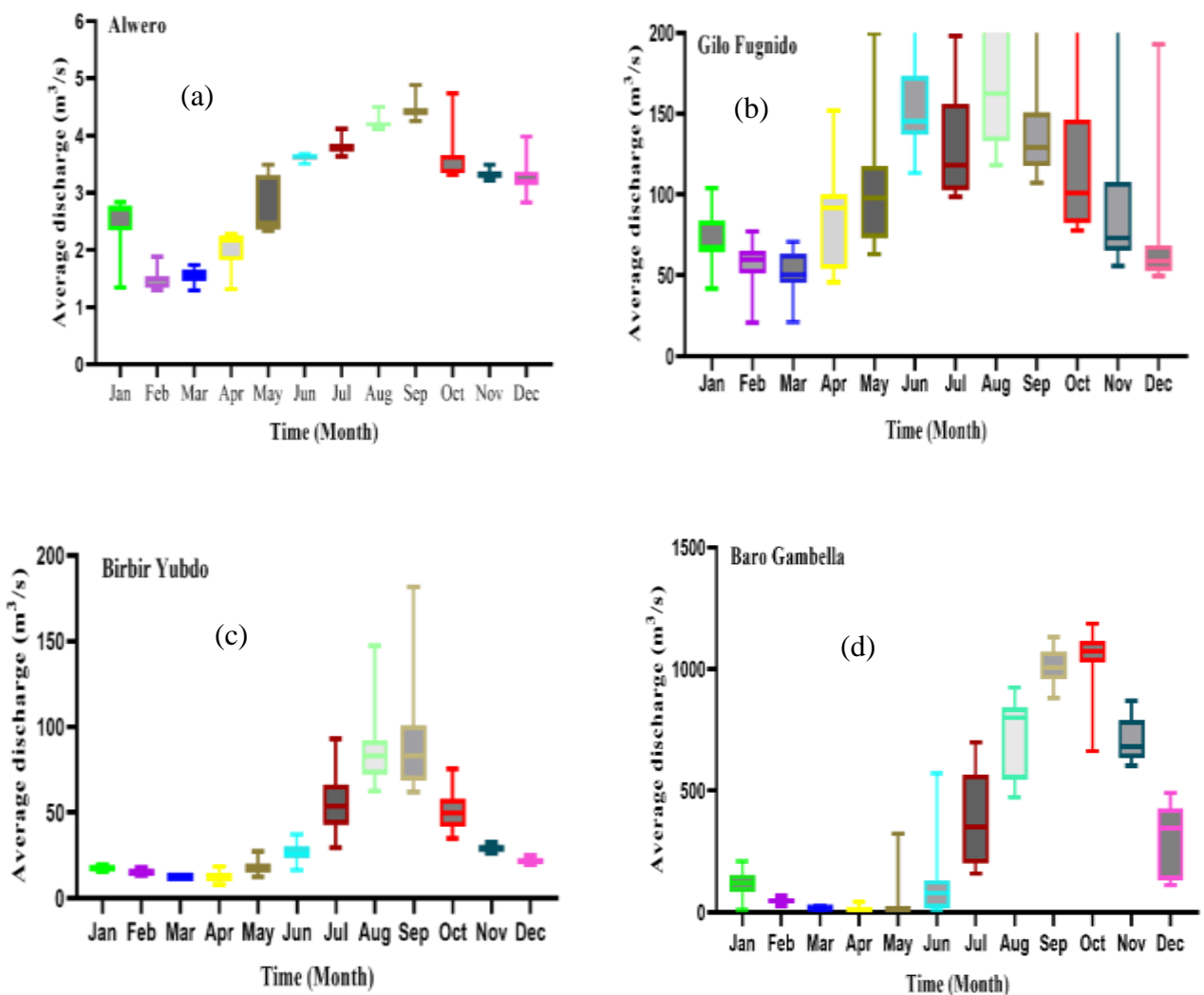


Figure 5.8 Surface water demand versus surface water potential in the lower Baro watershed

The outcome shows that the summer (Bega) flow decreased by 80% in most years and has increased by just about $20 \text{ m}^3/\text{s}$, which was not much. As a result, following regulation, the summertime peak flow decreased. This finding suggests that the watershed exhibits high fluctuations during these particular months. According to studies, surface runoff increases due to a decline in forested, grassland, and rangeland, as well as an increase in slope length, and steep slopes, which can impact water scheme practices (Leta et al., 2022). There must be more tremendous surface water potential than there is today to satisfy the present and future agricultural water needs of various water users (Chintalacheruvu et al., 2022; Ho et al., 2020); since the existing surface water resource needs to be appropriately managed, there will be an unmet demand for water both in the current accounting year and in the future (Gebrehiwot & Gebrewahid, 2016). The surface water suggests that either supply distribution to a particular demand site or the availability of storage facilities needs to be improved. However, the water balance of surface irrigation potential with crop water requirements must be achieved to ameliorate the water security system's supply and demand imbalance (Yimere & Assefa, 2022; Tsakmakis et al., 2018).

However, watershed management is a successful strategy for boosting soil moisture and water availability in arid and semiarid regions like Lower Baro. A little shift in the average monthly streamflow can considerably impact the amount of water available for human and agricultural usage (Eshete et al., 2022; Traore, 2022); because the timing and volume of streamflow vary widely within the study region due to changes in land use and climate, as seen in Figure 5.9 (a-h), Alwero and Gilo Fugnido had a lot more variation than the other stations. However, because the reservoir helps to restrict the spring flood, the advantage also benefits the downstream region (Olabiwonnu et al., 2022). A declining streamflow trend leads to less available water, which impacts the water supply for agriculture and other uses. The lower Baro watershed station revealed statistically significant variability in the eight gauging stations. All the graphs indicate the sustainable environmental flow variability in the ecosystem (Papadaki et al., 2020; Rani & Sreekesh, 2019).



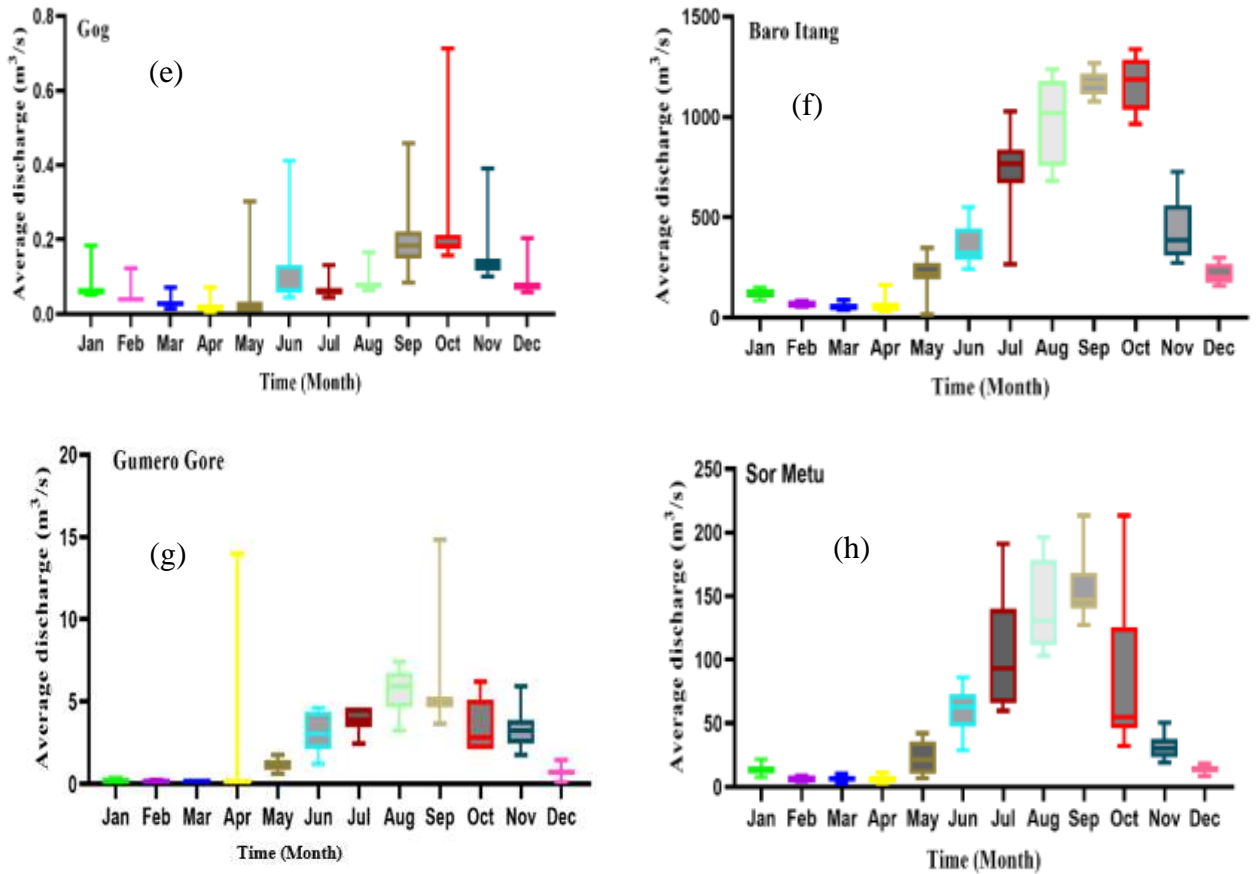


Figure 5.9 Monthly streamflow variation in lower Baro tributaries

The calibration of the model from the link between observed and simulated streamflow revealed that high correlation, with a coefficient of determination (R^2) of 0.88 for the Baro Gambella station. Moreover, the Nash efficiency coefficient (NSE) of 0.91, as compared with the neighboring stations shown in Table 5.3. The length of the data used in this study might be to fault for the small change. Because of the weather periodicity, hydro-meteorological time series almost always show seasonality (Anand et al., 2018; Okungu, 2017). The surface runoff result was 46.54 Mm³, slightly higher than the previous studies' results due to climate change's impact on the region (Muleta, 2021). The statistical approaches commonly used to analyze the scenarios-based surface irrigation potential and the crop water demand hydrological models, such as NSE and sensitivity analysis, must fully capture this subjective viewpoint, incorporating a wide range of uncertainty causes (Johnston & Smakhtin, 2014). The overall outcome, however, highlighted that the model's catchment area parameters accurately reflect the processes occurring to the best of their ability to address supply and demand disparities. However, water should be added or subtracted; it is a trade-off between higher temperatures and less precipitation and maximized water demand, which is likely to significantly reduce long-term runoff and water availability, particularly in summer (Todmal, 2020).

In general, water stress is expected in near future due to climatic variability. Moreover, become more severe in most areas of the catchment. The result of this study similar with the findings of (Isa et al., 2023) water availability in Ethiopia is highly variable and is trending downward under future climate variability scenarios.

Table 5.3 Calibration and validation of monthly streamflow variability

Stream gauging station	Calibration (R^2)	Validation (NSE)
Alwero	0.78	0.71
Gilo Fugnido	0.70	0.75
Birbir Yibdo	0.71	0.74
Gog	0.81	0.72
Baro Gambella	0.88	0.91
Baro Itang	0.75	0.72
Gumero Gore	0.85	0.92
Sor Metu	0.70	0.72

To increase model accuracy, WEAP outputs historical observations and modifies model parameters. Computer software called Parameter Estimate Tool (PEST) is used for uncertainty analysis and model-independent parameter estimation (Hamza & Getahun, 2022; Agarwal et al., 2019). The variance of the observed and simulated monthly streamflow gauging obtained after executing the in the WEAP model. As a result, the monthly inflow and outflow changes in increasing and decreasing trends. The outcomes in terms of hydrological model runoff resistance factor for inflow (a) and outflow (b) as shown in Figure 5.10.

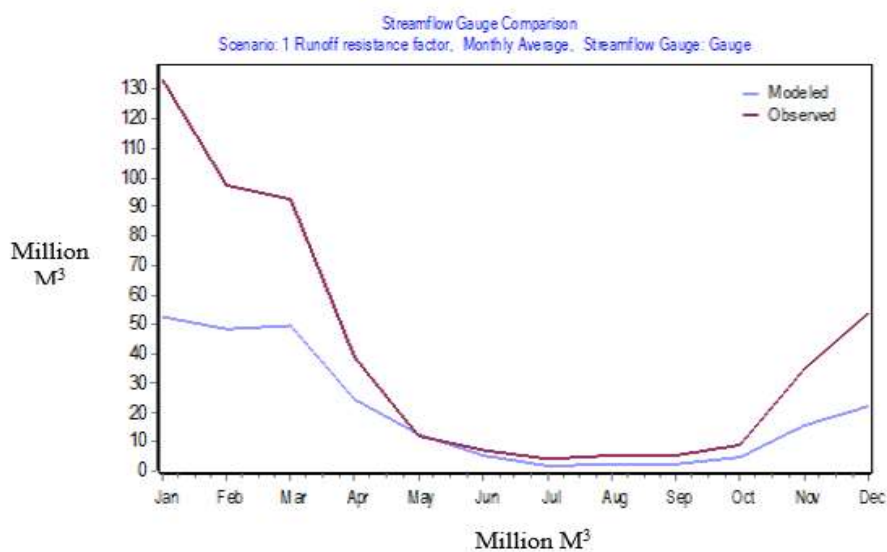


Figure 5.10 Monthly Stream gauging comparison and runoff resistance

The intrication of the systems with multiple sectors in a single catchment or transboundary river system to assess the water requirements of various watershed (Tena et al. 2019). In this study the land class inflow and outflow of the surface water monthly ET, can be interpreted as interms of runoff resistance factor, soil water capacity, preferred flow dirction, root zone conductivity, deep water water capacity, and deep conductivity. Furthermore, the total amount of water saved 80-10 million m³ decreased for the forecast of water demand until 2030. The result, showed that more water could be saved than in the reference scenario. This finding indicates that the savings were proportionate to the demand, meaning that they had a bigger effect in the scenario with the higher water demand due to faster population expansion as shown in the Figure 5.11.

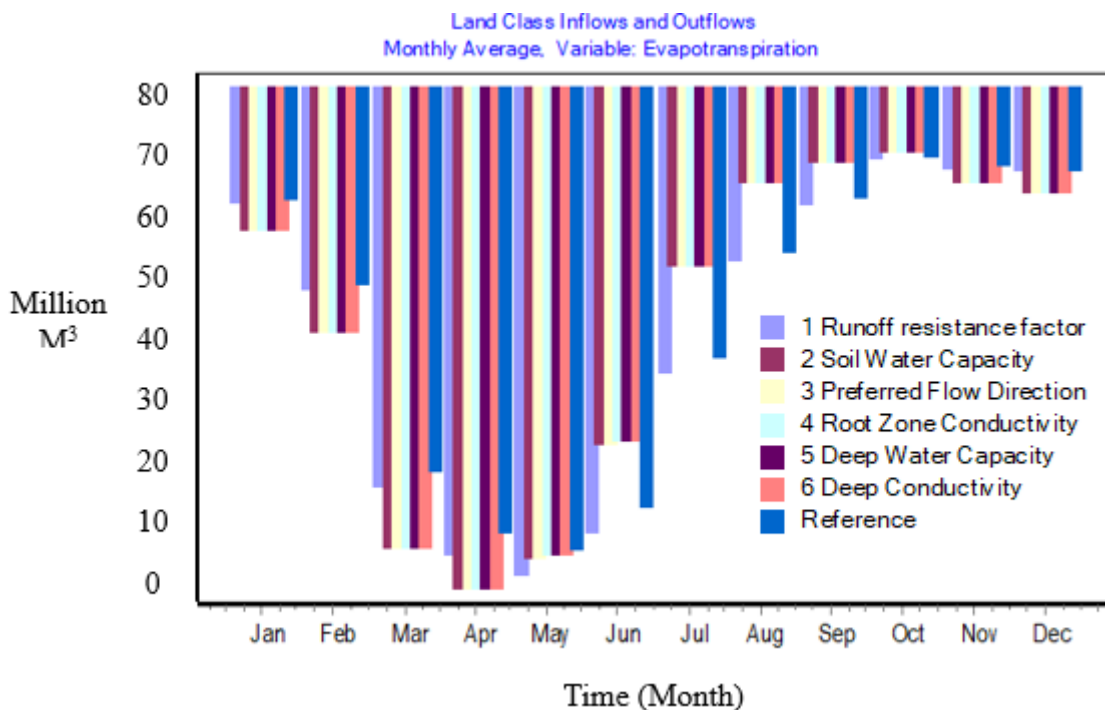
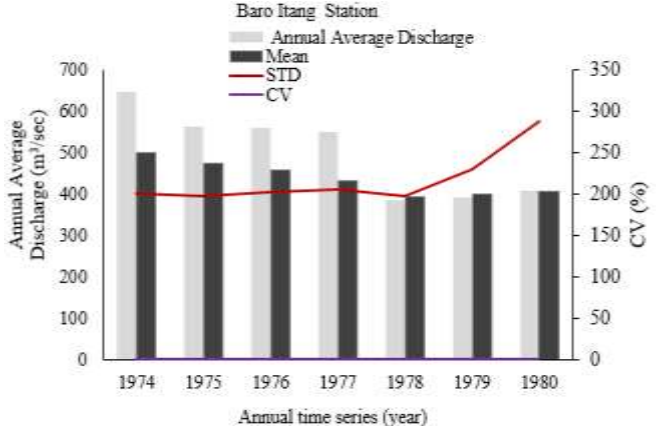
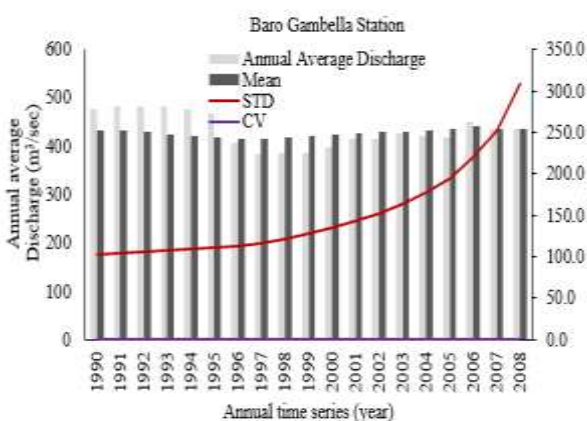
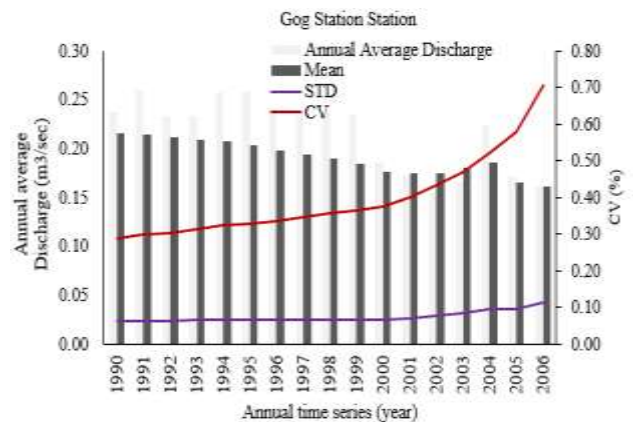
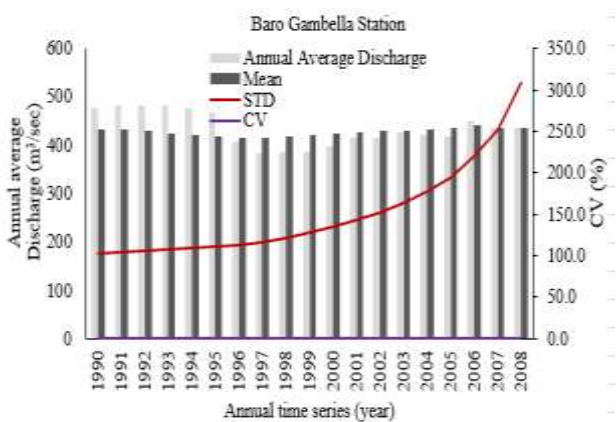
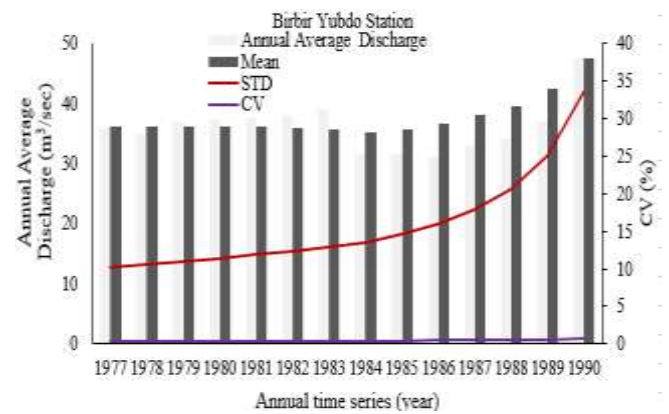
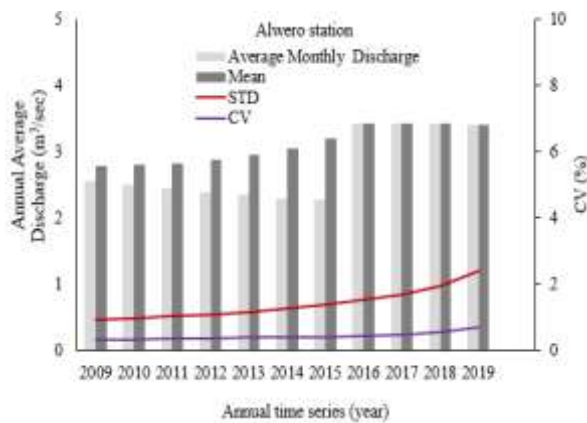


Figure 5.11 Monthly land class inflow and outflow with respect to ET

The result of the time series of the annual average discharge over eight gauging station varies in mean, and standard deviation as shown in Figure 5.12. Study shows that more than the total surface water potential is needed to fulfill the current and future crop water requirements among multiple water users (Chintalacheruvu et al., 2022; Ho et al., 2020). Since the unmet demand was encountered for a current account year and future water demand if the available water resource needs to be managed correctly (Gebrehiwot & Gebrewahid, 2016). More suggests that the problem is not with the watershed supply but instead with the distribution of the supply to a particular demand point or the availability of storage facilities. Thus, options for allocating water include: building new hydraulic structures and restoring existing ones,

sing ponds and tanks, increasing the number of small reservoirs, options on farms, and improving water transmission networks to address the water scarcity issue (Yimere & Assefa, 2022; Tsakmakis et al., 2018). However, a watershed management strategy for boosting soil moisture and water availability in arid and semiarid regions of lower Baro increases irrigation productivity. The standard deviation and coefficient of variance values drop when soil moisture levels rise and vice versa (Almagbile et al., 2019); this implies that variability decreases as the soil gets wet (Jha, 2011; Zwart & Bastiaanssen, 2004).



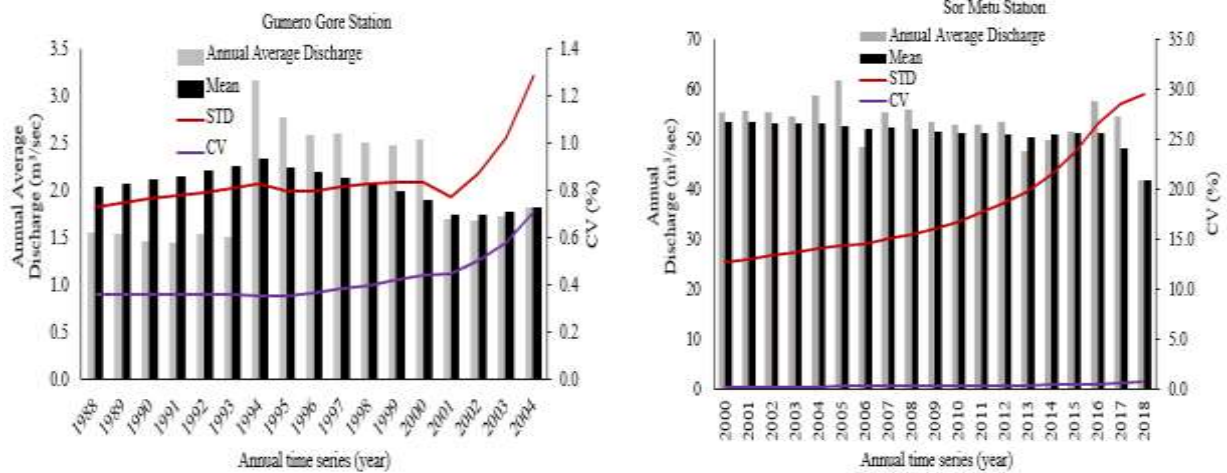


Figure 5.12 Eight gauging sites and the entire lower Baro watershed variation in mean, standard deviation, and coefficient of variation

5.8 Conclusions

This study uses scenarios based hydrological model to predict surface water potential; the reference scenarios are rainfall and streamflow based on the data from 2000-2014 and 2020-2030. To assess yearly and monthly scenario-based surface water potential, irrigation water demand, and future estimates through 2030. The region revealed substantial fluctuations in surface water potential followed by modest variability. In addition, Penman Montieith FAO56 is used to analyze the ET trend. The highest predicted monthly inflow surface water potential, irrigation water demand, hydropower potential, and livestock water demand are 60.3 Mm³. The corresponding outflow value was 52.4 Mm³. Additionally, the total estimated mean annual surface runoff that leaves the basin for Gog, Sor Metu, Baro Itang, Birbir Yubdo, Baro Gambella, Alwero, Gumero Gore, and Gilo Fugnido was 462.06 Mm³. The underlying trend of temperature increase and extreme temperature variability may aid ET. The ETc, Eff rain, irrigation requirements, and total agricultural water demand were determined using the Cropwat8.0 model. The region has enough resources to meet all the demands. However, the gap increases the strain on water supplies. Given this situation, consider surface irrigation potential and crop water requirements carefully to close the gap between current needs and future water availability. To limit negative, stakeholders shall be aware of surface water potential and water demand use in watershed management, water conservation, and irrigation methods. Large areas for agriculture, so emphasis should be placed on crops that use little water.

The mechanisms ensure funding for upkeep and improvements to the infrastructure supplying water to farms and other water consumers. Despite a substantial record of time series for the watershed is required, to increase the attribution of large-scale irrigation water demand in the basin watershed.

The next chapters discuss the detailed satellite ET-based irrigation performance for rainfed and irrigated areas.

CHAPTER 6 SATELLITE ET-BASED IRRIGATION

PERFORMANCE: STRATEGIES TO INCREASE RAINFED CROPS

PRODUCTION IN THE LOWER BARO, ETHIOPIA

6.1 Introduction

The performance indicators of the FAO Water Productivity open-access Portal Database (WaPOR) are essential for increasing water usage effectiveness, supporting performance-oriented management, detecting obstacles, and evaluating system performance against that of other products. The use of agricultural land and water resource methods to give data on these variables at different spatial and temporal dimensions is also rising (Sawadogo et al. 2020). In addition, agricultural land and water resource strategies are highly used to provide information on these variables at multiple spatial and temporal scales (Tang et al. 2020). Currently, remote sensing (RS) technology allows for high spatial and temporal resolution measures of agricultural performance (Bwambale et al., 2022; Karimi et al., 2019).

Integrating RS technology with agricultural, water, and energy management still needs to be improved (Sanders and Masri, 2016). Provide practical information for determining crop water productivity and is an essential measure for agriculture planning and water resources management (Sheffield et al. 2018). Based on the movement, strength, and size of the storm, rainfall events in the arid and semi-arid tropics show extreme temporal variability, producing maximum significant differences at a local level. Filling in the missing data is a prerequisite for modeling any hydrological events using various techniques. The absence of an observer causes the issue of dealing with missing meteorological data, incorrect measurements, malfunction of instruments, relocation of stations, and loss of records in developing countries like Ethiopia (Boke, 2017). Therefore, this study collected rainfall, temperature for the selected area, and discharge for the gauge station. ET will be estimated and analyzed for the trend based on current and feature of water demand. Water is a scarce natural resource that is essential for human survival and the advancement of civilization (Abera et al., 2021). The two main sustainability challenges are global water scarcity and the growing demand for agricultural water to enable increased food production (Yawson, 2022).

However, the enormous variation in crop yields worldwide has recently been brought to light by several articles, which have also identified mechanisms that could potentially increase crop yields (Brauman et al., 2013). Due to the scarcity of land and water, this demand is kept high by the growing human population (Kummu et al. 2016). Irrigated crops only need 13-18% of the world's water for transpiration, which affects productivity and production (Nesru, 2021). Crop water productivity (CWP) has become more well-known as a gauge of agricultural performance in recent years (Gebrehiwot & Gebrewahid, 2016). Nevertheless, recently, the pace of gain from increasing irrigation has reduced; this makes it difficult to improve through irrigation extension due to increased warmth (Yimere & Assefa, 2022; Mesfin et al., 2020). One of the most crucial strategies for boosting agricultural productivity in arid regions and allowing farmers to preserve harvests in the face of drought and rising temperatures is irrigation (Rogy et al. 2022).

Furthermore, the center pivot system is one of the most used irrigation systems worldwide (Alves Souza and Neiva Rodrigues, 2022). Most studies on yield gap analysis have focussed on cereal crops; in addition to this, sugarcane and vegetables received less attention (Van Loon et al., 2018; Chapagain & Hoekstra, 2011). The foundation of sustainable development is science; to tackle urgent global and local concerns, the SDGs, and beyond, new scientific insights paired with cross-cutting technologies innovations (Ho et al., 2020; Montoya et al., 2016). The sustainability of agriculture in areas with limited surface water resources, particularly in lower Baro for crops with high water requirements, irrigation performance, must be improved (Mandal et al., 2020; Haj et al., 2018; Teshome et al., 2018; Santos et al., 2010). Although projections for sugarcane for the next ten years indicate a slowdown in the increase of global sugar consumption, the pace of growth is still anticipated (Van Oort et al. 2017). Investigating the main elements restricting, reducing crop production in farmers' fields using yield gap analysis at the regional level is helpful (Silva et al., 2021).

6.2 Suitability factors

The duration of the irrigation flow, crop adaptation, erosion control measures, and irrigation technique are greatly influenced by the land gradient and slope (Berhanu et al. 2013). With surface irrigation, when the gradient rises, the following negative impacts as occur in increase in the risk of erosion, difficulty in controlling water, reduction in the usable length of irrigation runs, and a narrowing of crop options (Moisa et al. 2022).

The Shuttle Radar Topographic Mission (SRTM) digital elevation model (DEM) data, with a resolution of 30 m, was used to calculate the slope . Using GIS-based multi-criteria evaluation (MCE) tools, the future land suitability for the respective station in lower Baro was assessed based on the pairwise comparison procedure and weight rates as shown in (Eqn 6.1).

$$V_i = W_j X_{ij} \quad (6.1)$$

Where V_i is the overall score for alternative i , W_j denotes the relative weight for criteria j , and X_{ij} is the priority of alternative i concerning criteria j . A surface slope is its incline or gradient and is frequently stated as a percentage. Due to its impact on runoff, drainage, erosion, and crop selection, the slope is crucial for the criterion and maintenance of soil. There are three methods in cropwat8.0 for determining crop water requirements. After comparing the outcomes of the three ways, determined using the FAO/AGLW formula's dependable rain method produced the lowest outcome. Table 6.1 below defines the different slope classes of agricultural appropriateness for the research region based on the FAO manual.

Table 6.1 Slope class for surface irrigation suitability

Slope class	Suitability score
0-2 %	4
2-5 %	3
5-8 %	2
>8 %	1

6.2.1 Irrigation land suitability

In the land suitability map, the upstream and center portions of the area were found to be very suited for surface irrigation because of the short Euclidian distance from the water source, deep soil depth, flat slope, and high accessible surface water storage capacity; on the other hand, surface irrigation was inappropriate for the watershed's northwest sections.

The soil-adjusted vegetation index (SAVI) is the soil-adjusted vegetation index, NIR is near-infrared stands for band 5, and RED is band 4. L is typically equal to 1 in places with no green vegetation cover, 0.5 in areas with some green vegetation but not much, and 0 in areas with a lot of vegetation (which is equivalent to the NDVI method). The values produced by this index range from -1.0 to 1.0. The SAVI method is a vegetation index that attempts to minimize soil brightness influences using a soil brightness correction factor. The NDVI and SAVI equations as shown in Eqns 6.2 and 6.3.

$$SAVI = \frac{(NIR - RED)}{(NIR + RED + L) * (1 + L)} \quad (6.2)$$

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \quad (6.3)$$

6.3 Land use, slope, and soil

Based on the four slope classes, the study region's suitability for installing surface irrigation systems and the area covered by the suitability classes are provided. The value of each parameter was estimated using the pair-wise comparison matrices method. Each of the eight parameters has a different weight of influence for examining a potential surface irrigation location. Crop water requirements analysis using cropwat8.0, particularly water depth, is necessary to fulfill the maximal output potential in the given growing environment (Multsch et al. 2017). Studies suggested the analysis is acceptable because the difference between the eight criteria for surface irrigation appropriateness was just 0.03 (Moisa et al. 2022). Based on the surface irrigation suitability assignments given, the land suitability ranking was shown in Figure 6.1. When determining whether a piece of land is suitable for surface irrigation, it helps to have a clear picture of flow conditions undisturbed by anthropogenic causes (Ekka et al. 2020). However, this was confined by the data availability of rainfall, streamflow, and LULC. Since several years ago, LC changes have played a significant role in global environmental variation (Kabite et al. 2020; Belay & Mengistu, 2021); however, the soil marshy land vertisol with high erodibility (Halefom and Ulsido, 2020). Moreover, the basin's surface runoff potential is boosted from 37 to 49% (Kasaye, 2015); as we reviewed articles on the Ethiopian river basin (Basins, 2021).

Furthermore, the region encompasses most of the lower basin, which is rich in vertisols (Adeba et al. 2016). The prior study suggests assessing the highland's suitability for surface irrigation (Worqlul et al. 2017).

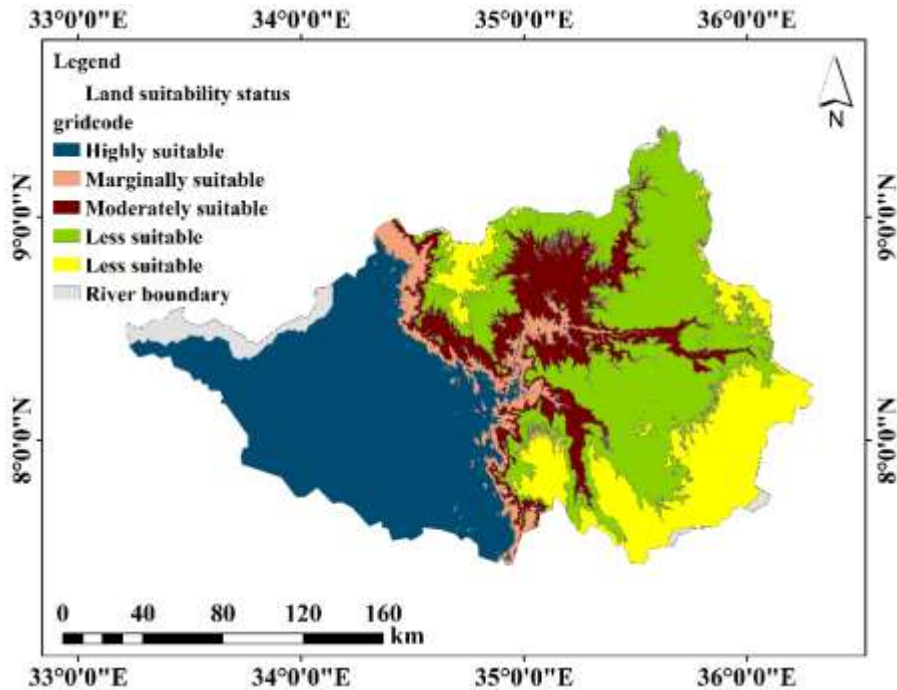


Figure 6.1 Weighting the suitability of surface irrigation

6.4 Results and discussion

Geospatial analysis was carried out to identify and classify diverse landscapes based on comparable hydrologic responses to quantify the geographical and temporal variability of WUE and sWUE in the lower Baro watershed tributaries. Ethiopia is a nation whose development is heavily dependent on agricultural products (Abdulahi et al., 2022). However, the land located near surface water sources (rivers) was thought more suited for surface irrigation for several reasons, including access to water and minimal power usage for the pump. The Euclidian distance from the surface water source, soil depth, and slope were given the most weight in examining the land suitability. Agricultural production is influenced by soil depth since it determines the depth to which roots can grow. Deep soil was given less importance than surface irrigation and vice versa. The qualities of the theme feature and its relationship to irrigation appropriateness are taken into consideration while determining weights.

A pairwise comparison of the feature classes and the weights assigned to each feature were used to obtain the geometric mean and normalized weights. This was often used in an arid region where vegetation cover was low and it outputs a value between -1 and 1. In this study, the SAVI was quantified based on the data from USGS earth explorer from 03/30/2023-04-30-2023. In particular for dryland areas of lower Baro, soil-adjusted vegetation indices have been created to offer better estimates of aboveground biomass. Because of their brightly reflecting soils and low vegetation cover, semi-arid rangelands has frequently make it difficult to evaluate aboveground biomass using RS. The result indicated a maximum value of 0.87 and a minimum of -1.5 and the NDVI result show (b) 0.58 maximum and -1 minimum. The NDVI and SAVI map as shown in Figure 6.2.

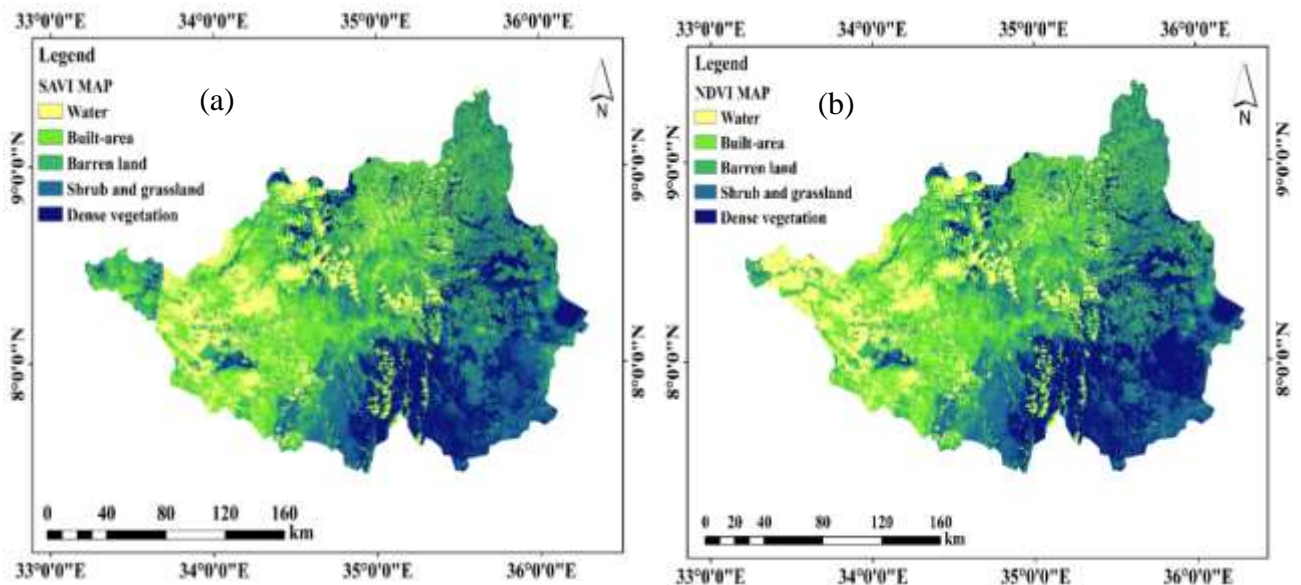


Figure 6.2 Soil-adjusted vegetation index and normalized difference vegetation index for the lower Baro tributaries

The study found that the pair-wise comparison matrix indicates the 8 factoring parameters for the multi-criteria decision layers (MCD). These were, the mean annual temperature, rainfall, soil depth, soil texture, soil drainage, LULC, stream, and slope variability, which significantly affect the irrigation potential of the catchment area. As a result, the pairwise comparison of the procedure, and weight rates were given in Table 6.2. The result value in this study, 1 indicates equal importance, moderate importance (2), strong importance (3), and very strong importance (4), and 1/2, 1/3, and 1/4 were intermediate values as a comparison in the analytical hierarchal method. Surface irrigation also very well suited to the study area's, but soil drainage is concerned.

Moreover, the studied area is only partially unsuitable for surface irrigation, according to the spatial distribution of soil drainage of the selected stations. Only a very little quantity of bare ground, settlements, and water bodies were presented in the study region, which primarily consisted of cultivated land, woodlands, and grasslands.

Table 6.2 Pairwise comparison matrix for the selected parameters

Factors	Temperature	Rainfall	Soil depth	Soil texture	Soil drainage	LULC	Stream	Slope
Temperature	1	1	2	3	3	4	4	3
Rainfall	1/2	1/2	1	3	3	4	3	4
Soil depth	1/2	1/2	1/2	2	3	4	4	3
Soil texture	1/2	1/3	1/2	1	3	4	3	3
Soil drainage	1/2	1/2	1/2	1/2	1/2	2	2	2
LULC	1/3	1/3	1/3	1/2	1/3	1	2	3
Stream	1/4	1/4	1/4	1/3	1/3	1/3	1	2
Slope	1/4	1/4	1/4	1/4	1/3	1/3	1	1

6.5 Schedule irrigations based on evapotranspiration (ET)

As a result, the cropwat8.0 in the lower Baro River shows that the total crop water demand for the four crop types rice, sugarcane, maize, and vegetables was 917.2 mm/decade throughout the entire growing season and required 7.02 l/s/h flows in each one-hectare area. In Ethiopian highlands in the Blue Nile Basin, the majority of irrigation water demand occurred in all six irrigation nodes between the drier months of November and June, with little to less IWR occurring between July and October (Yimere & Assefa, 2022). The low-land Baro watershed projected values for maize in the chosen driest five months of May, February, March, January, and April were 1, 0.9, 0.78, 0.78, and 0.34 l/s/h. When there is a lack of water, you must reconsider habits to maximize what is available (Eshete et al., 2020). Many arguments exist for less water, even when it is more available (Asitatie & Gebeyehu, 2021; Johnston & Smakhtin, 2014). Water discharge from excessive water consumption could squander soil and fertilizer (Gezhagn et al. 2017). Nitrates, nitrites, and other farm pollutants were deeply percolated and leached as a result of excessive irrigation (Abebe et al. 2021).

Water demand in lower Baro follows a seasonal pattern that differs depending on the crop (Kahlerras et al. 2018). To have enough water to produce an economically viable harvest and be aware of the crops' water usage requirements, the optimal time to irrigate a particular field also depends on the soil's capacity to store water and the most recent irrigation the crop received (Rising, 2020). It is possible to increase irrigation efficiency by timely irrigation techniques like deficit irrigation, conservation tillage, and setting up more effective irrigation systems (Boke, 2017; Ouda et al. 2013; Irfan et al. 2018). The aesthetic impact of too much water was less than that of too little, but it also wastes soil and fertilizer in addition to water (Woldegebriel et al. 2022). Surface irrigation systems could have been more efficient (Yidana et al. 2011). Study shows the expected crop water, each irrigation event always results in 100% of the field's surface is wet, and the only actual variations between the scenarios are the altered irrigation dates and watering rates (Tsakmakis et al., 2018). Maize used less water than rice, sugarcane, and vegetable production, which required hours of water per acre for production. This was the result of the number of irrigation systems used and how each irrigation turn was used for the selected crops as shown in Table 6.3.

Table 6.3 Irrigation scheme supply

Crop Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Rice deficit in mm	0	0	0	0	309	187.4	141.5	169.5	110.4	0	0	0
Sugarcane in mm	208.6	217.1	207.7	88.2	148.9	42	64.9	148.7	136.1	141.9	99.7	191.3
Maize in mm	0	0	0	0	0	41.3	105.4	171.1	96.7	7.3	0	0
Small vegetables	0	0	0	0	0	103.8	110.1	145.5	22.1	0	0	0
Net Irri. Req.												
Irrigation(mm/day)	0.5	0.6	0.5	0.2	2.7	2.2	2	2.8	1.6	0.4	0.3	0.4
(mm/month)	16.7	17.4	16.6	7.1	83	66	62.7	86.2	46.6	11.9	8	15.3
(l/s/h)	0.06	0.07	0.06	0.03	0.31	0.25	0.23	0.32	0.18	0.04	0.03	0.06
Irrigated Area (% total Area)	8	8	8	8	31	54	54	54	54	15	8	8
Irrigation requirement for the actual area (l/s/h)	0.78	0.9	0.78	0.34	1	0.47	0.43	0.6	0.33	0.3	0.38	0.718

6.6 Irrigation schedule

As a result, cropwat8.0 showed that the total net irrigation, percolation losses, actual water usage by the crop, and potential water, were 1269.1, 483.2, 641.7, and 641.7 mm. The irrigation efficiency was 100%, and total rainfall, efficiency, rain, and rain loss were 37.5, 28.4, and 9.1mm. Innovative irrigation methods can improve water efficiency, give farmers a competitive advantage, and have a positive environmental impact (Levidow et al. 2014). Field efficiency of 70%, the actual irrigated need of 613.3 mm, rain efficiency of 75.7%, and thick soil. Moreover, the basin watershed surface runoff potential is boosted from 37 to 49% (Kasaye, 2015); as we reviewed articles on the Ethiopian river basin (Basins, 2021). The first stage lasts from planting until around 10% of the ground has been covered.

The crop development stage spans from 10% ground to adequate full cover; the mid-season stage lasts from complete coverage until the beginning of maturity. The sector is predicted to become a water user with increased agricultural investment in such geographically constrained places (Dau et al., 2021; Nurhusein, 2020). As a result, the rice, maize, sugarcane, and vegetable production required hours of water per acre. The ET_c of a disease-free crop was defined as the depth of water (mm) required to satisfy this need; the crop would grow in broad fields with general soil conditions, including soil water and fertility. The statistics of previous studies on ET_c for the soil water balance approach are not achieved daily throughout the growing season since soil water content, is only assessed after every five days (Chang et al., 2015). This is due to decreased surface water variability due to land use (Alemayehu & Nigussie, 2015).

As the water demand grows, water conservation is required for irrigation (Fard & Sarjoughian, 2021; Giri et al., 2018). During the initial stage of the crop, irrigation requirement comes to around 63.7 mm/dec for nursery and land preparation a maximum of 223.2 mm/decade. The effective rainfall from nursery operation 5.3 mm/decade (May 1 decade) to the initial stage (Jun 3 decade) was only 65.3 mm/decade. The difference between the irrigation water requirement amounts and effective rainfall was about (36.5 mm/dec) which was supplied through surface water. The crop water demand of Alwero irrigation from the development stage of the crop (May 1 decade) to the final stage (September 1 decade) was 917.8 mm/decade and effective rainfall from the development stage of the crop (May 1 decade) was 36.5 mm/dec which was lower than the irrigation requirement at the initial and final stage of the crop. However, more water resource like stored rainwater in on-farm reservoirs is very much useful (Muleta, 2021).

In addition to rainfall to meet crop irrigation water demand as well as for land preparation in this area (Ndeketea & Dundu, 2022). It is also understood that, if there are no additional water sources, it is better to go for direct seeding of rice, sugarcane, maize, and vegetable. Where farmers could avoid agricultural water demand for nursery and land preparation, there would be less productivity. This is highly related to the winter monthly Kc which showed that from early to late season (Hasanuzzaman, 2019). As a result of this study, the maximum ETc in the month of June of the second decade was 7.12 where as the the minimum was 0.6 in the first nursery of the first decade. Moreover, ETc mm/decade in the months of 2nd May was 54.3, but in the same month of the 3rd decade the value was increased to 67.8. This is due to the variation of growth of the crops. However, the Kc was increasing and decreasing. The overall decadal monthly crop water requirement and irrigation productivity as shown in Table 6.4.

Table 6.4 Crop water requirement and irrigation production

Month	Decade	Stage	Coeff (Kc)	ETc mm/day	ETc mm/dec	Eff rain mm/decade	Irr. Req. mm/dec
May	1	Nurs	1.2	0.6	5.4	0.1	5.3
May	2	Nurs/LPr	1.08	5.43	54.3	0.0	80.5
May	3	Nurs/LPr	1.06	6.16	67.8	0.0	223.2
Jun	1	Init	1.10	6.76	67.6	3.9	63.7
Jun	2	Init	1.10	7.12	71.2	5.9	65.3
Jun	3	Deve	1.13	6.41	64.1	5.7	58.5
Jul	1	Deve	1.17	5.42	54.2	5.6	48.6
Jul	2	Deve	1.22	4.70	47.0	5.8	41.2
Jul	3	Mid	1.24	5.07	55.7	4.1	51.7
Aug	1	Mid	1.24	5.56	55.6	1.7	53.9
Aug	2	Mid	1.24	5.77	57.7	0.0	57.7
Aug	3	Late	1.24	5.30	58.3	0.4	57.9
Sept	1	Late	1.19	4.54	45.4	1.2	44.2
Sept	2	Late	1.13	3.87	38.7	1.4	37.3
Sept	3	Late	1.07	3.73	29.8	0.8	28.9
					772.9	36.5	917.8

As a result, Alwero, Baro Itang, and Baro Gambella 23.1, 15.99, and 14.65% are highly suitable, Gilo Fugnido 8.44% moderately suitable, and Sor Metu, Birbir Yubdo, and Gumero Gore 7.98, 7.69, and 6.14% less suitable as shown Table 6.5. The potential of lower Baro for surface irrigation, which helps to improve community livelihoods, is demonstrated by this study. LULC affects the water demand of crops grown in irrigated and rainfed systems (Wang & Yang, 2014).

Since an increase in temperature will trigger a higher water demand for ET by crops and natural vegetation, leading to more rapid depletion of soil moisture (Mohaideen and Varija, 2018). In the Eight tributaries, heterogeneous land scape five land suitability zones, and three unsuitable zones are identified for irrigation investment. The cause of temporal variation is the incoming solar energy, heating or cooling of the atmosphere, heating or cooling of the ground, and evaporation or condensation of water (Cherinet et al. 2019; Papacharalampous et al. 2018). The amount of water that would evaporate if energy were the only limitation (i.e., moisture availability does not limit the evaporation (Burn and Hesch, 2007). The crop requires irrigation water for transpiration and deep percolation, and ETo is influenced by critical environmental factors like solar radiation, air temperature, wind speed, and relative humidity (Tadesse et al. 2018).

Table 6.5 Surface irrigation suitability class and its coverage in km²

S no	Station Name	Suitability Classes	Area (km ²)	Area (%)
1	Alwero	Highly suitable	4696	23.1
2	Gilo Fignido	Moderately suitable	1716.5	8.44
3	Birbir Yibdo	less suitable	1563.0	7.69
4	Gog	Marginally suitable	3,250	15.99
5	Baro Gambella	Highly suitable	2978.3	14.65
6	Baro Itang	Highly suitable	325.25	15.99
7	Gumero Gore	less suitable	1,249	6.14
8	Sor Metu	less suitable	1622	7.98
		Total	20325	100

6.7 Land suitability for rainfed crops

The total area of Saudi stars under lease in Gambella is 140-500 kha. Still, only ten kha are under the production of the Alwero Dam, one of the Baro River tributaries. Saudi Star applies water to the rice crop fields through the diversion structure from the Alwero Dam site. The optimal land conversion area for rainfed crop yield is further categorized using a combination of the ETa/ETp, ETa WaPOR, slope classification map, and land use map. In this study, the range of slope is 10 to 15% gradient on moderate slopes, 16-30% gradient slope, slopes that are highly steep 31 to 60% gradient, and slopes that are too steep are > 60% gradient. As a result, the slope of Baro River

shows from 0-2, 16-30, 2-8, 30-50, 8-16, and >50%, as shown in Figure 6.3. The sector becomes a water user with increasing agricultural investment in geographically constrained places (Mulsch et al., 2017). There are many reasons to invest in agriculture, but more needs to be done to satisfy the future food demand of the expanding population living in emerging countries (Salem et al. 2022).

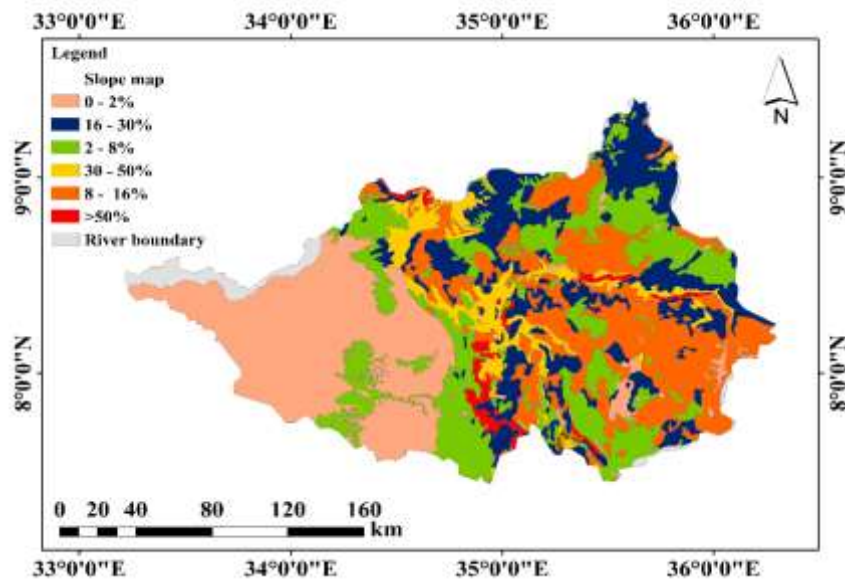


Figure 6.3 Slope map of the lower Baro watershed tributaries (2016-2019)

Due to the rising demand for food, it is necessary to anticipate the need for timely mitigation action (Abdullah et al., 2015). A framework for irrigation performance assessment using WaPOR data is shown in Figure 6.4.

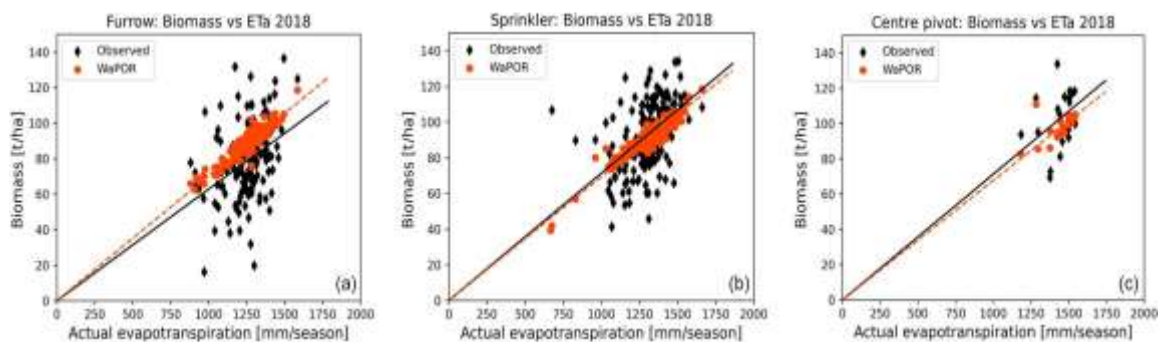


Figure 6.4 The link between biomass as determined by the Estate and obtained from WaPOR) of furrow (a), sprinkler (b), and center-pivot-irrigated (c)

As a result, of the framework of irrigation performance assessment using WaPOR data, Ethiopia's agriculture sector plays a central role in the lives and livelihoods of most Ethiopians (Getnet and Dugasa, 2019). In December, Gambella gets 67.61mm of rain and approximately three rainy days, and humidity is close to 68% (Degife et al. 2021).

6.8 Water consumption and agricultural production system

There is usually a drop in return flow to the resource due to limiting water diversions. As a result, a conservation program may leave the amount of net consumption by an irrigation system relatively intact. The source of agricultural water consumption is estimated to be 22% of blue water and 78% of grey water (Giri et al., 2018). According to the end of sustainable development goal estimate, Ethiopia's population will be 148.6 million in 2030 (Rockström et al., 2017). Studies suggested that enhancing the availability of surface water resources is one of the best ways to raise the quantity and quality of groundwater resources (Tork et al., 2021). Moreover, decreases numerous environmental issues, including rising energy usage and a sharp fall in groundwater levels (Askari et al., 2021). However, soil texture is one of the most crucial elements defining soil quality and suitability for agricultural production (Khalil, 2017). The reason is to makes it possible for plants transport water from regions with high water potential to those with low water potential (Safavi et al., 2015). At the same time, protecting the environment and using water resources relatively (Sawadogo et al. 2020). Due to this, the country's agricultural production has been significantly changing to decrease the food aid and commercial grain import (Fikadie et al. 2022).

6.9 Potential evapotranspiration (PET)

ET is one of the components of water use efficiency and resulting crop productivity (Haile, 2015). Appropriate irrigation scheduling should be extensively valuable for water management performance, especially at a farm level. However, Periodic information on ET based on remote sensing data would be essential to minimize uncertainty in the crop parameters and subsequent accurate water balance estimation (Kamble et al. 2013). The year-long warm temperatures and irrigation help satisfy the significant water demand for sugarcane for optimum growth and yield (Drastig et al. 2016). AET returns land-based water to the atmosphere through evaporation and transpiration from the soil and the plant canopy (Osorio et al. 2014). Due to the seasonal rainfall variation in the catchment with time and space (Alem et al. 2022). It tracks the system's ability to provide equitable water distribution, irrigation water adequacy, yield reduction, and water productivity (Zhang et al. 2021). The methodological study used the following assessments to carry out the anticipated approach.

6.10 Irrigation performance assessment

Only by using better farming methods and farm management is possible to meet this expanding demand. Knowing the potential of irrigation led to the entire gross area of Lower Baro and a plan proposes to irrigate with various crops over a year. The specific relationship between ET and crop yield has been established and quantified in terms of crop yield.

6.10.1 Improved agricultural practice

Without considering the three primary elements namely water (W), energy (E), and food (F), it is difficult to control these circumstances (David et al., 2022; Adebisi et al., 2021; Meier et al., 2017; Aivazidou et al., 2016). In these studies, four irrigation performance monitoring criteria were selected namely Equity, adequacy, reliability, and CWP in lower Baro tributaries. Increasing CWP is vital regardless of prospects for growth or the demand, according to ET-based WaPOR statistics. The flowchart of the performance of irrigation is shown in Figure 6.5.

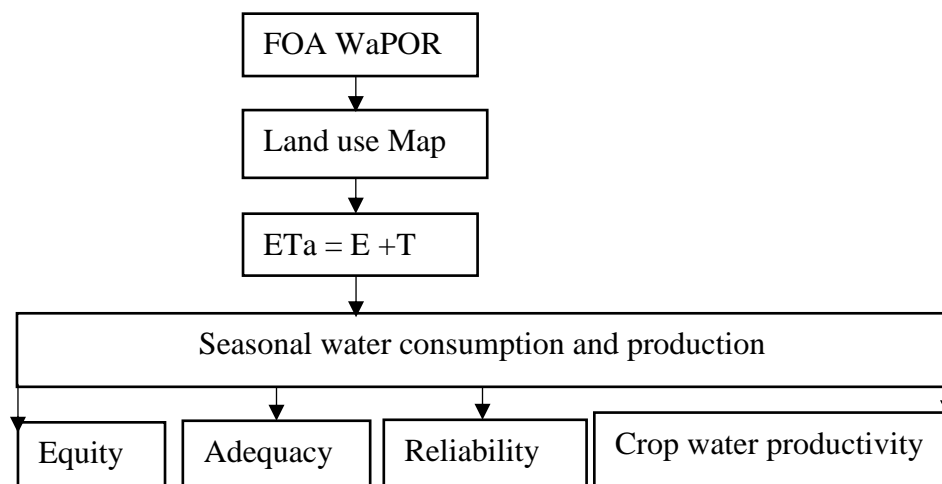


Figure 6.5 A framework for evaluating the performance of irrigation systems using WaPOR is shown schematically

6.10.2 Appropriate land area conversion

Based on the analysis of the chosen sub-catchments, possible areas that are appropriate for the cultivation of the chosen rainfed crops are converted from pastoral land. In the irrigated maize, where the yield gap is equal to the difference between Y_p and Y_a , the rainfed crop; the yield gap is computed as the difference between Y_w and Y_a (Schils et al., 2018). The coefficient of determinants is used to select the function from among a set of linear and nonlinear functional forms that most closely match the set of data (Nesru et al., 2022).

The average and the maximum yields and the increase in yield gaps by 1/3, 2/3, and 3/4 were applied to estimate the increase in rainfed crop production for eight sub-catchments in the lower Baro tributaries watershed namely Alwero, Gilo Fugnido, Birbir Yubdo, Gog, Baro Gambella, Baro Itang, Gumero Gore, and Sor Metu represented as A₁, A₂, A₃, A₄, A₅, A₆, A₇, and A₈ on the bases of coefficient of determinants as shown in Eqn 6.4.

$$Y = A_1 + A_2ETa + A_2SR + \dots + A_8F \quad (6.4)$$

Where Y is cropping yield (Kg/ha), ETa is actual seasonal evapotranspiration (mm), SR is the seed rate (Kg/ha), and F is the fertilizer application rate (Kg/ha). The operational range and acceptable range of relative evapotranspiration were established using the target and critical crop production. Based on GYGA's data used for different production levels as determined by growth defining, limiting, and reducing factors shown in Figure 6.6.

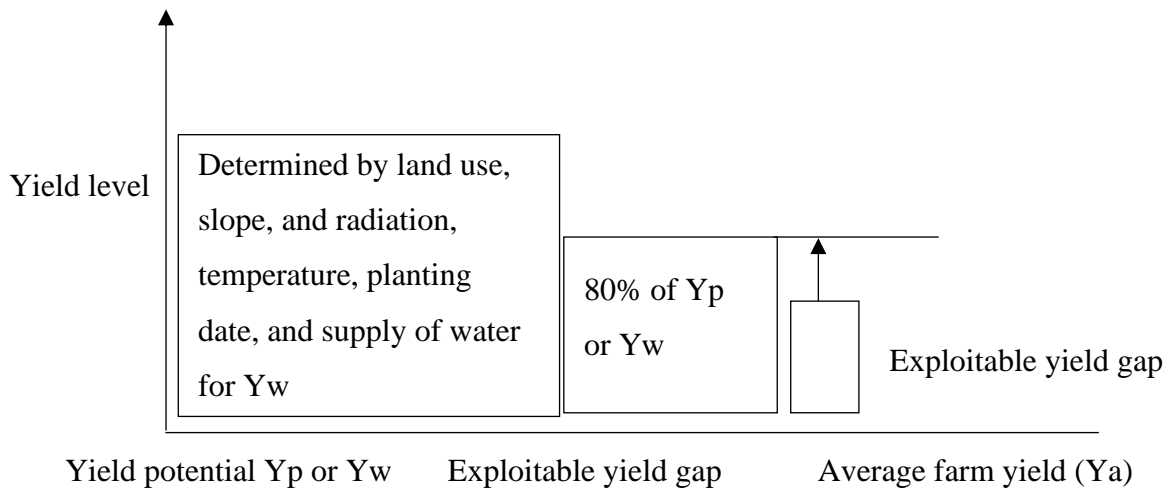


Figure 6.6 Global yield gap atlas (GYGA) different production levels as determined by growth-defining, limiting, and reducing factors

Due to the linear relationship between ETa and yield, irrigation's main goal is to make sure that ETa can keep up with ETc throughout the growing season (Gibson et al. 2017). In this study, each performance indicator is indicated in Eqns 6.6-6.8.

$$\text{Equity} = CV(ETa) \quad (6.5)$$

$$\text{Reliability} = CV\left(\frac{ETa}{ETp}\right) \quad (6.6)$$

$$\text{Adequacy} = \frac{\text{Seasonal } ETa}{\text{Seasonal } ETp} \quad (6.7)$$

$$\text{Relative water defecit} = 1 - \frac{ET_a}{ET_p} \quad (6.8)$$

Reliability is the degree to which water delivery conforms to the prior expectations of users and is expressed as $CV(ET_a/ET_p)$ as shown in Table 6.7.

Table 6.7 Summary of all the various clusters employed in lower Baro

Category	Cluster Name	Command Area	Type of Management Grower
Land holding	growers on a small scale	< 50 ha	Run modern business line
	grower on moderate Size	50 - 1000ha	Farmer-managed and commercial
	grower on a large scale	>1000 ha	Farmer-managed and commercial
Management type	Estate managed	>1000 ha	Run along modern business lines
	Farmers association	50-500 ha	Farmer managed communally
	Individual growers	3-100 ha per farm	Farmer managed individually
Location	Alwero	4696	Farmer's associations and commercial
	Gilo Fignido	1716.5	Run along modern business lines
	Birbir Yibdo	1563.0	Farmer managed individually
	Gog	3,250	Farmer managed individually
Area (km ²)	Baro Gambella	2978.3	Farmer's associations and commercial
	Baro Itang	325.25	Farmer managed communally
	Gumero Gore	1,249	Farmer's associations and commercial
	Sor Metu	1622	Farmer managed individually
Irrigation method	Center Pivot	5 %	-
	Sprinkler	10%	-
	Furrow	25 %	-
	Drip	20 %	-

6.11 Crop water productivity

With an emphasis on the output local-to-global significance, this study calculates yield gaps. The enhanced productivity was assessed based on an analysis of the agricultural land and average yield gaps. The area might should to create a lower Baro watershed for rainfed agriculture to boost the output of rice, sugarcane, maize, and vegetable crops. The previous studies' yield gap results of lower Baro revealed that irrigation has almost no effect on potential yields (Degife et al. 2018). Utilizing better drought-tolerant crop varieties were help to conserve water. The most effective way to decrease water losses and increase water consumption efficiency in the soil-plant system is to improve irrigation technology, such as water harvesting (El-Gafy, 2017).

Many academics have turned to mathematical programming models to guide the distribution and use of irrigation water to enhance productive utilization (Letseku & Grové, 2022). The real-time satellite ET-based irrigation performance and strategy for the rainfed crop at spatial and temporal variation were crucial. Equity represents the uniformity in the spatial distribution of water use among fields by the different growers. The spatial correlations of ET of rice, sugarcane, maize, and vegetable growers were an indicator to investigate the equity of water use. Moreover, as an ET indicator increases from 35 to 45 °C the value of ET goes to zero. This shows that high temperature doesn't mean higher ET. Previous studies have used a top-down spatial framework for yield gap analysis (Deng et al. 2019).

6.12 Rainfed crop rice, sugarcane, maize, and vegetable production

The evaluations of the CWP and ETP/ETa of the lower Baro area were for crop cultivation. The value of R^2 was a maximum of 0.97 observed at Baro Itang and the minimum value was observed at Gilo Fugnido as compared to the other sub-catchments. Out of 477 small-scale modern irrigation systems irrigating 0.052 Mha in 2004 and 2005, 13% are completely inactive and 12% are serving less land than industrialized countries (Kedir, 2021). The CWP of wheat and maize is demonstrated against the net irrigation water application in several studies (Zwart & Bastiaanssen, 2004). In rainfed locations, ETa-WaPOR is overestimated; but at low locations, ETa-WaPOR is significantly underestimated (Chukalla et al. 2022). The yield gap in terms of metric tons of the world crop production summary of Ethiopia for a specific region, the yield of 2021/2022 is 3.08, and from Jun 2022/2023 to July projected is 3.23 (Dukhnytskyi, 2019). Applying fertilizers and water at the correct rates will ensure the most yields in the safest manner possible (Van der et al. 2018; Cecagno et al. 2016). In light of this, any agricultural water deficit (more specifically ET deficiency), directly indicates whether the entire system of water supply, water distribution, and soil moisture increase function following the crop demand (Zaveri & B. Lobell, 2019). Conventionally, farm productivity was a significant measure of the production of irrigated agricultural land, expressed as the ratio of grain yield to a harvested unit area (kg/ha). The highest attained coefficient of determination (R^2) value, which indicated the highest level of equitable distribution of water from the evaluated results was shown in Table 6.8.

Table 6.8 Crop yield, ETa, seed rate, and fertilizer correlation coefficients for each sub-catchment

Sub catchment	A ₁	A ₂	A ₃	A ₄	A ₅	A ₆	A ₇	A ₈
Rainfed crops	0.96	-0.46	-0.30	0.86	0.76	0.97	0.93	-0.99

6.13 Land productivity

In this study, the moisture content ratio (θ) allows for converting fresh yield into summer dry yield by accounting for water content in the harvested product. In rice, the light use efficiency (LUE) was 1 for C3, and C4 crops, the harvest index (HI) was 0.43, the above-ground biomass (AoT) was 0.75, and the θ was 0.15. In sugarcane the LUE was 1.8 for C3 and C4 crops, the HI was 1, AoT was 1, and the θ was 0.7. For maize the LUE was 1 for C3 crops and 1.8 for C4 crops, the HI was 0.35, AoT was 0.93, and θ was 0.26. Global blue water use for agriculture would need to rise by 760 km³/year to develop and deepen irrigation across these territories. According to FAOSTAT (2020) data for the period 2008-2018, the average estimated wheat yield was 3203 kg/ha, and the average estimated potato yield was 31495 kg/ha, which was comparable to the reported wheat yield of 3000 kg/ha (Safi et al., 2022). For vegetables the LUE was 1 for C3 and C4 crops, the HI was 1, AoT was 1, and θ was 0 for the sub-catchment of the lower Baro. Studies mentioned that in Ethiopia, the irrigated production region, only Teff among the cereals exhibited a slight 4.3% overall rise. In contrast, Barley, Wheat, Maize, and Sorghum saw 12.5 to 3.3% decreases, and 11 to 12% increases respectively (Malede et al. 2023). The regional offices of Oromiya, Amhara, SNNP, Gambella, and Tigray reported 28% of irrigation systems were typically destroyed and rendered useless, while 32.2% are irrigating less land than is created (Kedir, 2021).

As a result, micro-irrigated areas grew by 60% while planting areas with furrow irrigation decreased by 56%; during this time, the per-unit-product WF decreased by 20% (Wang et al., 2019). The biomass depends on clear images with a lower resolution level of one or two taken over time in 10 days in WaPOR. Because of this, humid climates are more problematic than dry ones. Due to the smaller size of the sub-catchments, seen in the spread of rainfed maize in the upper Baro of Sor River, it was determined that the land availability needed to be improved compared to the other seven sub-catchments. However, the Baro Gambella sub-catchment was one of the area where the land is becoming more readily available. Moreover, the Alwero sub-catchment was also seeing a rise in land availability as a result of the expansion of the field.

As a result, the Baro Itang sub-catchment had rather a moderate amount of appropriate land availability. Further more, the Gumero Gore sub-catchment, located in the upper area of Baro Gambella, had a relatively high land availability rate because of its sizable size and non-uniform topography. In regard, to Sentinel-2 (10 m visible bands) on less than 2 ha of land should improve inter-plot irrigation performance interpretation and monitoring (Karimi et al., 2019). Even though the yield and WP estimate were derived from the WaPOR data. The single HI value and the field data had high consistency. The HI should be adjusted, either upward or downward, based on timing, crop phenological stage, degree of various stresses, and crop sensitivity. In the Awash zone, sugarcane grows for an average of 585 days during 305 to 1037 days, or 0.8 to 2.8 years (Mersha et al., 2018). Expressed as the ratio of the weight of dry grains over the above-ground dry matter; the AoT ratio was influenced by several factors, including root development.

Studies stated that, according to an estimate made using satellite imagery hotspots, 23% of the earth's surface has been degraded over the last three decades, costing an estimated 54 billion dollars (Yigezu Wendimu, 2021). Global blue water use for agriculture would need to rise by 760 km³/year to develop and deepen irrigation across these territories. The study mentioned that from the period 2008-2018, the average estimated wheat yield was 3203 kg/ha, and the average estimated potato yield was 31495 kg/ha, which is comparable to the reported wheat yield of 3000 kg/ha (Safi et al., 2022). In this study, θ allows for converting fresh yield into summer dry yield by accounting for water content in the harvested product. In rice, LUE was 1 for C3, and C4 crops, the HI was 0.43, AoT was 0.75, and the θ was 0.15. In sugarcane the LUE was 1.8 for C3 and C4 crops, the HI was 1, AoT was 1, and the θ was 0.7.

For maize the LUE was 1 for C3 crops and 1.8 for C4 crops, the HI was 0.35, AoT was 0.93, and θ was 0.26. For vegetables the LUE was 1 for C3 and C4 crops, the HI was 1, AoT was 1, and θ was 0 for the sub-catchment of the lower Baro. According to past calculations, doing so would increase the world food calorie production by 54% kcal/year (Rockström et al., 2017). This study reported that land productivity was the crop yield per unit of land. A fixed value of 2.7 was applied to cropland in WaPOR and, through this interface, the value was multiplied by 1.8 for C4 crops, which had higher LUE as shown in Table 6.9.

Table 6.9 Sub-catchment area based on crop types

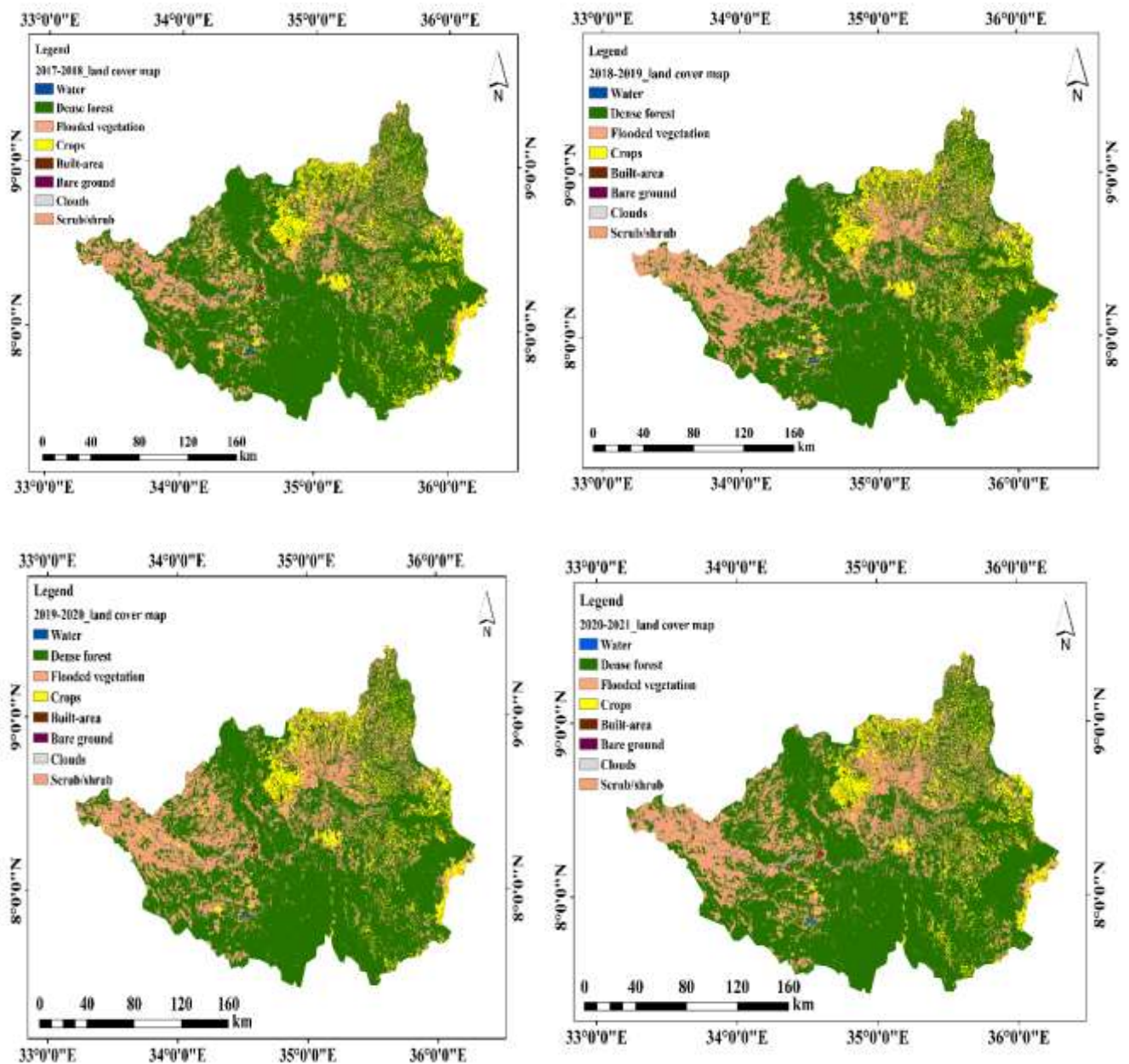
Sub-catchment Area (ha)								
Crop types	Alwero	Gilo Fugnido	Birbir Yubdo	Gog	Baro Gambella	Baro Itang	Gumero Gore	Sor Metu
Rice	22,000	460	8115000	25000	81000	33	3000	234
Sugarcane	10,000	14	2028754	513438	148610	37161	10040	2568
Maize	6,001.69	23	507194	255158	100942	34526	11141	3427
vegetable	280,000	70000	35000	17500	8750	4375	2188	1093

6.14 Land cover change at the watershed level

As a result of this study, there was a relatively straightforward operation for water, trees (dense forest), crops, built-up areas, bare ground, and clouds at the 10 m resolution of Sentinel-2. Because these feature groups frequently occur in agglomerations that are homogeneous. The classes of scrub/shrub and flooded vegetation turned out to be the most challenging due to their frequent appearance as mixtures of vegetation kinds and varied forms. In addition to the Sentinel-2 tile, annotators had access to a comparable high-resolution satellite image through Google Maps and ground imagery through Google Street View from the image's central point. For each annotation, we also provided the center point's date and coordinates. Within 20 to 60 minutes, each annotator had to complete at least 70% of a tile's labelling. A previous study in the upper Baro proved that from 1986-2017 the flood frequency increased peak flow, soil erosion, base flow, and annual mean discharge. Specifically, studies mentioned that, Sor and Geba catchment land use maps from 1987, 2001, and 2015, the producer's accuracy score ranged from 60 to 100%, 72.7 to 100%, and 63.6 to 100%, respectively (Hassen, 2022).

However, from 1987, 2001, and 2015, the user's accuracy varies from 75 to 96.7%, 85.7 to 100%, and 88.9 to 100%, respectively. The lowest values is discovered, because diverse land uses have comparable spectral characteristics. As a result, of this study, the spatial extent of each land cover type from 2017-2018, 2018-2019, 2019-2020, 2020-2021, 2021-2022, and 2022-2023 revealed that there were a decrease in the water body, cropland, and increase scrub/shrub land, trees, flooded vegetation, and bare ground.

This situation mainly occurred due to the population growth rate, which increased demand for agricultural land, fuel wood, and as an economic source. Because LC was dynamic, they altered the hydrology of the basin watershed, making it crucial to assess their effects on various hydrological components. The effect of vegetation cover on enhancing basin capacity, preserving moisture, and increasing water production has been noted by researchers as something that cannot be ignored (Achugbu et al., 2022; Dufera & Brijesh, 2023). But the places with the greatest increases in agricultural areas are the ones with losses in wooded and shrubland areas, which are associated with the greatest increases in surface flow and decreases in groundwater recharge (Anduaem et al., 2023). This, in turn, reduced other land cover types of the study area, as shown in Figure 6.7.



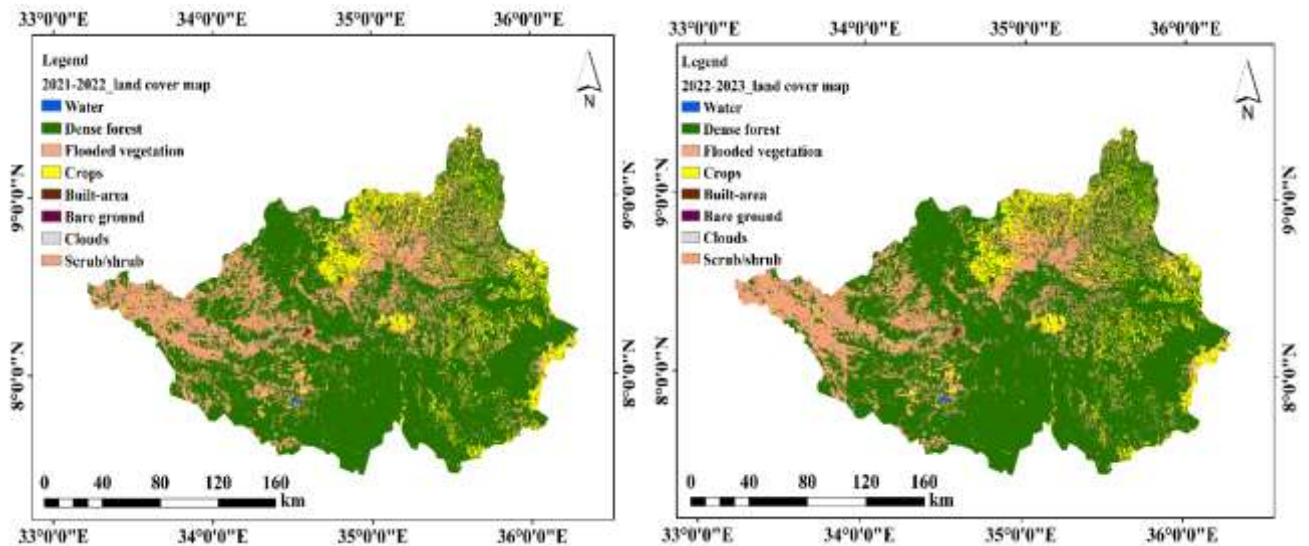


Figure 6.7 Land cover map of the lower Baro watershed (2017-2023)

6.15 Global map accuracy assessment by impact observatory

Following best practices for accuracy assessment impact observatory adjusted the acreage estimate for each class using its respective user accuracy as computed from the comparison to the validation set. This approach also allowed the impact of the observatory to produce a 95% confidence interval for each acreage estimate. This provides users with a clearer picture of the accuracy and the total area for each class with the Kappa coefficient calculated as the overall accuracy minus the chance of agreement divided by one minus of chance of agreement. A result found that the Kappa coefficient was 0.9 with a chance agreement of -0.55, as shown in Table 6.10. Fighting the consequences of rainfall, streamflow variability, unreliability in irrigated agriculture, and the use of water resources allow for extra and year-round irrigation (Hirko et al., 2023).

Table 6.10 Confusion matrix for classified land cover images from 2017-2023

Land cover class	Water	Trees (Dense forest)	Flooded vegetation	Crops	Built area	Bare ground	Scrub/Shrub	Row total	User Accuracy	Commission error = 1-user Accuracy
Water	33	2.89	2.77	2.33	2.53	2.05	3.72	49.29	0.67	0.33
Trees (dense forest)	11.24	76	2.15	2.19	2.31	3.23	3.56	100.68	0.75	0.25
Flooded vegetation	8.23	2.89	79	2.12	1.78	2.12	2.16	98.3	0.80	0.20
Crops	3.23	2.78	2.65	76	1.97	3.18	2.27	92.08	0.83	0.17
Built area	3.69	2.61	2.78	1.98	73	2.48	2.15	88.69	0.82	0.18
Bare ground	2.45	2.23	1.31	1.08	2.26	67.2	2.96	79.49	0.85	0.15
Scrub/Shrub	4.32	2.14	2.62	1.05	2.12	1.51	92	105.76	0.87	0.13
Column total	33.16	88.65	90.51	84.42	83.44	79.72	105.1	614.29	Overall accuracy	
Producer Accuracy	1.00	0.86	0.87	0.90	0.87	0.84	0.88	Overall sum	81%	
Omission error = 1-Prod Accuracy	0.00	0.14	0.13	0.10	0.13	0.16	0.12			

However, following best practices for accuracy assessment impact observatory adjusted the acreage estimate for each class using respective user accuracy as computed from the comparison to the validation set. The confidence interval quantifies the uncertainty surrounding the sample-based estimate of the area deforested. However, information on the size of the classification mistakes by the confusion matrix in the accuracy assessment, allows the area estimator to be adjusted. According to the findings, tree (dense forest cover) was the primary element preventing land degradation, and even with little negative changes in a forest structure, canopy cover could start the process. LC changes accuracy assessment has created an error matrix; estimating the error-adjusted land change area and the confidence interval is not tricky but produces valuable information on change that may be very different from the results obtained solely from the map (Olofsson et al., 2013). This study provided the essential data and calculations required to compile a thorough and exact report on the correctness of an LC map and area estimation, as shown in Figure 6.8.

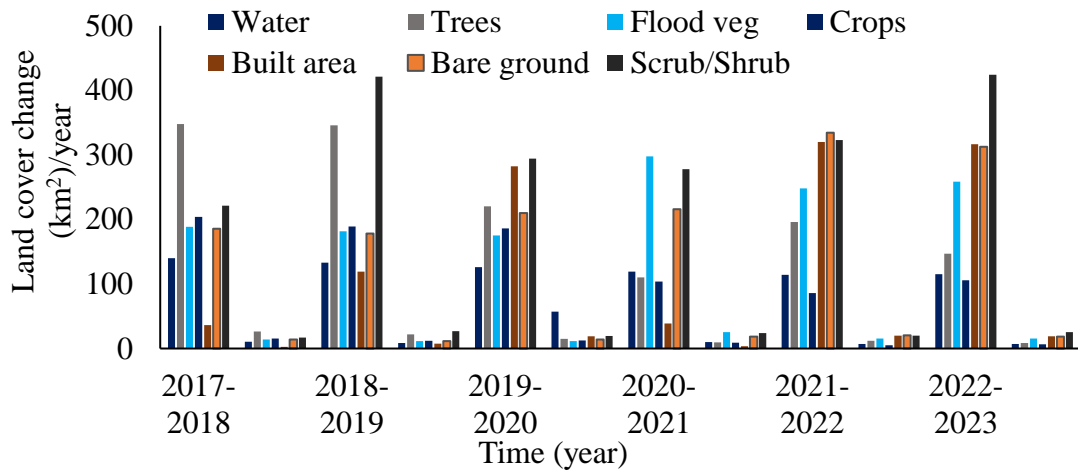


Figure 6.8 Land cover change (km²/yr) in the lower Baro watershed from 2017-2023

As a result, the yield response factor in maize was 1.25 high (more sensitive in water deficit areas). Saudi Star irrigation project was performing better CV of 5% than medium-scale and individual farmers' CV of 65%. The issues with the insufficiency and dependability of irrigation in some of the schemes were primarily the result of poor water management, and procedures at the scheme and farm levels. As a result, the number of growers in the estate, the farmer association, and the individual was 2.87, 0.87, and 0.35 kg/m³, respectively. When compared to other climate zones, estimates of crop water productivity and agricultural production based on tropical zones showed greater variation, with ranges of 1-10 t/ha and 1-12.5 kg/m³, respectively (Mohanasundaram et al. 2023). The average CV for metrics was determined as the performance of the various clusters (Blatchford et al. 2020). The most significant variable growers had those large scales controlled by commercial, family associations, and estates (Karimi et al. 2019). For the selected crop types, the water productivity of WaPOR of the ten years of real-life data result shows that for each sub-catchment of Baro Gambella, Gog, Gilo Fugnido, Birbir Yubdo, Baro Gambella, Gumero Gore, Sor Metu, and Baro Itang was 2.54, 1.3, 1.21, 0.96, 0.96, 0.96, and 0.95 kg/m³. The result was comparable with the standard ranges of the global WP from 0.62-2 kg/m³ to 4-11 kg/m³ (Safi et al. 2022). When speaking about a single crop, say the micro level of observing water in the soil (Zhang et al. 2021). As a result of the water deficit and yield relative to the equation, the yield response factors depend on the types of crops. The yield response factor in maize was 1.25 high (more sensitive in water deficit areas). In the lower Baro farmers who produce crops, the average water adequacy could be impacted by factors other than general water availability, as shown in Table 6.11.

Table 6.11 A Summary of seasonal indicator values for all clusters averaged in lower Baro tributaries

Category Name	Cluster Name	ET (mm/month)	ETp (mm/month)	Equity CV of ET	Adequacy CV of ET	Water Productivity kg/m ³
Grower scale	Small Scale	45.3	29.4	0.98	1.54	0.99
	Medium Scale	54.3	35.2	1.17	1.54	0.53
	Large Scale	64.9	3.25	0.10	19.97	2.52
Management regime of grower	Estate Managed	66.5	3.32	0.11	20.03	2.87
	Farmers Associations	54.3	35.2	1.17	1.54	0.87
	Individual Growers	64.9	42.1	1.40	1.54	0.35
	Alwero	66.5	3.32	0.11	20.03	0.78
Location of growers	Gilo Fignido	3.73	2.42	0.08	1.54	1.21
	Birbir Yibdo	3.87	0.19	6.45*10 ⁻³	20.37	0.96
	Gog	4.54	0.22	0.09	20.64	1.30
	Baro Gambella	4.7	0.23	7.8*10 ⁻³	20.43	2.54
	Baro Itang	6.76	0.33	0.01	20.48	0.95
	Gumero Gore	6.16	0.30	0.13	20.53	0.96
	Sor Metu	7.12	4.62	0.15	1.54	0.96
	Center Pivot	3.32	0.16	5.5*10 ⁻³	20.75	0.96
Irrigation method	Sprinkler	0.66	0.03	1.1*10 ⁻³	22.00	0.96
	Furrow	16.62	10.8	0.36	1.54	0.97
	Drip	13.3	0.66	0.02	20.15	0.99

ET generates between 1,300 and 1,404 mm of water annually and accounts for up to 80% of the water discharge from the Machar Marshes. Most of the increase in food production would come from increased productivity per unit of land. According to the Awash and Koga watershed evaluations in Ethiopia, the WaPOR is superior to other ET products (Blatchford et al., 2020). In this study, the analysis shows in the eight sub-catchments of Alwero ETa (less than 28), Gilo Fugnido (28-43), Birbir Yubdo (43-48), Gog (48-53), Baro Gambella (53-58), Baro Itang (58-60), Gumero Gore (60-63), and Sor Metu (63-67) mm. As a result, Sor Metu, the ETa/ETp, was 7.12 in the range of 63-67, and the average yield CWP was 120 kg/m³ (highest), ETa/ETp was 3.73 (lowest) in the ranges of 28-43 and the average yield CWP was 590 kg/m³ of ETa. Based on the analysis, the maximum seed rate was 985 kg/ha to cover the gap in rainfed agriculture. Fertilizer applications were 123 kg/ha, with the corresponding maximum number of householders of 70,490.56. The yield gap of ETa in the lower Baro watershed could be increased through seed rate and fertilizer control for the entire sub-catchments in the chosen crop area. ET measured how quickly the soil dried out (Santos et al. 2010).

The study mentioned that in humid, unlimited-water situations, ETa of interception of WaPOR does not accurately represent ETa on a continental scale (Blatchford et al., 2020). In this study, when ET was higher, the need to irrigate more in the sub-regional watershed scale. Moreover, the highest yield was 5600 kg/ha in the sub-catchments. The amount of crop ET had a direct relation to crop yield, as shown in Table 6.12.

Table 6.12 Average and highest rainfed crops yield, ETa, seed rate, and fertilizer in the sub-catchment

ETa (mm)	ETa/ETp	Average yield		Highest yield (Qts/ha)	Seed Rate (Qts/ha)	Fertilizer Rate (Qts/ha)	No of Holders
		CWP (Qts/m ³)	yield Qts/ha				
< 28	-	-	17.3	56	-	0.33	-
28-43	3.73	5.9	24.5	56	9.85	1.23	155.60
43-48	3.87	5.8	24.3	56	4.32	1.21	14,611.1
48-53	4.54	5.7	14.2	48	3.25	1.23	70,490.56
53-58	4.7	4.1	12.9	48	2.25	1.4	18,333.3
58-60	6.76	3.9	27.1	27	3.45	1.65	28,000
60-63	6.16	1.7	7.3	22	4.12	1.46	2,777.7
63-67	7.12	1.2	6.5	22	3.14	1.2	1,555.6

As a result, in comparison to the other five sub-catchments, the Baro Gambella sub-catchment had the most significant yield gap of 443.52, 887.04, and 1008.10⁶ kg, while the Gumero Gore sub-catchment had the lowest yield gap of 0.01, 0.02, and 0.03 kg respectively. Recent studies supported the water and land for improving the suitability for fertilizer, slope, drainage capacity, water holding capacity, and cropping systems (G et al. 2016). In December, Gambella gets 67.61 mm of rain and approximately three rainy days, and humidity is close to 68% (Degife et al. 2021; Hailu et al. 2019). The 4-year seasonal average WaPOR-based yield was 89 t/ha (86 t/ha for regions with furrow irrigation, 88 t/ha for areas with sprinkler irrigation, and 93 t/ha for areas with center pivot irrigation (Chukalla et al. 2022). Based on the WaPOR biomass product evaluation of the crop classification, the light use efficiency (LUE) is a coefficient for the efficiency by which vegetation converts energy into biomass (Blatchford et al. 2020). The land productivity leads to an increase in rainfed crop output throughout the lower Baro watershed, increasing the production of the selected crops by 1/3, 2/3, and 3/4 of the yield gap, as stated in Table 6.13.

Table 6.13 Increase the current rainfed yield of rice, sugarcane, maize, and vegetable field

Sub catchment	Agricultural land (ha)	Average yield (kg.10 ⁶ ·ha ⁻¹)	Highest yield(kg.10 ⁶ ·ha ⁻¹)	Increase in yield production (.10 ⁶)		
				0.33 of yield gap	0.66 of yield gap	0.75 of yield gap
Alwero	14,000	3*10 ⁻³	5.6*10 ⁻³	13.86	27.72	31.5
Gilo	1,315	3.2*10 ⁻³	5.6*10 ⁻³	1.38	2.77	3.15
Fugnido						
Birbir	634.4	5.6*10 ⁻³	5.6*10 ⁻³	1.17	2.34	2.66
Yubdo						
Gog	1,650	1.7*10 ⁻³	4.8*10 ⁻³	0.92	1.85	2.10
Baro	280,000	4.8*10 ⁻³	4.8*10 ⁻³	443.52	887.04	1008
Gambella						
Baro Itang	1914.09	2.7*10 ⁻³	2.7*10 ⁻³	1.70	3.41	3.87
Gumero	25	1.8*10 ⁻³	2*2*10 ⁻³	0.01	0.02	0.03
Gore						
Sor Metu	78	2.2*10 ⁻³	2.2*10 ⁻³	0.05	0.11	0.12

The primary cereal crop production YA in rain-fed agriculture for rice 6, maize 12, sugarcane 9, and vegetable 7 in metric tons/ha. Comparing the YW-YA, the crop production value result shows a significant difference in rice 1.5, maize 8.5, sugarcane 5.5, and vegetable 3.5 metric tons/ha. For water productivity, actual rice is 2.5, maize 4.5, sugarcane 3.5, and vegetable 4.5 metric tons/ha. However, using fertilizers and modern seeds became challenging (Abebe & Kebede, 2017). Additionally, a linear association between sugarcane crop production and ET is discovered, with a slope of around 10 kg/m³ and a corresponding value of 1.3 kg/m³ (Poolad et al. 2019). The results of the equity assessment in this study would be affected by the uncertainty of the ET product and must be treated cautiously (Azhar et al. 2014). The typical annual ET for a different producer cluster of crops was 1.5 tonnes, compared to the typical annual value of 1.3 tonnes for a crop such as wheat or maize (Chukalla et al. 2022). Increasing crop water productivity sometimes suggested one alternative to enrich crop yield (Akram et al. 2019). The exploitable yield gap explains the unusual convergence of the conditions for attaining water-limited yield. As a result, feeding the future population that was closing the gap in lower Baro tributaries to the selected crops in rice, maize, sugarcane, and vegetables showed significant trend variation observed in terms of metric ton/ha based on FAO (2012) as shown in Figure 6.9.

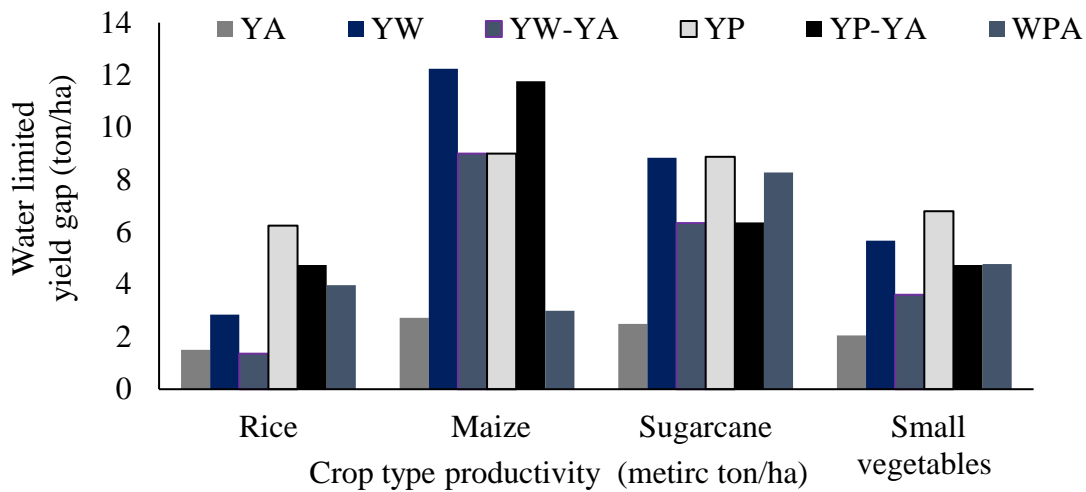


Figure 6.9 Crop-type productivity versus water-limited yield gap (ton/ha)

As a result, the limited water productivity potential was a maximum of WPP 25 metric tons/ha, but the actual yield from 1999-2017 was very low in the region of the study. This shows the limited surface water resource utilization was not properly used for the required rainfed crops in the region in terms of metric ton/ha as shown in Figure 6.10. One of the issues with determining the dependability of remotely sensed ET products in the lower Baro watershed was the lack of spatial layer validation of ET as well as the cost and complexity of such analysis (Karimi & Bastiaanssen, 2015). The CWP level values were reported in the regional and international literature (Poolad et al. 2019). FAO stated that ET could range from 1.3 to 2.2 kg/m³. The ETa-WaPOR value appears continually overestimated in irrigated areas. Some of the identified causes include the input of quality layers, local advection effects, and the relative soil moisture content (Sawadogo et al. 2020). However, combining multiple evaluation methods improves how the quantity of the ETa WaPOR product is assessed (Karimi et al. 2019; Zwart & Bastiaanssen, 2004). The rainfed systems without irrigation demonstrated a small CWP. Because of the seasonal change in rainfall in the watershed over time and space (Alem et al. 2022). The yield would only increase if additional water was available for ETc. The study mentioned that it is challenging to compare our findings with those of other studies on runoff water collection locally, regionally, and worldwide (Odeh et al. 2023). As a result, improving crop management at fields and securing. irrigation supplies, especially during summer (dry) years, raised crop yields and water productivity in the lower Baro watershed. The study's findings show that implementing irrigation management systems could raise production and bring more land under irrigation, with increases in yield and irrigated area of 20 and 140%, respectively (Mandal et al.

2020). Moreover, how atypical years farms among the observations could distort estimates of potential and water-limited production harvest time (Deng et al. 2019).

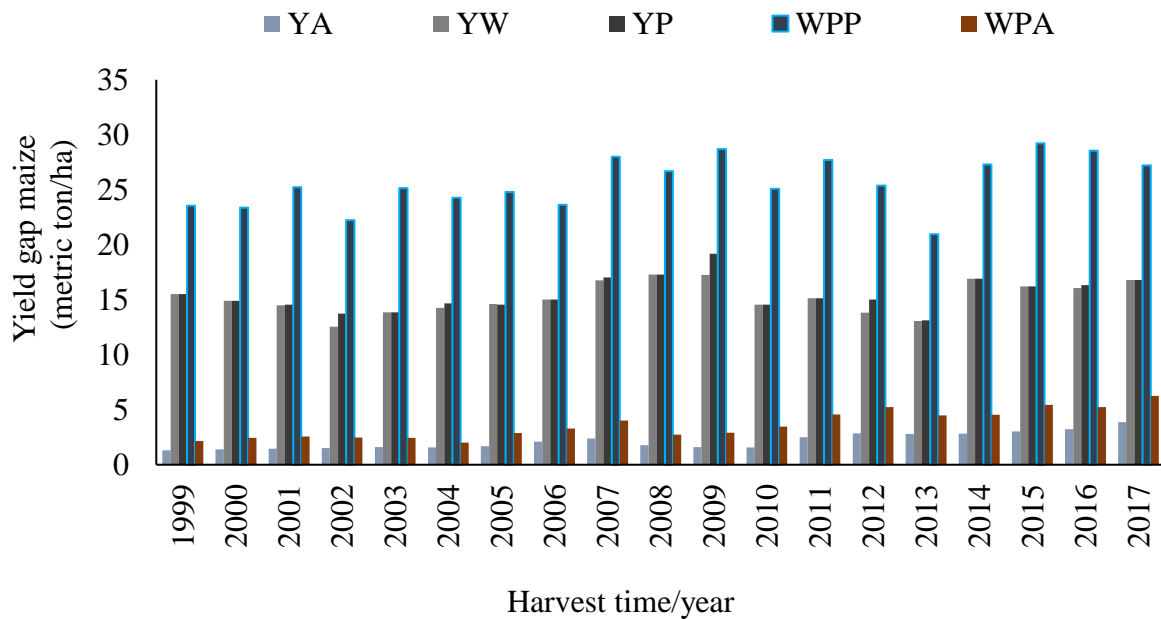


Figure 6.10 Lower Baro tributaries yield gap for Maize crop from 1999-2017

In this case, the result showed that the maximum Yw was 1200 kg/ha with the corresponding minimum Ya of 1300 Kg/ha. However, analyzing the trend's variation could lead to increasing and decreasing yield gaps. Maximum of 1.3 ton/ha in terms of YA and the corresponding YW variation 1.2 ton/ha for water-limited yield gap in the lower Baro watershed as shown in Figure 6.11. The temporal variation in YA reflected current soil and climate conditions, average farmer skill levels, and average technology usage (Deng et al. 2019). South and Southwest African regions have disproportionately high yields, whereas the North, Central, and Eastern regions have lower yields (Andersson et al. 2009). There were temporal scales that could be set to capture (eliminate) the environment's dynamic aspects (soil, climate, and ecosystem components). The analysis time frame must be clear and aligned with the standards for critically evaluating the data (Van Loon et al. 2018).

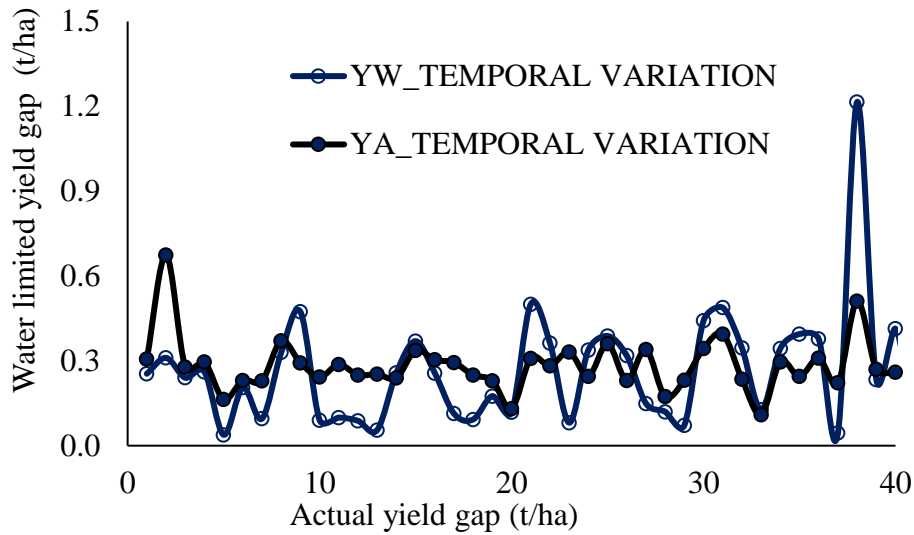


Figure 6.11 Temporal variation actual yield gap versus water-limited yield gap

In this study, as a result, the maximum temporal variation was 1.2 ton/ha, YW with a YP of 0.9 ton/ha and a CV value of 0.68. The corresponding minimum value was 0.1 ton/ha YW of 0.3 ton/ha of YP with a CV of 0.68. These patterns collectively may result in widening yield gaps in the lower Baro watershed, as shown in Figure 6.12. A single prediction of potential production (water limitation) employed as a reference in gap analysis does not accurately represent all circumstances within a cropping system and agroecological zone. Most farmers could not achieve the yield produced by a contest winner in the (highest-yielding fields) that would not benefit from the same climatic and soil conditions (Van Loon et al. 2018). Studies mentioned that the variability of CV ranges from 0.1-0.05 based on the observed rainfall data from 1972-2000 in the upper Baro River (Kebede et al. 2017).

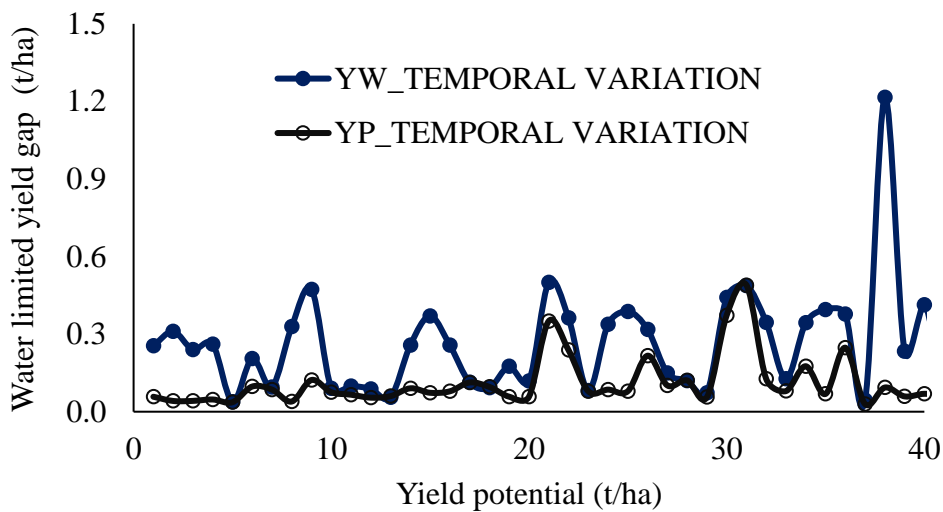


Figure 6.12 Temporal variation potential yield gap versus water-limited yield gap

6.16 Sustainable yield gap closure through irrigation

Effective irrigation management in these areas would lead to better water supply use for irrigation in lower Baro; moreover, this is made evident by the databases for reporting districts, comparative yield studies, and particular commercial fields. But the largest problem facing water managers today is increasing crop production with each drop of water used (Conrad et al. 2020; Perry, 2011). The productivity is affected by how feasible yield estimates are produced from the data used, especially from region to the globe (Bwambale et al. 2022). Investments in irrigation infrastructure, however, could be only justified if they result in a significant increase in production. Irrigation needs in areas of agriculture that are predominantly rainfed, where productivity is limited by the availability of water resources, increasing crop yields (Alves et al. 2022; Karthikeyan et al. 2020); ratios between irrigation water and total water requirements would express this condition. The paramount importance of spatial and temporal inter-annual variation in environmental variables on yield is a significant finding of the entire inquiry (Drastig et al. 2016; Hellegers et al. 2010). However, watershed management techniques have enhanced the water's long-term availability in rain-fed areas (Huchtemann & Frondel, 2010).

6.17 Spatial and temporal variability of the system water use efficiency

Every water condition is unique, and managing the water resources for irrigation production is highly important. Soil erosion is predicted to affect the environment, including increased land degradation negatively, decreased agricultural production, and soil losses (Panagos et al. 2022). Over 1 billion hectares (Bha) of land are subject to water erosion, over 1.6 Bha of land is subject to wind erosion, and about 13% of the world's continents are subject to erosive degradation (Wawer et al. 2005). In line with the trends shown above, key informants concurred that there was increased interest in soil water conservation (SWC) interventions at the watershed scale required. However, more research has been conducted on the sustainability of SWC techniques and how individual farmers adopt them, partly because most SWC methods in Ethiopia have been adopted through various initiatives (Adimassu et al. 2018). Around the world agriculture currently uses 70% of all freshwater withdrawals worldwide, and by 2050, demand will increase by 20% (Boretti and Rosa, 2019). Due to the concurrent increase in irrigation, agriculture systems must use water more efficiently (Mesfin et al. 2020). Existing ecosystems are under more stress due to increased weather variability, which takes the form of higher

temperatures, changing rainfall patterns, and longer/more frequent wet-dry cycles (Abera et al. 2021; Hailu et al. 2019; Wang & Yang, 2014). In Ethiopia, 30% of our anticipated production comes from rainfed agriculture. We have significantly increased commercial irrigation and paved the way to mitigate this. The term "efficiency" implies that components of a system for controlling soil, water, and crops can be altered to improve its performance (Eshete et al., 2020). Only a few studies have looked at sWUE or how it varies based on the kind of soil and management practices used (Wilson et al. 2022; Hasanuzzaman, 2019); previous research has looked at temporal changes in WUE for a single crop field due to management modifications (Wilson et al. 2022). It is easier to comprehend how we farm in terms of crop selection and associated practices in a changing climate; if we can estimate the soil attributes interact with management methods using sWUE variability (Ahn & Kang, 2014; Ferrant et al. 2014). The type of change, the time it takes to implement, and the soil conditions at the time of the modification affect how effectively water is retained and moved for plant growth. Any procedure such as conservation tillage, cover crops, and organic amendments enhances the soil composition or structure of sWUE.

The primary forces are rising temperatures, altered rainfall patterns, and intensifying precipitation (Prein et al. 2017). Previous studies have looked at temporal changes in WUE for a single crop or field as a function of management and weather changes. Only a few studies consider sWUE or how it fluctuates depending on the kind of soil and the management techniques (Hadri et al. 2022). Over the past 20 years, Ethiopia has made investments in SWC; a list of procedures to calculate the amount of SWC in various geographical regions (Adimassu et al. 2018). Therefore, the idea behind this study was that, unlike WUE, the variability in sWUE throughout the watershed. This can be indicates the interactions between soil characteristics, management practices, and climate change. Moreover, how well a soil-water-crop management system functions. Gambella region is one of the regions subject to this study, which looks at the spatial and temporal heterogeneity of both WUE and sWUE. However, the Alwero (Akobo) station of Saudi star irrigation is considered, to indicate the spatial and temporal variability as far as the productivity is concerned as shown in Figure 6.13.

6.18 Methodological overview

Overview of the methodology to identify and classify diverse landscapes based on comparable hydrologic responses, a geostatistical analysis was carried out to quantify the geographical and temporal variability of WUE and sWUE in the lower Baro watershed. Analysis was performed using the data from the Ethiopian National Meteorological Agency (ENMA) from 1986 to 2018 provided in this study, such as climatic information rainfall and temperature. In addition, this study used 45 years of streamflow/discharge data for eight stations namely, Alwero, Gilo Fugnido, Birbir Yubdo, Gog, Baro Gambella, Baro Itang, Gumero Gore, and Sor Metu with corresponding years from (2009-2019, 1977-1990, 1977-1990, 1990-2006, 1990-2008, 1974-1980, 1988-2004, and 2000-2018) from the Ethiopian Ministry of Water Resources Irrigation and Energy (MoWE) Department of Water Resources and Hydrology. However, in the study, the status of the area representative hill slopes was selected. Moreover, the water budgets are performed by subtracting the runoff, drainage, and ET losses from precipitation totals during each growing season. WUE is calculated as yield divided by ET, while sWUE defines as yield multiplied by the total runoff, drainage, and ET.

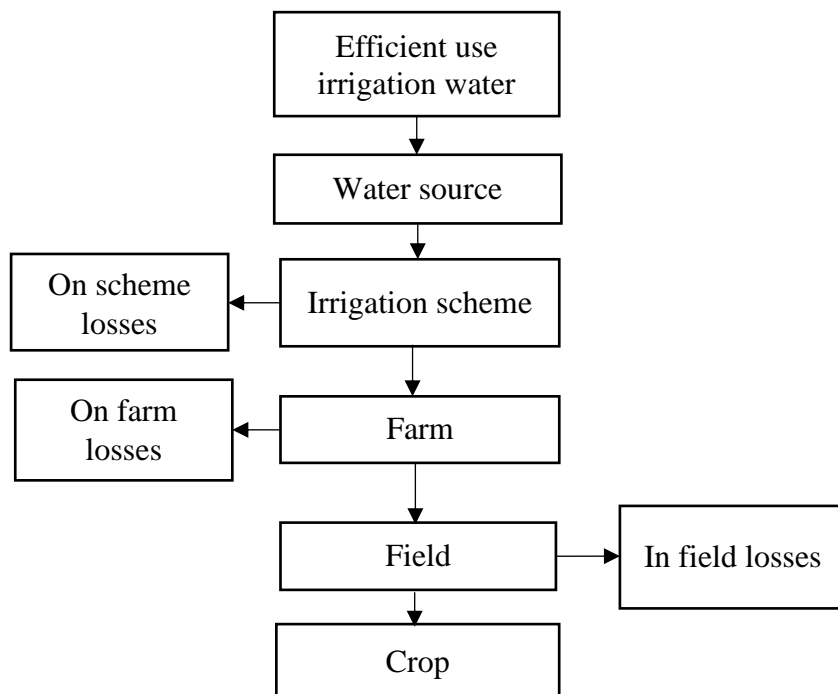


Figure 6.13 Flowchart of water use efficiency

6.19 Focus watershed

Gambella community leaders plan to resettle over 30,000 agro-pastoral people by leasing 42% of the region's land (Eshete et al. 2020). Due to landscape characteristics and management, WUE does not consider all water consumed or lost from the system. Aside from ET, runoff and drainage also affect the amount of water readily available in agricultural systems (Wilson et al. 2022; El-Gafy, 2017). The equation of the system of water use efficiency is shown in Eqn 6.9

$$sWUE = \frac{\text{Yield}}{\text{ET} + \text{Runoff} + \text{Drainage}} \quad (6.9)$$

6.20 Irrigation water amount

The most crucial factor in every region's prospective agricultural productivity is irrigation. However, even though water is already scarce, irrigation often uses much water. Usually, sensors could measure irrigation water depth of 50 and 75 mm in wheat and rice plots.

6.21 Evaporation (E)

Since the plants absorb nutrients through their roots during transpiration, higher grain yields are also a result (Agarwal et al. 2019). Because higher transpiration is necessary to have higher plant output (Ayyad et al. 2022). Every attempt is made to divert a larger portion of the soil ET share of the moisture to the transpiration component; most of the time, there needs to be more mention of the calculative aspect of evaporation in various study papers (Asitatikie and Gebeyehu 2021).

6.22 Drainage and seepage in irrigation

The system efficiency indicators, which irrigation designers generally utilize, were also reevaluated using the framework. When shifting the irrigation need from net to gross and accounting for system losses. This study produced a new system efficiency and assessed the Alwero irrigation system. As a result, the flow rate at the entry point of the system components must be measured and quantified. The water balance of the lower Baro is shown in Table 6.14. In general, wheat drainage losses are considered insignificant or less than 100 mm, whereas they are significant >2000 mm during the rice season. The more often measured, the greater the accuracy and reliability of the data among the parameters; the seepage from the diversion canal was 6.4%

which exceeded the confidence interval set by the system. It encourages a better understanding of water management at all levels (Ayyad et al. 2022). The water source entering the system components must be specified, as this is usually the parameter scrutinized by compiling the water balance (Rawat et al. 2018).

Table 6.14 Water balance for lower Baro watershed

Destinations	Volume (m³)	Confidence interval (CI)	% of inflow	of Desired	Action Required
On-farm irrigation system	60.3x10 ⁶	3	84	N/A	No
Evaporation from canal	7679	15	0.2	5	No
Seepage in canal	26,5206	30	6.4	5	Yes
Unlawful abstractions	0	15	0	0	No
Operational losses	9,842	15	0.3		
Evaporation from Dam	720	30	0		
Seepage from Dam	18,241	30	91.2		
Unaccounted water	34,2886	30	8.8		
	36,1127	30	100		

6.23 Comparison of WUE with other studies

In the Gambella region, rainfed maize has WUE values averaging 0.96-6.64 kg/ha/mm due to relatively high yields averaging 0.4 and 0.3 Mt in 1997-2017, respectively. Currently, increasing by 35%, which is near the maximum yield of 1.8 Mt seen in lower Baro. Irrigated rice has the lowest higher WUE values from 2 to 3 kg/ha/mm. The results for hillslopes with comparable hydrologic responses were aggregated; as compared to trends and magnitude changes to evaluate temporal and spatial variability across the watershed. Moreover, recent meta-analyses from multiple sources have made it easier to compare WUE results with other published values. Measurements of WUE for maize range from 2 to 40 kg/ha/mm in 10 different countries with a significant coefficient of variation, CV of 0.38 (Wilson et al., 2022). Rainfed rice, sugarcane, maize, and small vegetables in the lower Baro had WUE values ranging from 2 to 3 kg/ha/mm, while irrigated rice had lower WUE values from 2 to 3 kg/ha/mm due to the higher yields. Additionally, rotating maize with other crops increased the WUE from 12-14 kg/ha/mm to 3-23 kg/ha/mm. As a result, increasing fertilizer rates raised the WUE values from 9 to 26 kg/ha/mm across the region Gambella. In the Gambella region, rainfed maize has WUE values averaging 0.96-6.64 kg/ha/mm due to relatively high yields averaging 0.4 and 0.3 Mt in 1997-2017, respectively. Currently, increasing by 35%, which is near the maximum yield of 1.8 Mt seen in the lower Baro watershed.

6.24 WUE and sWUE compared to one another

When comparing WUE and sWUE for the different crops, there are greater distances between the cumulative distribution functions of rice, sugarcane, maize, and vegetables. The further distances between the lines indicate a more substantial influence from runoff on the crop. Additionally, maize is more sensitive to spatially variable parameters, like, in this case, runoff. sWUE values of yield divided by tend to correlate runoff, followed by precipitation and ET. Further, it can be illustrated as yield becomes less water-limited as the growing season precipitation increases. WUE for maize is correlated with yield and temperature, while sWUE is predominantly correlated with runoff (Wilson et al. 2022). The sWUE values correlated with precipitation and ET for rice, sugarcane, and vegetables. The WUE and sWUE values for maize appear less affected by hydrology, highlighting the crop's low drought sensitivity (Mbava et al., 2020). However, further increases in growing season precipitation result in continuously more runoff and hence a decrease in sWUE as the system loses more water, making it difficult to identify its genuine connection here with WUE/sWUE (Garcia et al., 2010). Nonetheless, the soil types with higher water content can supply adequate moisture to plants when rainfall does not occur. Moreover, the spatial variability is higher than the temporal change of sWUE for cereal crops. The temporal change averaged 20% thus, the average spatial variability was more significant than the average temporal variability.

6.25 Rice production improved productivity through reduced water use

Over 60% of people eat rice in the world. It urgently needs to increase rice output by 70% to satisfy the predicted demand by 2050 (Santos et al. 2010). According to an FAO assessment that examined rice production and population growth over the previous ten years (Deng et al. 2019). Given the rising demand for rice, there is a pressing need to research rice cultivating methods. In general, four habitats for rice cultivation: irrigated 50% of the total amount of rice farmed, rainfed lowland 34%, rainfed upland 9%, and flood-prone 7%. The most fruitful cultivation occurs in the irrigated rice habitat, which is crucial to supplying the world's food needs (Rising, 2020). However, water availability, irrigation practices, and the time water remains in the rice field during the growth phase significantly impact irrigated rice (Okada et al. 2018).

In the rainfed ecosystem, erratic water supplies include severe drought, flood, and occasionally both during a single cropping season and infertile soil. Its acidic or saline nature is the most frequent variable that reduces rice yield (Adhikari et al. 2018). As a result, this compels us to create novel water management strategies for rice farming that boost output in various environments. Additionally, water use can be controlled by either producing water-stress-tolerant cultivars that can produce more when less water is available or by controlling the soil to create conditions ideal for growing rice in water-scarce environments (Afroz et al. 2021; Wang et al. 2016). Similar to population growth, settlement expansion within the watershed has dramatically increased from 2017-2023. From 1990 to 2021, the settlement's area increased from 14,586.7 ha to 18,541 ha; studies across Ethiopia's many areas support this (Teklay et al., 2023).

6.26 Alwero rice cultivation techniques in water-scarce conditions

Farmers follow a traditional method of cultivation and cultivar selection based on their natural adaptability to environmental changes. However, rice farming has focused on improving rice cultivation methods, leading to a wealth of technological possibilities for cultivation to increase yield under water-limited circumstances. The yield penalty was reduced through a cumulative approach to water management and planting high-yielding varieties that thrived in water-limited environments. Before determining the consequences of water-limiting conditions, water management strategies, such as short-term, long-term, and anticipatory phenological adaptation measures, are therefore necessary, and they often aim to minimize effects.

6.27 Reducing water outflows and unbeneficial water depletions

Early canopy closure reduces evaporation at various growth phases by selecting rice cultivars with vigorous seedlings or adjusting crop density. These techniques also improve the crop's capacity to compete by reducing weed transpiration. Other weed-control strategies include the use of pesticides, human or mechanical weeding, opportune flooding, and land leveling, which can reduce unproductive water losses brought on by transpiration by weeds. A successful strategy for increasing rice's water productivity and lowering water inputs is soil mulching, particularly in non-saturated aerobic soil conditions.

6.28 System of rice intensification

A climate-smart agroecological approach is needed to boost rice productivity by adjusting water, soil, plant, and supplement management. The SRI philosophy is based on the following four fundamental principles, which are interconnected: the establishment of plants quickly, soundly, and early; the reduction of plant density; the improvement of soil conditions by adding organic supplements; and the careful management and reduction of water use. Studies indicated that rice cultivation releases carbon emissions due to water stagnation. Off-season tillage, crop substitution, and micro-irrigation reduce the quantity of water for agriculture. Adjustments regularly account for shifting soil properties, climatic patterns, water management, ease of access to the availability of natural resources, and the decision to practice organic farming exclusively (Adebiyi et al. 2021).

6.29 Sprinkler irrigation

Most rice is grown for human use today in flood-prone areas, where there is a water shortage and loss by deep percolation, seepage, surface runoff, and evapotranspiration. Mechanized sprinkler irrigation systems in the lower Baro, one of many methods for water-saving irrigation, are gaining popularity among farmers in different nations due to their ease of control, higher water use efficiency, and increased production. Sprinkler irrigation can produce a total depth of 414 mm in rice instead of 1168 mm in flooded rice, using 20-50% less water. Sprinkler irrigation also allows farmers to use soil conservation practices like crop rotation and no-till farming.

6.30 Interactions between water and fertilizer at the field and agricultural levels

Usually, non-water elements such as soil fertility and CWP when less than 40-50% of the potential. Nevertheless, yield gains occur at a nearly proportionate rise in ET when yield levels are over 40-50% of their potential; when yields increase, incremental increases in water productivity decrease (Molden et al. 2010). So, before hitting the maximum limit, there is much room for increasing production relative to ET. The management approaches that create this heterogeneity are significant because they raise the prospect of potential improvements in the proportion between ET and marketable yield. Balanced fertilizer use should ensure sustained productivity in the intensive cropping system for the high-productivity fields. Because an absence of it could result in a rapid fall in yields and water, use efficiency over time.

6.31 Water productivity when there is a water shortage

Soil nutrient mining is severe in sub-Saharan Africa; the focus is on little, timely watering and managing soil nutrients, increasing the WUE by 10-25%. In rain-fed agriculture, soil fertility is frequently the limiting factor for higher yields; due to inadequate rainfall infiltration and plant water intake from weak roots, soil degradation through nutrient depletion and loss of organic matter results in a substantial yield decrease tightly tied to water determinants.

6.32 Conclusions

In the lower Baro watershed, short-term climatic droughts result from a 34 °C increase in growing season temperature between 2016 and 2050 and a commensurate drop in March precipitation totals. Due to these modifications, maize and small vegetable yields have significant yield declines of 20 and 35%, respectively, and rice yields have seen a 5% decline; as a result, sWUE values drop. The ability of soil types with better water retention capacities to hold rainwater that plants can use when there is little rainfall makes them usually more suited to high productivity. These factors, which may influence the unpredictable nature of water use and storage in a watershed, have yet to be considered at different spatial scales. Minimizing the ET transpiration stream is very beneficial from the moisture absorption perspective.

Therefore, mulching the soil surface is essential to increase water productivity. The mulch is a physical barrier to evaporating water, and the soil is moist afterward. To determine which management measures would mitigate the effects of a more variable climate on sWUE, the timing of management activities (such as irrigation, planting/harvesting dates, and fertilizer applications) was the same. Nevertheless, management strategies must consider certain soil-geomorphological traits to increase agriculture's water use efficiency. These variables, which might affect the unpredictability of water usage and storage in a watershed, have yet to be considered at various spatial scales.

The next chapters include a Summary, Conclusions, and Recommendations.

CHAPTER 7 SUMMARY AND CONCLUSIONS

7.1 Summary

The primary objective study is to explore the surface potential and irrigation productivity at different landscapes. The land cover change and its implication for hydrological variables and soil erodibility, as well as climate change, were the causes of yield reduction. The work was carried out using PRISMA systematic review focused on the soil moisture WEAP hydrological model at the limited surface water irrigation. The FAO water productivity satellite ET-based irrigation performance quantifies the yield gap in the lower Baro watershed tributaries. Moreover, the LC change using remote sensing ESRI 2020 LC Sentinel-2 data was used to see the LC change from 2017-2023. The research was conducted in the lower Baro watershed, Gambella region, Ethiopia. Firstly, four crops, rice, sugarcane, maize, and vegetable, predominantly grown in this region, were selected along with a bare field. The low yields obtained in arid and semi-arid environments can be improved by at least 1/3, 2/3, and 3/4 through the repartitioning of current moisture processes at the watershed scale, despite the difficulties of less-than-ideal rainfall for cropping seasons, the occurrence of dry spells, rising soil, and nutrient loss. Under such a condition, with consideration of this study helps for better understanding the spatiotemporal soil moisture variation within the catchments. Moreover, FAO water productivity increases precipitation by filling the yield gap, through WUE, sWUE, and policymakers for the betterment of irrigation water supply. Therefore, improve soil infiltration and water storage, which decreases runoff and the water lost by ET and raises sWUE.

7.2 Conclusions

Objective 1: To review the land cover change and its implication for hydrological variables, soil erodibility, and yield reduction

- The prediction inquiry indicates that LC is crucial for keeping track of the water balance. This study used the PRISMA method to examine 83 prior research on LC implications, hydrological parameters, and soil erodibility in Ethiopia's lower Baro watershed. Only 2% of abstracts were reviewed from 2007 to 2022, a single-article LC change monitoring in various methods, with various outcomes. The review study examined the hydrological variables, soil erodibility, characteristics, estimates, and effects of the LC shift as well as

the relationships between the hydrological process and the LC, hydrological process and climate change, potential ET, and rainfall in the lower Baro watershed. Each type of accuracy loss has a different severity level, ranging from minimal to moderate to severe.

- The availability of surface water for agricultural use is declining due to rising residential and industrial demand and population pressure. Another consequence of climate change is uncertainty about water supplies and production. The lower Baro watershed of the chosen gauging stations exhibits a closed water balance due to the annual surface inflow total, including rainfall and canal water inflow, nearly equal to the simulated annual ET. The irrigated cultivation of rice in Alwero does, however, also show signs of long-term unpredictability.

Objective 2: To explore statistical and trend analysis of hydro-meteorological data

This study examined that, there are substantial changes in mean annual streamflow, standard deviation, and monthly trends of the probability density function of the rainfall recorded at 8 stations from 1986-2018 in distributed arid and semi-arid areas of the lower Baro watershed, South West Ethiopia. In contrast, winter (Kiremt) rainfall variability directly affecting agricultural production is less variable over eight stations in the study region. The goodness of fit provides a means for the selection of a preferred distribution. They do not test how well the model fits better able to link models of the probability density function of the Easy Fit program by Math ware technologies shows the fitting of the statistical distribution in lower Baro tributaries. The test and its set of maximum critical values observed in the Baro Gambella sub-catchment showing that $\sigma = 12.6$, $\mu = 11.9$, and $\gamma = 0$, and the corresponding lowest observed result found in the Sor Metu sub-catchment $\sigma = 0.80$, $\mu = 1.75$, and $\gamma = -0.03$.

Objective 3: To quantify the surface water potential and irrigation water demand of lower Baro watershed tributaries

- Distributed hydrological modeling, which involves running a field scale model for all possible combinations of weather, crop, soil, and water in the research area, can be used to examine the effects of spatial heterogeneity on the regional water and CWP. Soil moisture initial conditions are important in targeting areas for irrigation development. A combination of distributed WEAP hydrological modeling and regional-level real--

time satellite data is required to assess the region's peak water requirement. Comprehensive water productivity analysis of an irrigation system requires a substantial amount of ecohydrological information at different spatial and temporal scales.

- To limit the adverse effects on their livelihoods, stakeholders should be aware of surface water potential and demand in water management, water conservation, and irrigation methods. Despite a substantial record of time series for the Basin watershed required; for the attribution of large-scale surface water potential and demand in the basin to long-term climatic changes. After correcting all the input data estimates of ET and crop water requirements for the chosen crop types in the lower Baro tributaries using the Cropwat8.0, the selected irrigable site was located below the gauging place of the study area and had a total area of 20,325 km². As a result, the following are concluded from the outcomes.
- Based on thick soil, pre-pudding irrigation at 0.5 m of soaking depth, field efficiency of 70%, the actual irrigated need of 613.3 mm, and rain efficiency of 75.7%. The statistics show that irrigation efficiency was 100%, percolation losses were 483.2 mm, and potential water was 641.7 mm. Total rain loss was 9.1 mm, effective rain was 28.4 mm, and the total rainfall was 37.5 mm. Besides, the variation in monthly streamflow over 45 years was calculated using graph pad prism 9.4. The pairwise comparison method's mean annual temperatures, rainfall, soil depth, soil texture, drainage, LULC, stream, and slope values are 4, 5, 11, 14, 20, and 3%, respectively.
- The future land suitability for surface irrigation was assessed in the GIS-based multi-criteria methods. The result of this study found that Alwero, Baro Itang, and Baro Gambella sub-catchments were highly suitable 23.1, 15.99, 14.65, and 8.44%, Gilo Fugnido was moderately suitable was 8.44%, whereas Sor Metu, Birbir Yubdo, and Gumero Gore were less favorable 7.98, 7.69, and 6.14%. For the selected crops, the crucial months of January, February, March, April, and May, resulted in a total crop water need of 917.8 mm/decade. This suggests that the predicted flow amount varies daily and is available each month. The projected values of maize for the selected driest five months are 0.78, 0.9, 0.78, 0.34, and 1 l/s/h. Due to the suitable irrigation land and the available water flows, the study area's irrigation potential varies each month by a minimum of 8% and a maximum of 54%. Thus, it demonstrates that during low flow periods, the amount of potentially irrigable land exceeds the capacity of the surface water supply.

Objective 4: To investigate the satellite ET-based irrigation performance: strategies to increase rainfed crops production in the lower Baro watershed tributaries

1. The present study investigated the satellite ET-based irrigation performance of WaPOR water and land productivity and the global yield gap assessment of rainfed crops. Additionally, based on the yield gap increase, the land conversion that resulted in the predicted 2050 in lower Baro rainfed crops output objectives were assessed. The crop yield gap output was increased by 2050, and lower Baro would have water stress; thus, this study looked at various water use opportunities there in the lower Baro watershed. Increasing the area of rainfed crops and irrigation boosts the yield of current agricultural land. The techniques for rainfed crop production were assessed using crop production function, crop water productivity (CWP), and relative evaporation (ETa/ETp) measurements.
2. The link between crop productivity and water use mainly determines the requirement for more water for food. However, the Baro Gambella sub-catchment had the most significant yield gap of 443.52, 887.04, and 1008.10⁶ kg, while the Gumero Gore sub-catchment had the lowest yield gap of 0.01, 0.02, and 0.03 kg among the selected crops, compared to the other five sub-catchments. Thus, it produces more rainfed crops, bridging the yield gaps; the crops showed a significant temporal trend variation of water-limited and potential yield observed in metric ton/ha.
3. Future studies must focus more on how climate change affects water and land productivity. WUE gives a less realistic picture of how a soil-water-crop management system functions in agricultural systems than the sWUE index, which considers runoff and drainage in addition to evapotranspiration. Eight distinct landscape types, including those with high-clay, high-organic matter soils, moderate slopes, and loess soils, were identified in the lower Baro watershed. Short-term climatic droughts result from a 34 °C increase in growing season temperature between 2016 and 2050 and a commensurate drop in March precipitation totals. Due to these modifications, maize and vegetable yields have large yield declines of 20% and 35%, respectively, and rice yields a 5% decline. As a result, sWUE values drop.

4. The average geographic variability was higher, though the geographical variability of sWUE values for rice was 11%, whereas, for vegetables and maize, it was 25 and 16%, respectively. The ability of soil types with better water retention capacities to hold rainwater that plants can use when there is little rainfall makes them usually more suited to high productivity. The timing of management activities such as irrigation, planting/harvesting dates, and fertilizer treatments was left unchanged to identify which management strategies would reduce the effects of a more variable climate on sWUE. These factors, which may influence the unpredictable nature of water use and storage in a watershed, have yet to be considered at different spatial scales. From the moisture absorption perspective, minimizing the ET transpiration stream is very beneficial.
5. To determine which management measures would mitigate the effects of a more variable climate on sWUE, the timing of management activities (such as irrigation, planting/harvesting dates, and fertilizer applications) was the same. Nevertheless, to increase agriculture's water use efficiency, management strategies must consider certain soil-geomorphological traits. These variables, which might affect the unpredictability of water usage and storage in a watershed, have yet to be considered at various spatial scales. The critical suggestion surface water assessment resulted in alternatives for water management that are related to reducing poverty, ecosystem services, water productivity, basin watershed, land management, rainfed and irrigated agriculture, and using water with marginal quality.
6. The condition of natural resources, particularly surface water in the lower Baro tributaries catchment, South Western Ethiopia, as shown from the study, has been under tremendous pressure due to rapid population growth, poor agricultural practices, deforestation, rapid changes in land cover, and climate variability over the last three decades. This study contributed to narrowing a knowledge gap by making land-use planning and sustainable surface water resources management relationships quantitatively. Moreover, it is helpful to contribute landscape change analysis with hydrological parameters for an enhanced understanding of surface irrigation and the hydrological implication of soil erodibility. This provides an appropriate solution for designing a strategy to reduce the adverse effect of soil erodibility and climate variability of the hydrological process.

It also supports decision-makers, and surface water resource planners to enhance land productivity to advocate for sound land productivity while confirming environmental sustainability. Such improvements are required to address issues relating to sustainable surface management and maximizing yield in the lower Baro watershed.

7.3 Limitations of the study

The study used limited climatic and streamflow data for assessing the surface water potential and irrigation demand in lower Baro watershed tributaries. There are not many published articles in the study region. Especially, LC change and its implication for hydrological variables and soil erodibility for the landscape, in particular. Due to time constraints and to keep things better, an optimization of surface water demand and potential; in the future, more studies should incorporate optimization. The WEAP model demand and supply assumptions of the catchment water balances will provide sufficient spatial information in a detailed manner for the proposed application.

The main shortcomings in the region include the lack of long-term hydrology and high-resolution geospatial data for the design of irrigation accuracy assessment. Other limitations of the current study include uncertainty analysis of parameter estimation during surface water demand analysis estimation.

Due to the various factors in the water balance analysis, the demand and potential of the lower Baro become inequitable. Streamflow, whereas a declining streamflow trend, leads to less water availability, which impacts the water supply for agriculture and other uses. lower Baro watershed station revealed a statistically significant rising and a declining trend in both rising and dropping rates. Rising rates were favorable while dropping rates were negative at every station. Therefore, modifying the WEAP hydrological model will necessitate including interaction among the watershed, provided that landscape position.

The results in this study primarily depend on data from the WaPOR database; thus, they should be interpreted with care. Additionally, over the ten years, the WaPOR data source has fluctuated.

7.4 Future scope of the study

A projected increase in barren land and settlement area could influence the basin's local rainfall mechanism, while high rainfall could also exacerbate the rate and extent of land degradation by increasing soil loss. Only a few extensive studies have looked at the effects of LC on land erosion at basin-wide hydrology, as well a few researches have been aimed at anticipating future LC trends. The performance of different hydrologic models must compare catchment characteristics and the effects of LC change related to surface water potential and irrigation water demand. Very little research has been done in Ethiopia, especially in the northern highlands, to analyze the impact of distributed hydrologic modeling and to manage water resources sustainably.

Climate evidence with a higher spatiotemporal resolution is required to create climate change scenarios for hydrological modeling and applications. By appreciating the value added by downloading climate information to learn about the downloaded climate change estimates, additional research on climate impact assessment can help to provide a solution for such activities. Given that the current study could not prove the relationship between rainfall and baseflow, it is understandable that more research is required.

Alwero irrigation is a technology that gives the right kind of recommendation for site-specific and field-specific crops. In this study, the use of remote sensing, hyperlocal weather forecast, and Kc tables from FOA 56 significantly improved the peak crop water requirement of the crops at a particular brought station. Collecting the information and understanding the irrigation method improve surface water utilization. The right amount of water at the right time and the right place. It helps the farmer to increase the yield reduction by irrigating the land. A better simulation of the lower Baro watershed can be achieved with more comprehensive data and extended time series. A reliable, current, and ongoing database of water levels, discharges, and extreme rainfall indices for the entire Basin watershed; in this regard, it is essential on a larger scale. Moreover, this work is needed for the rest of the tributaries out of the eight sub-catchments; the impact of the development of each watershed alone, and the cumulative effect of development on itself and downstream.

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PUBLICATIONS

7.5 International Journal Papers

1. Land Cover Change and Its Implication to Hydrological Variables and Soil Erodibility in Lower Baro Watershed, Ethiopia: A Systematic Review (**Journal of Sustainable Water Resource Management**)
2. Satellite ET-Based Irrigation Performance: Strategies to Increase Rainfed Crops Production in the Lower Baro, Ethiopia (**Journal of Water and Land Development**)
3. Integrated Spatial and Temporal Variability of the System Water Use Efficiency in a Lower Baro River Watershed, Ethiopia (**Journal of Water and Climate Change**)

RESUME



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