QUANTIFYING SURFACE WATER AVAILABILITY AND DEMAND ANALYSIS IN THE POORLY GAUGED CATCHMENTS OF JEMMA SUB-BASIN, ABBAY/UPPER BLUE NILE BASIN, ETHIOPIA

MSc THESIS

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

MARCH, 2023

QUANTIFYING SURFACE WATER AVAILABILITY AND DEMAND ANALYSIS IN THE POORLY GAUGED CATCHMENTS OF JEMMA SUB-BASIN, ABBAY/UPPER BLUE NILE BASIN, ETHIOPIA

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A THESIS SUBMITTED TO THE FACULTY OF BIOSYSTEM AND WATER RESOURCES ENGINEERING, WATER RESOURCES AND IRRIGATION ENGINEERING DEPARTMENT

INSTITUTE OF TECHNOLOGY, SCHOOL OF GRADUATE STUDIES

HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN WATER RESOURCES AND IRRIGATION

(SPECIALIZATION: IRRIGATION AND DRAINAGE)

MARCH, 2023

SCHOOL OF GRADUATE STUDIES

HAWASSA UNIVERSITY

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This is to certify that the thesis entitled "Quantifying Surface Water Availability and Demand Analysis In The Poorly Gauged Catchments of Jemma Sub-Basin, Abbay/Upper Blue Nile Basin, Ethiopia" submitted in partial fulfillment of the requirements for the degree of Master's with specialization in Irrigation and Drainage, the Graduate Program of the Department of Water Resources, and Irrigation Engineering, and has been carried out by Samuel Ababu Faris**.** Id. No GPIRDR/0007/13, under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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We, the undersigned, members of the Board of Examiners of the final open defense by Samuel Ababu have read and evaluated his/her thesis entitled "Quantifying Surface Water Availability and Demand Analysis In The Poorly Gauged Catchments of Jemma Sub-Basin, Abbay/Upper Blue Nile Basin, Ethiopia", and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree.

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As members of the Board of Examiners of the final Master's degree open defense, we certify that we have read and evaluated the thesis prepared by Samuel Ababu under the title entitled "Quantifying Surface Water Availability and Demand Analysis In The Poorly Gauged Catchments of Jemma Sub-Basin, Abbay/Upper Blue Nile Basin, Ethiopia", and recommend that it be accepted as fulfilling the thesis requirement for the degree of Masters of Science in Water Resources and Irrigation Engineering with Specialization in Irrigation and Drainage.

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ACKNOWLEDGMENT

My sincere gratitude is directed first and foremost toward St. Marry and her beloved son for making every task of mine simple from the beginning to the end and for bestowing upon me courage, endeavor, and wisdom. I want to express my gratitude to Assosa University for all of its help with my academic endeavors. My cherished family and friends were the only people I had with me at all times, and I am grateful for all the love and support you have given me. My sincere gratitude is extended to Dr. Sirak Tekeleab (Major advisor) for all of his insightful criticism, professional ideas, and superb work style throughout the project. I appreciate all of Dr. Kannan Narayanan's time, assistance, and advice. Last but not least, I want to express my gratitude to all concerned government officies that gave their time to gather the data and paperwork required for this study.

STATMENT OF THE AUTHOR

First, I declare that this thesis is my original work and that all sources of materials used for the study have been properly acknowledged. It has been submitted in partial fulfillment of the requirements for MSc degree at Hawassa University and I extremely declare that it is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate. I have followed all ethical and technical principles for the proposition, data Collection, data analysis and compilation of the thesis. Any scholarly matter that included in the thesis has been given recognition through citation.

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ABBREVATIONS

CSA	Central Statistical Agency
CUP	Calibration Uncertainity Program
CWR	Crop Water Requirment
DEM	Digital Elevation Model
DSS	Decision Support System
EFR	Enivronmental Flow Requirment
Etc	Crop Evapotranspiration
ET_O	Actual Evapotranspiration
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GTP	Growth Transformation Plan
GWQ	Ground water flow
Ha	Hectare
HEC-HMS	Hydrologic Engineering Center-Hydrologic Modeling Software
HRU	Hydologic Response Unit
IWRM	Integrated Water Resources Mangement
Kc	Crop coefficient
L/c/d	Liter Per Capita Per Day
LAT Q	Lateral flow
LULC	Land Use Land Cover
MCM	Million Meter Cubec
MOWE	Ministry of Water and Energy
NSE	Nash-Sutcliffe Simulation Efficiency

NMA	Ethiopian National Meteorological Agency
PET	Potential Evapotranspiration
PPU	Prediction Percent Of Uncertainity
PRMS	Precipitation Runoff Modeling System
R^2	Correlation Coefficient
SCS-CN	Soil Conservation Service Curve Number
SEI	Stockholm Environment Institute
SUFI-2	Sequential Uncertainty Fitting-II
SURF Q	Surface Runoff
SWAT	Soil and Water Assessment Tool
SWRRB	Simulator for Water Resources in Rural Basins
TLU	Tropical Livestock Unit
USGS	United States Geological Survey
UN	United Nations
WEAP	Water Evaluation and Planning
WHO	World Health Organization

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ABSTRACT

The socioeconomic activities and environmental changes with respect to the spatiotemporal variation of streamflow in the catchment intricates the supply and demand management system. Assessment of the surface water potential and demand analysis at a sub-basin level was aimed at estimating escalating demands of the catchments and meeting the society's needs without causing potential negative consequences on the ecological balance of the catchments. To quantify the surface water availability of the catchments, the soil and water assessment tool (SWAT) model was used after the sensitive analysis, calibration, and validation of the model was done by SWAT-CUP. The annual total demands was anlysed in water evaluation and palanning (WEAP) model after the surface water potenial was quantified. Different''what if'' scenario was developed to forecast future water demand, supply requirement, and unmet demands in 2022-2035. The model showed the mean annual flow depth in Beressa and Robigumer catchments was 174.4mm and 166.91mm, respectively and contirbutes to 37MCM and 149.05MCM surface water potential, respectively. From the mean annual precipitation recieved in the Beressa and Robigumer catchments, 48% and 43% was lost through evapotransipiration, respectively. The model performace showed satisfactory result with a value of 0.89(R^2), 0.87(NS), and 0.76(R^2), 0.74(NS) in calibration, and 0.71(R^2), 0.70(NS), and 0.72(R^2), 0.66(NS) in validation in the Beressa and Robigumer catchments, respectively. The CROPWAT 8.0 model was used to determine the irrigation water requirement of selected crops. The total consumptive water demand in 2022 was 11MCM(29.7%) and 8.1MCM(5.4%) of the total surface water potential of the Beressa and Robigumer catchments, respectively. The total water demand in projected irrigation area scenario was 125.64MCM(84.05%) of the surface water potential of the Robigumer catchment in the year 2035. The EFR was significant parameter to maintain the ecological balance of catchments. In the two last scenarios the total water demand were beyond the surface water potential of the Beressa catchment. To mitigate the future water stress and scarcity in the catcments, dopting rainwater harvesting, other potential sources, and integrated water resources management options are importannt.

Keywords: Beressa, Robigumer, SWAT, WEAP, Surface water and Water demand

1. INTRODUCTION

1.1. Background

Water is a precious asset, and without it, no life activity be on earth as it cannot be substituted with nothing else(Kiniouar et al., 2017). It not only help in survival, but also makes life comfortable and luxurious(Garg, 2006). The centrality of water to life triggers expedition for water on Mars. Beyond this fundamental association of water with 'life', however, water plays a major role in humanity's social and economic existence(Agnew & Woodhouse, 2010). The availability of water on the surface makes it easy to divert, impound or abstract and makes it vulnerable to climatic variations within a single season(Lane et al., 2017). As demand for water increases across the world, the availability is getting decrease due to socio-economic and environmental changes(Ahmed et al., 2021; Cuceloglu et al., 2017). Water obviously connects all these areas and any change in these drivers has an impact on it(Loucks & Van Beek, 2017).

World available water resources is uneven and exposed to contamination and requires high cost of treatment, that would reduces the maximum benefits of living and non-living things. The available quantity of water is affected by the socio-economic and enviromental changes. To maintain safe and sustainabile utlization of water resources, considering socio-economic as well as environmental aspects are strategically essential(Agnew & Woodhouse, 2010; Lane et al., 2017; Lukenga, 2019). Multiple benefits and the problems occurring in water resources should be addressed with comprehensive management and holistic approach to facilitate access to water and for development of water resources to meet the water demands of humans. Water is a limited resource. The world water resources do not change over time and cannot be restored if lost. The water resource is an essential field of economic growth, social progress, and environmental integrity. Therefore, water should be used sustainably(Ayt Ougougdal et al., 2020; Bezerra et al., 2021; Bryła et al., 2021). Especially in less economically developed countries, facing a growing challenge in meeting rapidly escalating demand for water, water demand management has emerged as a potentially powerful instrument with which to enhance socio-economic development amidst limited water supplies(Noon et al., 2021).

Ethiopia known as “water tower of Northeast Africa”, endowed with a substantial amount of water resources. The socio-economic activities of the country are anchored on water. Despite the fact Ethiopia has ample water potential, little of it has been used. Ethiopia is currently facing visible natural and socio-economic changes, which are modifying the availability and demand of water(Berhanu et al., 2014; Geremew, 2020; Yilma & Awulachew, 2009).

Water resource management works are becoming intricate and challenging to managers and policymakers related with the increase of multiple stressing issues related to climate effect, demographic change, temporal and spatial variability, improper assessment, and socio-economic activities. Considering set of realistic different scenarios in models helps to forecast and evaluate the impacts of different future trends and strategies before implementing them (Ristow et al., 2021; Sun et al., 2008; Tamir, 2018). This time, integrated water resource management is key for sustainable development, growth, and poverty reduction(Asefa & Ababa, 2011; Bezerra et al., 2021; Forio & Goethals, 2021). It is vital to heed on optimize the overall productivity rather than searching new source of supply(Spivak, 2021). A country water development plan must reconcile the available resource with the demand(Ahmed et al., 2021; Gupta, 2016).

Studying the water resources at a basin level is significant to manage the escalating water demand(Ahmed et al., 2021). Improper assessment of water resources is dangerous(Sagara, 2021). Water demand analysis define the available quantity of water, the prioritized users, means of resource allocation at the current and future use for better decision and improve performance(Ashine, 2021; Ristow et al., 2021).

1.2. Statement of the problem

The erratic nature of rainfall results the spatial and temporal variation of streamflow, this makes the supply system to be conditional, and analyse the variation of flow to mitigate the potential consequence due to the shortage and excess flow in months. Understanding the competing users ables to manage the flow properly and prevent the potenial negative consequence arise due imbalance of supply and demand. The rapid population growth, urbanization, anthropogenic activities, climatic changes, environmental changes impose stress and scarcity on the available potenial. The available surface water potenial and demands needs to be assessed for a safe and effecient utilization of resources.

Its mandatory to identify the competing users and scale of demand, to grow more crops with irrigation systems, provide adequate potable water, enhance livestock production, and maintain enviroment. Water supply should be based on the current and future demands. Developement and rehabilitation of water resources projects need sufficient and updated data on the available supply and demands. The information gap could be filled with research findings and other related works. So, delivering water without analysing competing users in the catchments would cause stress on the supply system.

Understanding the spatio- temporal variation of streamflow and able to assess surface water potential and demand at the catchment level is critical to address society needs. Updated and organized data on supply and demand is required to facilitate the area's potential development. Its quite necessary to clearly quantify the surface water potential and identify competing users with "what if" scenarios. That helps in reliable policy formulation, made sound decisions, and achieve integrated water resource management at the catchment level.

1.3. Objectives of the study

1.3.1. General objectives

The main objective of the study was to assess the surface water potential and analysis of the current and future demands in the poorly gauged catchments of Jemma sub-basin, Abbay/upper Blue Nile basin, Ethiopia.

1.3.2. Specific objectives

I. To assess the mean monthly and annual water balance of the sub-basin

II. To analyze the water demand of competing users in the sub-basin.

III. To evaluate the impact of “what if” sceanrios on the demand variation and supply requirement in current and future time

1.4.Research questions

I. How much is the surface water potential of the sub-basin ?

II. How much is the water demand of different sectors in the sub-basin now and in the future time?

III. What is the impact of developed scenarios on demand variation and supply requirement now and in future time?

1.5. Significance of the study

As the Jemma subbasin is experiencing socio-economic and environmental changes. This study essentially indicates the amount of available surface water potential and identifies the major demands of the Jemma subbasin for current and future trends. Determining the quantity and demand at a basin level is fundamental to reconciling the available water with the escalating demand, since the imbalance is negatively affecting the country's economic growth. Such studies at this level are an input in the planning, management, and policy formulation processes and are vital for examining the impacts of investment options and making evidence-based decisions. Furthermore, it will be used for further research.

1.6. Scope of the study

This study is aimed at quantifying the surface water potential and analyzing competing demands in the gauged catchments of the Jemma sub-basin. The study will express the surface water potential of both catchments for the period 1990–2018. It defines the physical, hydrological, and climatic characteristics of the catchments based on the spatial and temporal scales. The demand analysis is considered depending on the existing surface water potential of both catchments. The study considers critical competing demands such as domestic, agriculture, and livestock in the Beressa and Robigumer catchments. This research identifies the various scenarios that have a significant impact on the supply and demand of the study area under current and future socioeconomic and environmental changes in the period 2022-2035. The EFR is taken into consideration in both catchments for demand analysis in order to maintain the minimum flow requirements of the rivers on their downstream sides. Finally, the study focused on the best possible scenario options to manage the supply and demand of both catchments.

2. LITERATURE REVIEW

2.1. Surface water potential

Water is the basic entity of the environment(Lane et al., 2017).Water, as a fundamental resource needs for human life and the environment(Bryła et al., 2021; Loucks & Van Beek, 2017).Water in our planet found in the atmosphere, the oceans, on land and within the soil and fractured rock of the earth's crust. The water molecules move from one location to another by the solar energy(Lukenga, 2019). Life can thrive in hostile environments with minimum amount(Lane et al., 2017).The availability of water determines the pattern of the Earth's terrestrial biomes such as forest, grasslands, and deserts. A model globe illustrates 70% of the earth is covered of water. Of that total water, 97% is in the oceans and is undrinkable without desalination treatment. Of the remaining fresh water, less than one half of one percent is available in surface sources such lakes, rivers and swamp . The water cycle is depend on the movement of surface , atmosphere, and transpiration of living cells(Lukenga, 2019).

Surface water is an important resource and part of the public spot in urban areas(Van Der Meulen et al., 2020). Surface water systems, typically formed by rainfall or meltwaters over non-permeable or semi-permeable geologies, are usually characterized by rivers or streams which crises- cross a landscape, forming lakes in depressions and draining catchment areas in route to the sea. Rivers, streams, and lakes offer abundant services to humans including navigation, opportunities for commercial, recreational, fishing, provision of aquatic and riparian habitat, and outlets for the natural assimilation of waste. The environment provides these benefits for living beings(Lane et al., 2017; Tamir, 2018). Most ancient civilizations have risen and radically collapsed with regard to the condition of the water source(Lane et al., 2017). Freshwater is an essential natural resource and is vital for sustaining life and maintaining the balance of ecosystem(Njoku et al., 2022). In fresh water there are critical terms denoted by color of blue and green. Blue water is that the sum of river discharge and deep groundwater recharge. Green water resource is the moisture in the soil, which is renewable part that can potentially boost economic returns and the source of rainfed agriculture. Thus, it is key to study the blue and green water potential for effective water resources planning and management (Ashine, 2021; Lane et al., 2017). Globally, only 3% of water is fresh water that can be directly used by people(Lv et al., 2021). Even out of this 2.2% of surface water, 2.15% is fresh water in glaciers and icecaps and only of the order of 0.01% is available in lakes and streams, the remaining 0.04% being in other forms(Geremew, 2020; Harun, 2021). The 99% of the fresh water is locked up in snow and ice or in lakes, while rivers and other surface fresh water bodies make up 0.01% of all the water in the world. Excluding the water which is frozen within ice caps and mountain glaciers, Earth has around 10.6 million km^3 of freshwater(Lane et al., 2017). When the surface water level is high enough, ground water comes to the surface naturally, springs, may form lakes, ponds, and river(Loucks & Van Beek, 2017). Hydroclimates impart a major influence on the distribution of water resources in the form of accessible surface water and ice(Lane et al., 2017). Pressures on water systems can be quantitatively assess on indicators of water demand relative to water availability(Eldardiry et al., 2020). Importantly there are factors to our abilities in maximizing the available quantity of water for human activity due to the physical, social and economic constraints(Lane et al., 2017).

The water resource is an essential field of economic growth, social progress, and environmental integrity(Ahmed et al., 2021). This resource is greatly affected by human activities, lack of appropriate conservation, socio-economic, and climatic changes are causing growing problems related to water. In many regions of the world, the availability of water is uneven and are being polluted, which negatively affects the aquatic ecosystems and reduces the availability(Bryła et al., 2021; Eldardiry et al., 2020; Pandey et al., 2021; Vargas-Pineda et al., 2020). Over consumption of water is generated from an increasing population demands and its respective processes of industrialization and which imposes great stress on surface water(Bryła et al., 2021; Vargas-Pineda et al., 2020). In order to gain sustainability in water resources, accounting socio-economic, engineering intervention as well as environmental aspects are strategically vital in terms of access to water and for development of water resources to meet the water demands of humans(Bryła et al., 2021; Tarebari et al., 2018). Water is a limited resource that do change over time and cannot be restored if lost. Therefore, should be used sustainably(Njoku et al., 2022). Indeed, quantify the surface water potential is essential(Tamir, 2018).

2.2. Surface water potential of Ethiopia

Ethiopia surface water potential has 0.7 % the country's land. It has 12 major basins, and differently sized water bodies. However, three of the major basins are dry basins, which do have insignificant flow. The country's surface water potential is 124.4 billion cubic meters (BCM). Since most of the rivers are transboundary, 97 % of this estimated annual stream flow of the country flows out of Ethiopia into neighboring countries and only 3 % of this amount remains within the country(Berhanu et al., 2014; Geremew, 2020; McCartney et al., 2010). Like the rainfall, the surface water also exhibits variability in spatial and temporal scales. Spatially, the major rivers flowing to the west and joining the Nile system. These include the Abbay, Barro-Akobo, Mereb, and Tekeze basins, which contributes significant surface water and cover 39 % of the land mass of the country. It accounts for about 70 % of the estimated surface water flows in this section. While the Eastern Highlands covers about 33 % of the country land mass contributes only 8 % of surface water of the country.

In addition to the two major flowing basins, the Great Rift Valley flows to the south and north of the central part of Great Rift Valley around Meki. Exclusively Awash flows to the northeast direction and attributes 4 % of surface water. It is the most used basin of the country. The south flow section includes two basins, the Rift Valley Lake basin, and the Omo-Gibe basin. They cover about 5 % of the land mass and 18 % of the surface flow(Berhanu et al., 2014; McCartney et al., 2010).

Accordingly, in examining the major lakes of the country, Ethiopia has 11 fresh and 9 saline lakes, 4 crater lakes and over 12 major swamps or wetlands. They cover about 7,300 km^2 area and store about 70 BCM of water. Geographically most of the lakes are found in the Rift Valley Basin. They have abundant fish resource. Most of the lakes have no surface water outlets, while Ziway, Tana, Langano, Abaya and Chamo, are exoteric. Furthermore, Shala and Abiyata lakes contains high concentrations of chemicals and Abeyta is currently used for production of soda ash(Berhanu et al., 2014; Geremew, 2020).

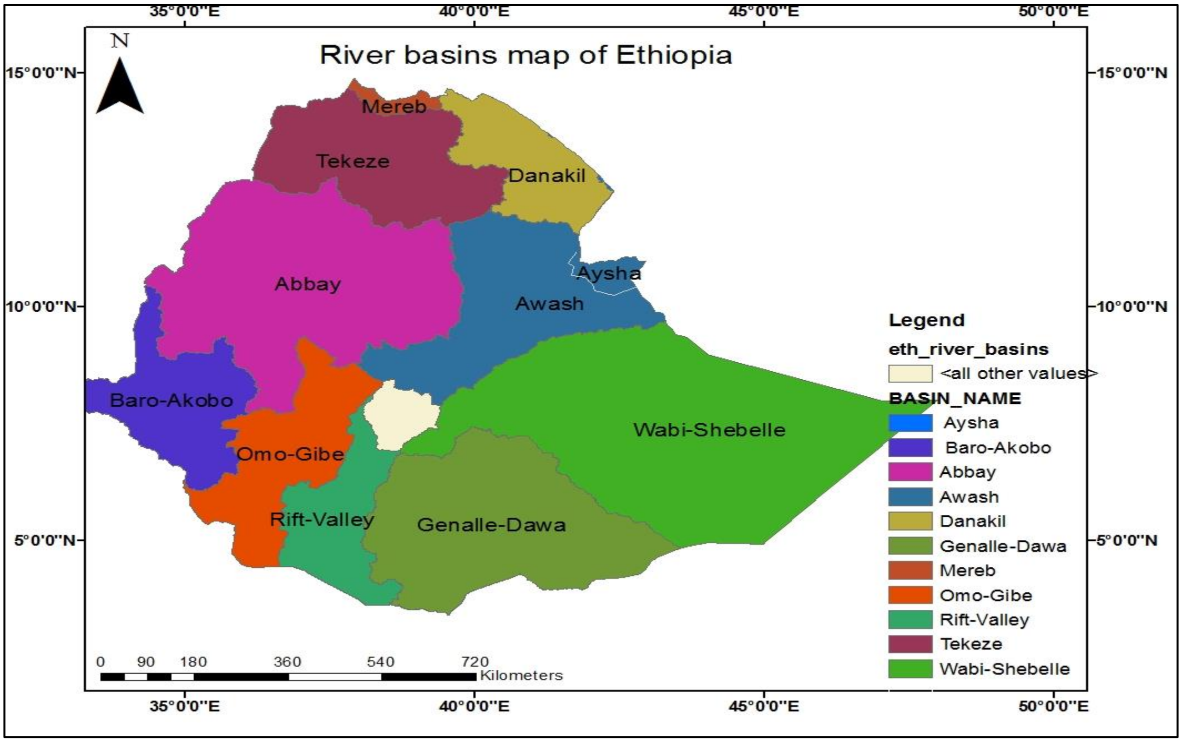

Figure 2: 1 The river basin map of Ethiopia

Table 2: 1 Surface water potential of Ethiopia's river basins

River Basin	Catchments area (km^2)	Annual run off (BCM)	Specific discharge ($l/s/km^2$)
Abbay	199,812	54.4	8.63
Awash	110,000	4.9	1.41
Barro-Akobo	75,912	23.23	9.7
Genale-Dawa	172,259	6.0	1.1
Mereb	77,120	0.72	3.82
Omo-Gibe	52,000	16.6	6.66
Rift Valley	5,900	5.64	3.44
Tekeze	82,350	8.2	3.16
Wabi-Shebelle	200,220	3.40	0.53
Danakil	64,380	0.86	0.42
Ogaden	79,000	N. A	N. A
Aysha	2,223	N. A	N. A

(source:(Berhanu et al., 2014)

Regarding to the Nile, Ethiopia contributes about 85% of the Nile water, mainly during the rainy seasons from June to September. The primary tributaries are the Bosheilo, Welaka, Jemma, Muger, Guder, Finchaa, Anger, Didessa and Dabus on the left bank and the North Gojam, South Gojam, Wombera and Belles on the right bank(McCartney & Menker Girma, 2012). The Jemma River basin has an area of 15,782 km^2. It covers ~ 8% of the area and contributes ~ 14% of the total annual flow of Upper Blue Nile Basin(Worku et al., 2019). There are several small tributary rivers flowing into Jemma River. Jemma River flows from the West of the basin into Abbay River. Robigumer and Beressa River are gauged catchments. Robigumer covers 890 km^2 and Beressa covers of 216 km^2 of the Jemma watershed(Geremew, 2020; Yilma & Awulachew, 2009).

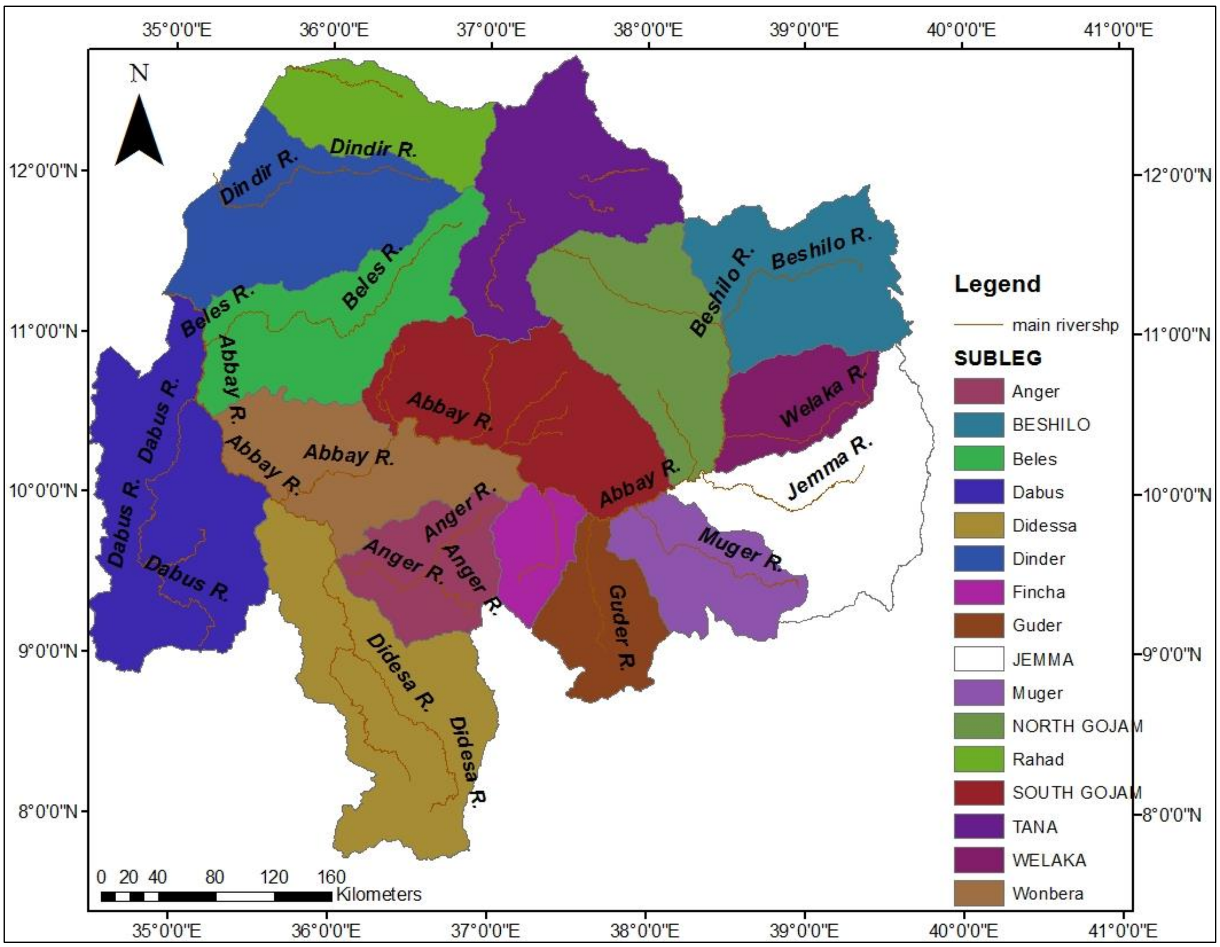

Figure 2: 2 The map of Blue Nile Sub-basins

2.3. Water demand condtions

Since the UN declares the human right to water, though the challenge of ensuring its delivery to users still vast(Lane et al., 2017). Water demand is the amount of water needed by users to satisfy their needs(Hu et al., 2021; Megebo, 2020). The opportunity to access and maintain secure water resources ensures the social and economic prosperity of a society(Lane et al., 2017). The country's prospective growth is determined by the availability of water for residential, commercial, and industrial purposes(Kiniouar et al., 2017; Ristow et al., 2021). Flow of water greatly vary between nations and continents, regarding to the prevailing climate and topography. Determine the amount of water that is currently used and required in the future are important parameters in water supply planning and management process(Meyer et al., 2019). Guaranteeing the supplying of water requirements under current and future conditions for the different stakeholders not only helps the economic growth, but also maintain ecosystem balance(Tarebari et al., 2018). Water resource systems are facing great challenge in satisfying the needs, because of the increasing demands coupled with climate change(Eldardiry et al., 2020). Current water issues are getting worsen due to competing users for sources of clean water, rapid population growth, and climate change and variability, cause significant problem to the water resources availability. Community's ability to access and, more importantly, to stabilize and secure water resources increases opportunities for its social and economic prosperity, in turn stimulating water stress and demands growth drives to more sophisticated water management solutions to be attained(Ayt Ougougdal et al., 2020; Meyer et al., 2019). Demand forecasts is needed to meet escalating demands, optimize crop yield, provide enough water for competing demands, upgrade the management of water, sediment, and nutrients under future climate changes(Pandey et al., 2021).

Forecasting water demand is one of the processes which is accomplished by employing different methods and it is used to estimate the future water need(Harun, 2021; Hu et al., 2021). Water demand is significant technical design parameter. It can be performed using local data or, established systems and standards(Koo et al., 2021). The number and type of users to be served, the expected population growth rate and the anticipated life of projects are crucial points under such analysis(Megebo, 2020; Nunes Carvalho et al., 2021). It studies the relationship between individuals and water consumption(Meyer et al., 2019). The analysis used to estimate future water for domestic and non-domestic purposes(Megebo, 2020; Purnawan et al., 2021; Vargas-Pineda et al., 2020). In estimating future water demand considering the socio-economic and climatic changes are critical elements(Megebo, 2020). In Jemma sub basin most of the economic structure are based on agriculture, livestock production, and as a community it suffers from frequent drought, climatic changes, lack of water supply and energy, so assessing the potential demand of the society regarding domestic and non-domestic needs are significant.

2.4. Previous studies and gaps in the Jemma sub-basin

Jiří and Vilímek (2010) : the study assessed Geo-risk management for developing countries-vulnerability to mass wasting in the Jemma River Basin, Ethiopia. Conceptual and applied analyses bearing on engineering geological, hydrogeological mapping, and zoning of vulnerability to mass wasting were conducted for nearly a 16,000 km^2 area of the Jemma River basin, central Ethiopian highlands. Work was aimed at the specific modification of current methodology and its practical field testing, user-oriented information dissemination, and training of Ethiopian staff in geo-hazard assessment. Also, environmental protection studies and water resources management to improve food and sanitary security were provided. The study recommends the effect of human activities and management ways on the environment.

Mengasha (2015): it was the evaluation of surface water resources availability under changing climate condition: in the two gauged catchments of the Jemma sub basin. The study was to understand the climate change impacts on surface water availability of Robigumer and Beressa river catchments. SWAT model was applied to determine runoff magnitude in the catchments and model uncertainty were assessed using SUFI2 in SWAT–CUP. The result showed that, there is an increase in flow volume that have an overall importance for agricultural activities practiced by local farmers; therefore, the study did only addressed the climate change impact on surface potenial and did not considered the future potenial effect on the demands of the area.

Worku et al. (2018): the study evaluates the performance of multiple RCMs driven by multiple GCMs in capturing the mean annual and monthly rainfall, distribution of rainfall events and large-scale climate circulation patterns (teleconnections) in the Jemma sub-basin, Upper Blue Nile Basin for the period 1981–2005. Observed data collected metrological data used for evaluation. The RCMs which capture rainfall climatology of the Jemma sub-basin and assesses the hydrological modeling, and other climate change mitigation and adaptation measures in the sub-basin.

Bekele (2018): studied the Hydro Power Potential of the Jemma River Basin by Using GIS And SWAT Model. 185 possible sites assessed based on 50% dependable discharge that were identified and capable to produce up to 0.980 GW installable hydropower potentials. From the total 185 site, 78 potential sites were generated from five stream order 3 streams and covers a total length of 134.79 kms. It earns installable power output of 0.534 GW and out of the 78 sites used to provide a best alternative electric power supply package for nearby local community through cost-effective manner. The study only signifies possible sites for hydropower generation in Jemma sub-basin.

Worku et al. (2020): this study evaluates bias correction methods and develops future climate scenarios using the output of a better bias correction technique at the Jemma sub-basin. The performance of different bias correction techniques was evaluated using several statistical metrics. The bias correction methods performance under climate condition different from the current climate was also evaluated using the differential split sample testing (DSST) and reveals that the distribution mapping technique is valid under climate condition different from the current climate. It recommends reducing the impact of future climate change climate adaptation strategies should be adopted under different climate scenarios.

Worku et al. (2017): this study siginifies the effect of Land use/land cover on runoff and sediment characteristics of Beressa catchment. The study is conducted using hydrological model integrated with GIS. Input data like LU/LC, weather and soil data features are required to undertake watershed simulation. The model has been calibrated and validated in SWAT-CUP. The study showed that agricultural and settlement areas have increased between 1984 and 2015, while barren, grazing land and forest area have decreased. However, the share of forest cover increased in between 1999 and 2015.

2.5. Hydrologic models

A hydrological model is an approximation of the actual system(Chow et al., 1988). It links the input–output which are measurable hydrologic variables to simulates the process of hydrologic events on surface and subsurface based on the water balance equation. A runoff model is a set of equations that helps in the estimation of runoff as a function of various parameters used for describing watershed characteristics(Horton et al., 2022). The two important inputs required for all models are rainfall data and drainage area. Along with these, watershed characteristics like soil properties, vegetation cover, watershed topography, soil moisture content, characteristics of groundwater aquifer are also considered(Devia et al., 2015). The objective of hydrologic system analysis is to study the system operation and predict its output(Chow et al., 1988). Different hydrological models are used by the researchers depending on their characteristics and potential applications(Horton et al., 2022). They require calibration and validation. Model calibration is adjustment of the model parameters and forcing within the range of the uncertainties to attain a model representation that meet specified criteria and Validation is a comparison of the model outputs with the actual data(Abdalla et al., 2022; Horton et al., 2022; Kalugin, 2022; Peel & McMahon, 2020).

Rainfall-runoff models are classified based on model input and parameters and the extent of physical principles applied in the model. It can be classified as lumped and distributed model based on the model parameters as a function of space and time and deterministic and stochastic models based on the other criteria. Deterministic model will give same output for a single set of input values whereas in stochastic models, different values of output can be produced for a single set of inputs(Chow et al., 1988; Devia et al., 2015). Another classification is static and dynamic models based on time factor. Static model exclude time while dynamic model include time. further classified the models as event based and continuous models. The former one produce output only for specific time periods while the latter produces a continuous output. One of the most important classifications is empirical model, conceptual models and physically based model(Devia et al., 2015).

A deterministic model does not consider randomness; a given input always gives the same output. A stochastic model has outputs that are at least semi random. In short, deterministic models make forecasts while stochastic models make predictions. Although all hydrologic phenomena involve some randomness, the resulting variability in the output may be quite small when compared to the variability resulting from real factors. In such cases, a deterministic model is appropriate. If the random variation is large, a stochastic model is more suitable. Most daily precipitation models are stochastic(Chow et al., 1988).

Hydrologic models can be classified into three main categories:

1. Lumped models: - Parameters of lumped hydrologic models do not vary spatially within the basin and thus, basin response is evaluated only at the outlet, without explicitly accounting for the characteristics of individual sub basins. Parameters of lumped models often do not represent physical features and usually involve certain degree of empiricism. The impact of spatial variability of model parameters is evaluated by using certain procedures for calculating effective values for the entire basin. The most commonly employed procedure is an area-weighted average. For example, many models of the rainfall-runoff process, treat the precipitation input as uniform over the watershed and ignore the internal spatial variation of watershed flow. The selection of lumped hydrologic models is often attractive user's choice because of their simple structure, minimum data requirements, fast set up and calibration, and easy use lumped models are not usually applicable to event-scale processes. Particularly reservoir routing is not simulated in the models. If the interest is primarily in the discharge prediction only, then these models can provide just as good simulations as complex physically based models(Beven, 2011; Chow et al., 1988; Devia et al., 2015).

2. Semi-distributed models: - Parameters of semi-distributed (simplified distributed) models are partially allowed to vary in space by dividing the basin into a number of smaller sub basins. There are two main types of semi-distributed models:

   A. kinematic wave theory models (KW models, such as HEC-HMS), and
   B. probability distributed models (PD models, such as TOPMODEL).

The KW models are simplified versions of the surface and/or subsurface flow equations of physically based hydrologic models(Beven, 2011). In probability distributed models the models spatial resolution is accounted for by using probability distributions of input parameters across the basin(Beven, 2011; Cunderlik, 2003).

The main advantage of semi-distributed models is that their structure is more physically-based than the structure of lumped models, and that they are less demanding on input data than fully distributed models(Chow et al., 1988).

3. Distributed models: - Parameters of these models are fully spatially-varied at a given resolution usually chosen by the user. Distributed modeling approach attempts to incorporate data concerning the spatial distribution of parameter variations together with computational algorithms to evaluate the influence of this distribution on simulated precipitation-runoff behavior. Distributed models generally require large amounts of (often unavailable) data for rainfall-runoff processes. However, the governing physical processes are modeled in detail, and if properly applied, they can provide the highest degree of accuracy(Beven, 2011; Chow et al., 1988; Cunderlik, 2003).

In order to select the appropriate model from the available ones, considering time, money, the objective of the study, requirements of the model and accuracy of the output are a few significant factors(Devia et al., 2015; Horton et al., 2022).

2.6. SWAT model and its application

SWAT, physically-based, continuous, theoretical, long-term, and distributed watershed-scale hydrologic model(Abdalla et al., 2022; Akoko et al., 2021; Aragaw & Mishra, 2022; Megebo, 2020). It operates on a daily time step on sub-basins identified using a digital elevation model(Aragaw & Mishra, 2022; McCartney & Menker Girma, 2012). It is being now used to examine the hydrological behavior of large and complex watersheds(Pandey et al., 2021; Zaibak & Meddi, 2022). Rainfall and temperature are the two essential climate variables in the SWAT model because they significantly impact various water balance components(Pandey et al., 2021). Its a GIS interface and computationally efficient and used in a variety of management strategies can be performed with less time and money consumption(Akoko et al., 2021; Ashine, 2021). It allows users to evaluate long term impacts; integration of multiple processes such as climate, hydrology, nutrient and pesticide, erosion, land cover, management practices, and processes in water bodies(Abdalla et al., 2022; Akoko et al., 2021; Aragaw & Mishra, 2022; Ashine, 2021; Cuceloglu et al., 2017; Horton et al., 2022; Megebo, 2020; Pandey et al., 2021; Peel & McMahon, 2020; Worku et al., 2019).

Mengasha (2015) used the SWAT model in assessment of the surface water potential of the gauged catchments of the Jemma sub-basin. The study ables to asses the hydrologic condtion of the catchments. It identifies the significant sensitive parametes that used to represent the actual hydrologic condtions of the streamflow. The model was calibrated and validated using the Sufi-2 algorithm. The model showed good aggrement with the observed data by the model performance evaluation criterias.

Megebo (2020) applied the SWAT model to assess the surface water potential of the Bilate river basin. The study revealed the model was good enough to predict the Bilte river surface water potential and can be used to propse and rehabilate water resources projects on the study area now and future. The model showed good fit with the observed data in coefficient of determination (R^2), Nash-sutchliff efficiency(NSE) and PBIAS model performance evaluation criteria.

Ashine (2021) used the SWAT model to modelling the surface water potential of the Somodo watershed. The model enough to assess the surface water potential of the watershed and ables to identify the sensitive parameters the significantly affect the flow of the watershed. The model was calibrated and validated using sufi-2 algorithm and showed good agreement with observed data in model performance evaluation criterias.

Worku et al. (2017) the SWAT model applied to modelling the runoff -sediment response to the landuse/ landcover changes in Beressa watershed. The model ables to show the landuse/ landcover changes and the effect on the runoff- sediment characterstics of the watershed. The model showed enough perorfmance on predicting the effect of enviromnetal changes on the flow condtion of the watershed.

2.7. Water resources models

The increasing pressure on existing water resources, the present framework of water allocation system is becoming highly inefficient(Agarwal et al., 2018). Assesing the performance of water resources systems needs knowledge of properties and performance, which depends on data availability and use within models and decision making(Ward et al., 2019). Forcasting water demand at basin level techniques and model to be use with the available data, time and the scope of area under consideration for reliable water resources management(Harun, 2021; Ristow et al., 2021). Computer based Decision Support Systems are being used worldwide. At the basin and sub-basin level several software programs are designed to simulate water development and management policies(Harun, 2021).

2.8. WEAP model and its application

WEAP model is designed for planning, management and allocation of constrained water resource and environmental quality. It is a user-friendly, flexible, and transparent planning for analysis of current water demand and supply patterns and, for designing and evaluation of alternative scenarios. That includes domestic, livestock, irrigation and environmental water demands with the equation of equipment efficiencies, water use rate, re-use and allocation whereas, supply side includes stream flow, catchment, reservoir and ground water(Devia et al., 2015; Negasa et al., 2022). WEAP 21 model simulations are constructed as a set of scenarios, where simulation time steps from as short as a single day to more than 100 years. These demands scenarios are computed and applied deterministically to the Linear Program (LP) allocation algorithm. Demand analysis is depend on all supply and resource calculations that allows allocation routine which determines the final delivery to each demand node, based on the priorities specified by the user(Yates et al., 2005). WEAP 21 can be used both as a database tool in which it maintains supply and demand information(Ward et al., 2019). The priority-preference information input to the model are assigned a unique priority number, which are integers that range from 1 (highest priority) to 99 (lowest priority)(Yates et al., 2005).

Harun (2021) applied the WEAP model to determine the competing users , estimate total annual water demand and unmet demand with " wha if" scenarios in three time horizons (2020-2050). The model was able estimate the total water demand and unmet demand of the Dabus watershed tibutarie of Blue nile Basins.

Megebo (2020) used the WEAP model to analyse the comperting users, the current and futre water demand and unmet demands of the Bilated river in 2018-2035 reference period. The study showed the model was enough to predict the current and future demands with provide the environmental flow requirement that helps to maintain the ecological balance of the watershed.

Ashine (2021) in the study of the total water demand of 2018-2050, the WEAP model was used to analyse the existing and future competing users, their demand and the unmet dmands of the somodo watershed. The model predicts the total water demand in different "what if" scenarios.

3. MATERIALS AND METHODS

3.1. Description of study area

3.1.1. Location of study area

Jemma River is located in the East part of the Blue Nile River Basin between 9° 05’ 37’’ – 11° 10’ 07’’ N latitude to 37° 12’ 07’’- 40° 0’ 01’’ E longitude. The Jemma sub-basin has an area of 15,782 km^2. It covers ~ 8% of the area and contributes ~ 14% of the total annual flow of Upper Blue Nile Basin. Jemma River flows join into Abbay River(Worku et al., 2019; Yilma & Awulachew, 2009). It drains parts of the Siemen Shewa zones of the Amhara and Oromia Regions(Bekele, 2018; Yilma & Awulachew, 2009). Jemma sub-basin has several watersheds, among them, Beressa in the upstream and Robigumer in the middle stream are important where they constitute weather station and hydrological gauge stations(Worku et al., 2019, 2021). Beressa River has an area of 213 km^2 and Robigumer River has an area of 893 km^2. The picture of the study area provided *(*Appendix Figure 1: 5).

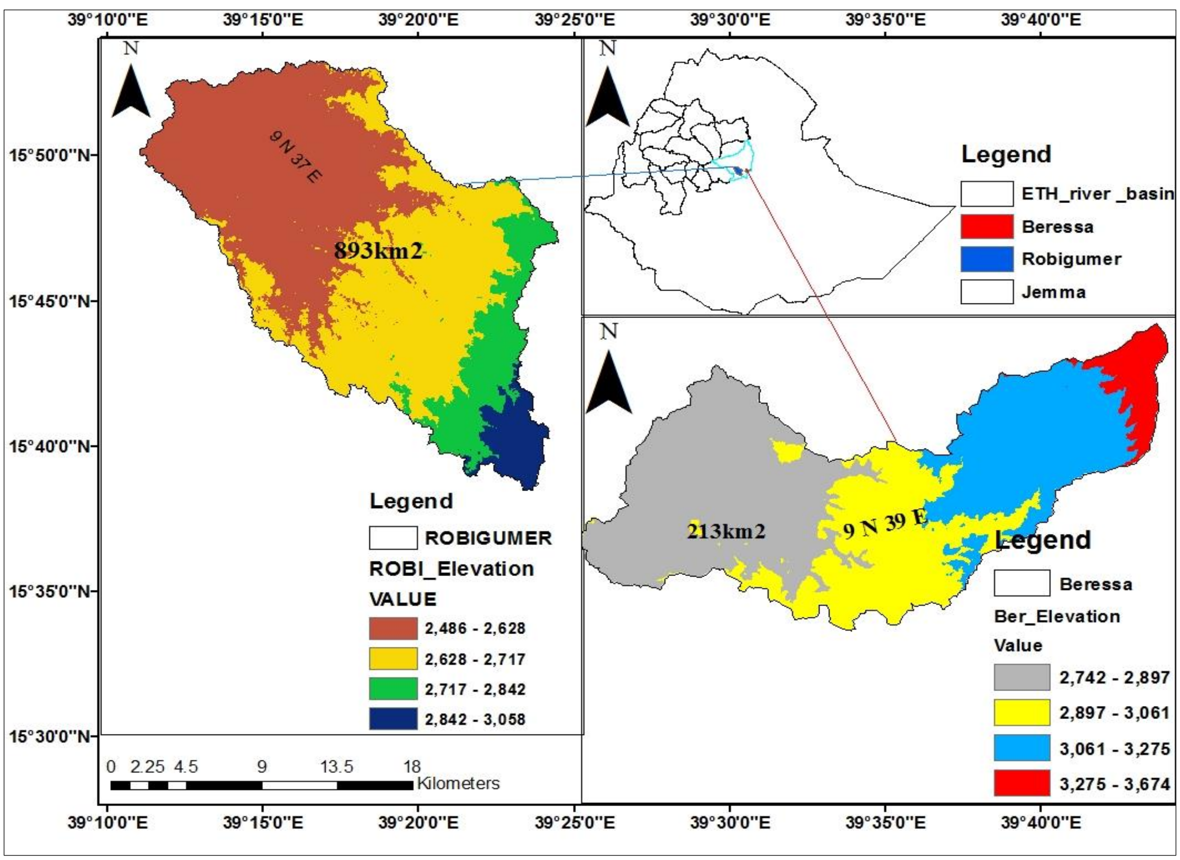

Figure 3: 1 Location map of study area

3.2. Material used for the study

Material used for analysis of the data in this research are: -

3.2.1. Data analysis software

I. Ms-Excell

It used to prepare the hydro-metrological data and make the data available to run the SWAT model, since SWAT needs well-organized and prepared data for better simulation.

II. Global Postioning System (GPS)

It is device used for collecting and registering the coordinates of the study area, in order to investigate the actual condition and analyze the LULC for a supervised assessment.

III. XLSTAT

This software was used to fill the streamflow data of the catchments obtained from MOWE. The software used in different data filling purposes of research works.

IV. ArcGIS

ArcGIS used for the watershed delineation by analyzing the properties (e.g. land use, soil types, and slopes) of each sub-watershed, which need DEM as input data and used as interfence swat.

3.2.2. Hydrological models

Different models used in this research for the better result of the study due their own specific purposes, and these are SWAT, SWAT-CUP, Cropwat, and WEAP models.

I. Soil Water Assessment Tool (SWAT)

SWAT is a basin-scale model which used a daily time step to simulate long-term hydrological processes under different factors. It was used to quantify the available surface water potential of the catchments and understand the hydrological water balance.

- Weather generator database

It was used to prepare the meteorological data of the gauges sataions according to theSWAT input database format.

- Automated base flow separator

It was used to separate the base flow of the catchments and used for the asses the water balance of the catchments in SWAT model run.

II. SWAT -CUP

It was used execute sensitivity analysis, calibration, and validation by sequential uncertainty fitting-II (SUFI-2) and know performance of the model and find best fit with the observed data.

III. Cropwat

It was used to calculate reference evapotranspiration(ETo), crop water requirement irrigation water requirement, and irrigation scheduling, using rainfall, soil, crop, and climate data. The model used for determining the irrigation water requirment of crops in demand analysis.

IV. WEAP

It was used to asses the total water demand, supply requirement, unmet demand and understand the possible water allocation system of the study area.

3.3. Data collection, management and quality test

3.3.1. Data collection

The data used for this study were primary and secondary data. The primary data obtained during field vist. The secondary data was obtained from governmet office and international institution database.

Table3: 1 Data used for this study and their sources

Data type	Description/ purpose	scale/period	source
DEM	Watershed delineation in SWAT model	(30x30m)	MOWE & USGS
Landuse/cover map	Land use classiffication map	2017	MOWE
Soil map	Soil classification map	2014	MOWE
Meteorological data	Daily Rainfall	1990-2018	Ethiopian National Metrological Agency (NMA)
	Daily Air temperature		
	Daily Relative humidity		
	Daily Sunshine hour		
	Daily Wind speed		
streamflow	Daily Beressa flow for calibration and validation	1990-2014	MOWE
	Daily Robigumer flow for calibration and validation	1990-2009	
Population	Both human and livestock for water demand analysis	2007-2022	CSA and Woreda Bureau

3.3.2. Data management

The SWAT model requied to have a well prepared, long term, quality data to asses the surface water potential of the study area. Before inserting any data into the models the collected data that are either primary or secondary should be checked and assessed for better quantitative and quality results. The data is requested for thirty years of climatic data that basically considering the available streamflow data of both catchments. The meteorological data obtatined from Ethiopian Nation Meteorological Agency (NMA) was from 1990-2018 of eleven station. From the available station only 6 of them was used for data anlysisis and climate data preparation, this selection is based on the percentage of missing data and nearby station that significatly contribute within the study area. The thiessen polygon was used to identify the best nearby station for the climate data analysis in both watersheds.

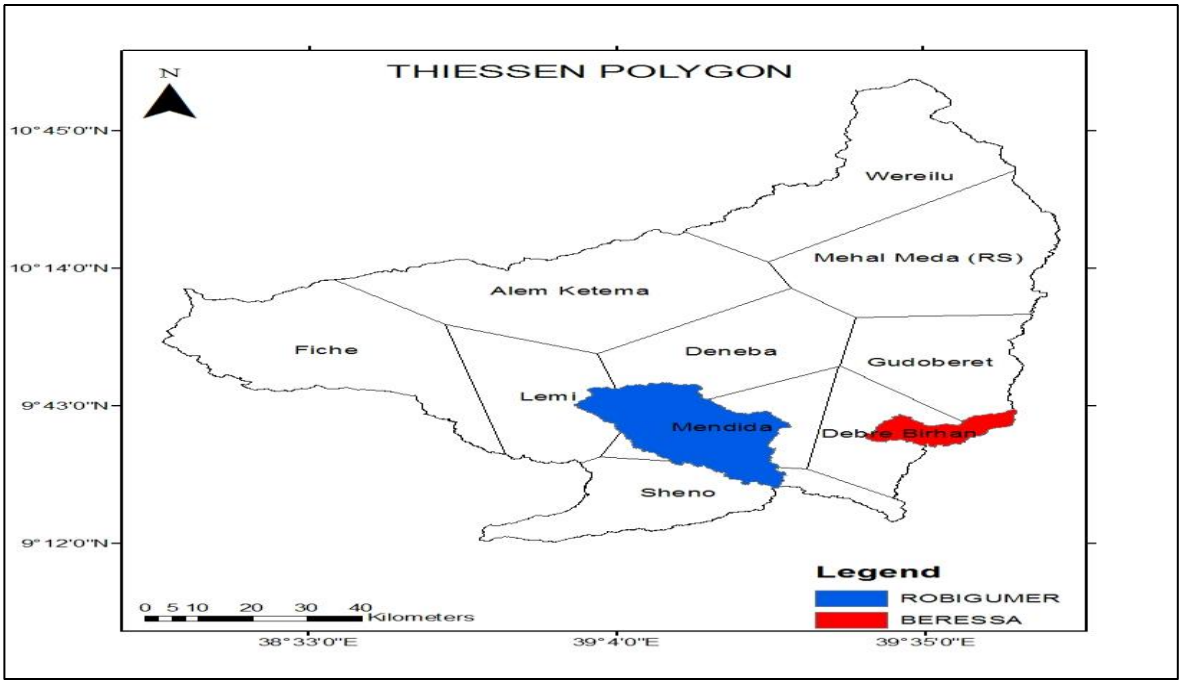

Figure 3: 2 Thiessen polygon map

Table3: 2 Meteorological station of study area

S.No	station	Elevation(m)	Longtiude(degree)	Lalttitude (degree)
1	D/Birhan	3206	39.51	9.67
2	Gudobert	3075	39.68	9.80
3	Mendida	2791	39.31	9.65
4	Deneba	2650	39.19	9.86
5	Sheno	2870	39.28	9.33

From the above all meteorological stations debrebirhan station has only all climatic data with less missing. While Deneba station has only one climatic data with high missing data.

I. Filling data

Data is the most important element in any field of study. The data which is collected or measured should be enough and consistent to make anlaysis, otherwise the work will be incomplete or difficult to perform. In hydrological works most of the time the data period is long inorder to adequately perform analysis and perform data based prediction. Within such a long period of time having a consistent and complete data is a difficult issue. Especially in developing countries data insufficiency and poor quality are common problems. The eror might arise from human, instumental or natual conditons. So filling the given data with the appropriate method is mandatory task.

To estimate the missed data there are numerous techiniques developed depending on the possible conditon. It might need to estimate the missing cllimatic data from the nearby gauging station or homogenous region. The most common techiniques adopted in filling missing climatic data are Arthemitc mean, Inverse-distance, normal ratio and linear regression methods.

Arthimetic mean method is appplicable when the annnual mean prcipitation of the missed station is within or less than 10% of the other nearby station. However, the average annual precipitation differs or morethan 10% of the other nearby stations average annual precipitation this method is not recommend to use.

Normal ratio method is simple and applicable when the average annual preciptation of the station differs or morethan 10%. It is weighted of the stations by the ratio of their average annual preciptation values. For this study this method is adopted. This is due to it’s simple, accurate and accounts possiblities of various condtions. The stations found in the study area differs more than 10% of the other average annnual preciptation of nearby stations. This method gives better estimation than the other techinques available for filling missing data.

The missing prciptation denoted by Px and given by

$$Px = \frac{Nx}{N}\left(\frac{P1}{N1} + \frac{P2}{N2} + \frac{P3}{N3} + \cdots \frac{Pn}{Nn}\right) \quad ....3.1$$

Where:- Px is the missing value of precipitation to be computed,

Nx is the average value of rainfall for the station in question for recording period,

N1, N2, N3…Nn is an average value of rainfall for the neighboring station, P1, P2, P3......Pn is the rainfall of neighboring stations during a missing period and N is the number of stations used in the computation

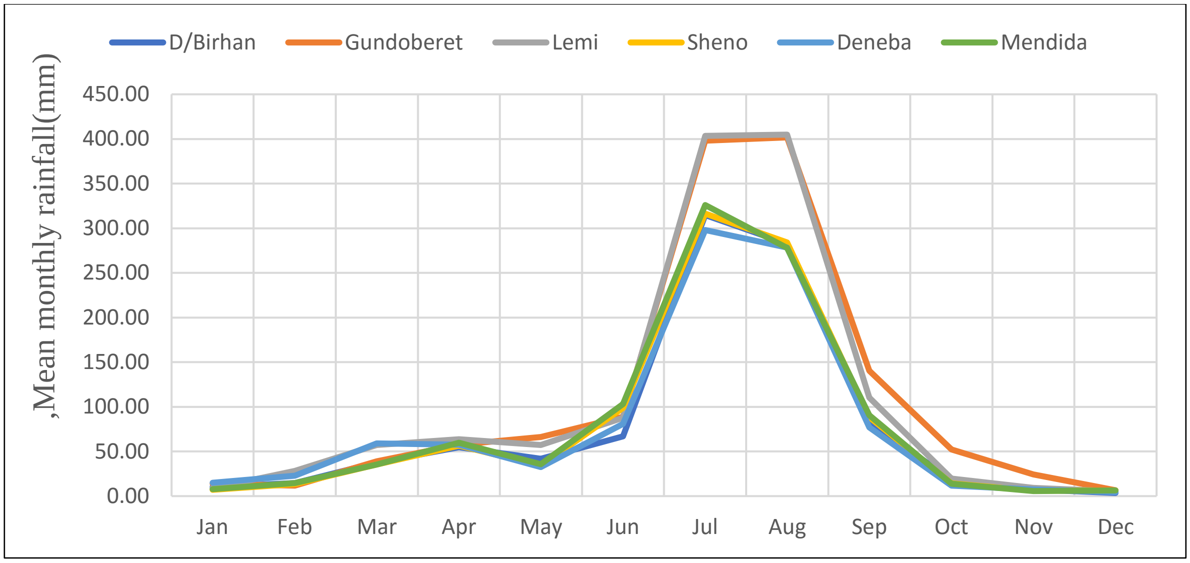

Figure 3: 3 Mean monthly rainfall of gauged stations (1990-2018)

The climatic station that used for this study shows similar records of data pattern and consistent time-series graph.

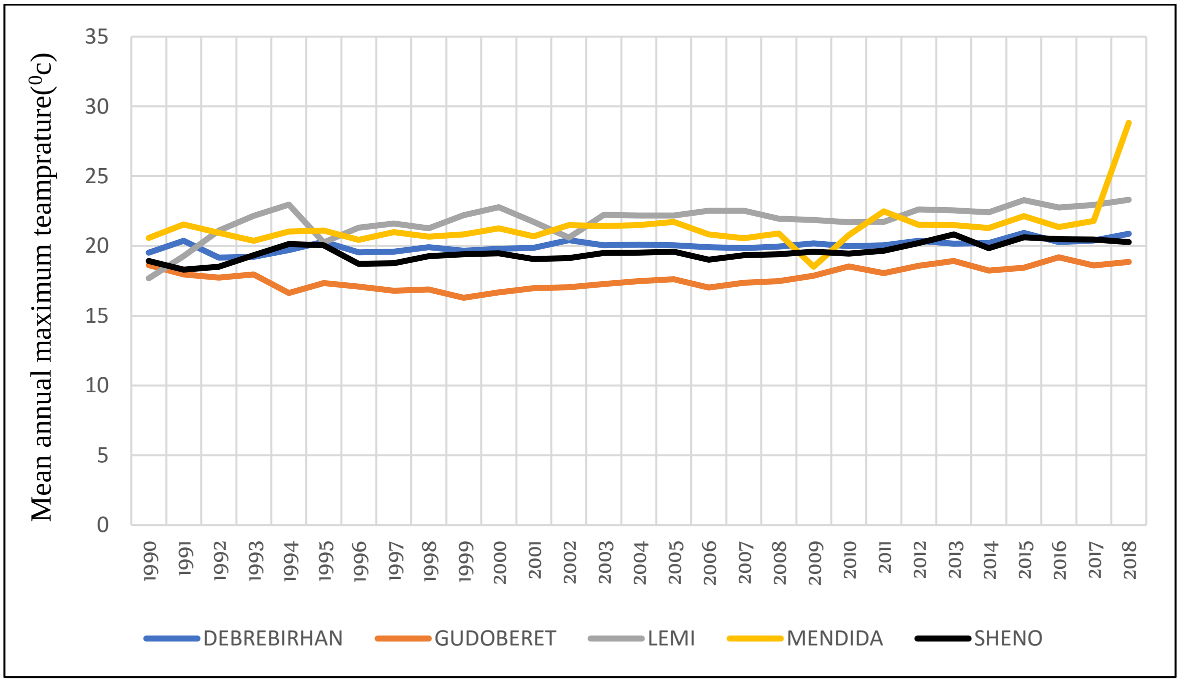

Figure 3: 4 Mean annual maximum temprature (1990-2018)

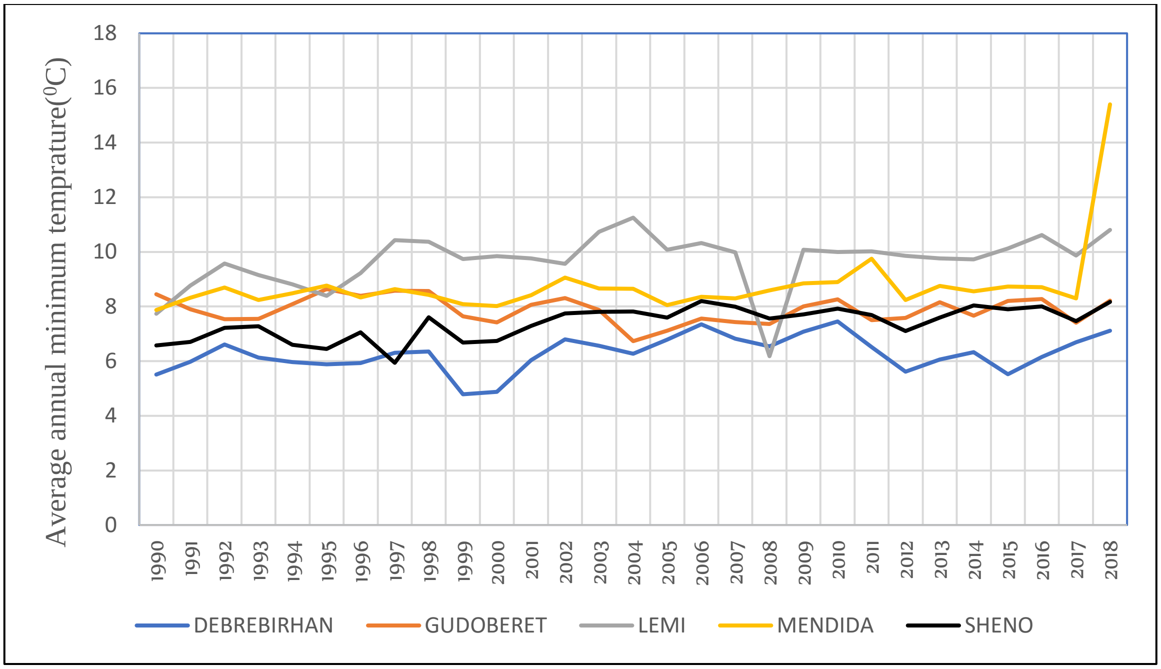

Figure 3: 5 Mean annual minimum temprature (1990-2018)

3.3.3. Data quality test

I. Consistency of data

After the data has filled the climatic data of the station should be ckecked it's consistency of data. This consistency of data helps to figure out the gauging sation condtion within a long period of records of data. The records that have taken into analysis might not be with the right path. Sometimes the data with in or around the sation might affect the data measurment and recording. Even in storing the data there may be some errors. This error have a big impact in each and every hydrologic process.

A consitent of data is the correct sorted data format of a long period records without any significant change with the time. This way of data makes easy and accurate every hydrlogic data analysis carried out. Consistency of data is releveant and siginficant parameter in data anlysis process.

While checking the consistency of a gauging station the length of records and standard of gauging sation should be taken into account. Most hydrologic studies perform conistency of data by techinique of Double mass curve. This methd helps to detect the possible inconsistency and adjust the incorrect to correct values.

Double mass curve is the method of comparing the gauging staion annual rainfall values with the other neighbouring sations cumulative value graphically. If a signicant slope defection is observed while drawing the sation value with cumulative that shows the inconsistency where it is occured. There should be corrective measuure to adjust the value and this done by multiplying the rainfall values with the ratio of corrected slope to original.

The DMC method is given by

$$Px' = Px\frac{M'}{M} \quad \text{...} 3.2$$

Where Px’: -is corrected precipitation at station x

Px: - is originally recorded precipitation at station x

M’: - is Corrected slope of the double mass curve, and

M: - is original the slope of the double mass curve

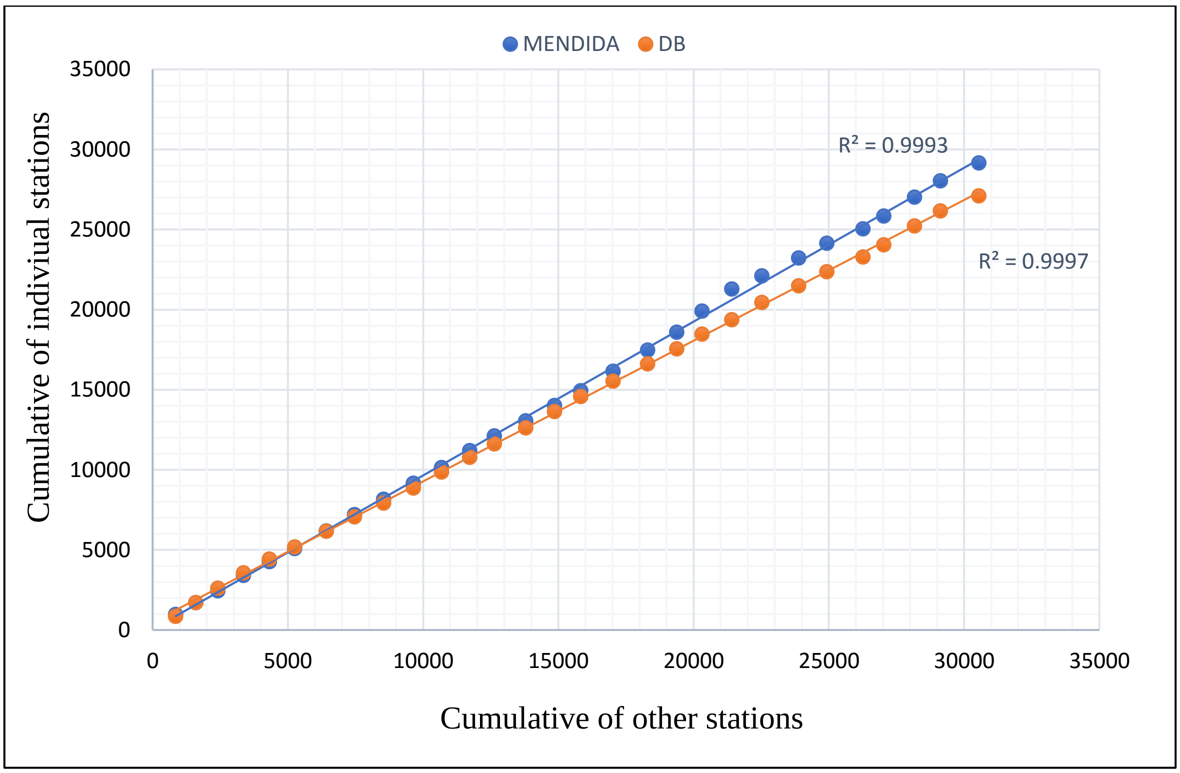

Figure 3: 6 Double mass curve of gauged stations

II. Meteorological data outlier test

Outlier of data is the occurence of a data outside the trending value. The outlier might be at minimum or maximum depart from the other normal values of recorded data. The removal or retention of a data significantly affect the stastistical parameters of copmuted value ,especially when the sample size is small.

Accodring to(Chow et al., 1988);The outlier test is performed after matematheical and hydrological computaion is carried out. By taking the station skew manage to identify the higher or lower outlier value from the sample data set. If the station skew is greather than +0.4, tests for high outliers and if the staion skew is lessthan -0.4, tests for lower outliers. Where the station skew is between ±0.4, tests for both high and low outliers should be applied before eliminating any outliers from the data set.

The following frequency equation can be used to detect high outliers:

$$XH = Xav + K_n S_y \qquad 3.3$$

Where: - XH: - Logarithmic high - outlier test threshold,

S_y: - standard deviation

K_n: -10- percent significance-for samples of size **N** from the normal distribution

If the logarithms of values in a sample are greater than XH in the above equations, then they are considered high outliers. Accordingly, the information that indicates a high outlier is a maximum over an extended period, the outlier is treated as historic flood data and excluded from the analysis. If the record does not contain enough information to correct for high outliers, they shall be retained as part of the systematic record.

$$XL = Xav - K_n S_y \qquad 3.4$$

Where:-XL: - logarithmic low- outlier test threshold.

The outlier test for basic stations has been done and tests for both high and low outliers were applied. The outlier test result shows that the largest recorded value for all stations does not exceed high outlier test. The threshold value and the smallest recorded value is not below minimum outlier value, so both high and low outliers were not detected and the rainfall data is safe for outliers.

III. Hydrological data outlier test

The same prcodure has applied for the stream flow data obtained from MOWE in both hydrological gauging stations of Beressa and Robigumer catchemnts. The outlier test gives great contribution by detecting the departing values that significantly affect the sample data set. This helps to manage the data before applying for calibration and validation process.

Flood peaks considered high outliers should be compared with historic flood data information at nearby sites. Historic flood data comprise information on unusually extreme events outside of the systematic record. If information is available that indicates a high outlier is the maximum over an extended period of time, the outlier is treated as historic flood data and excluded from analysis(Chow et al., 1988).

Table3: 3 Hydrological data outlier test of: a) Beressa Catchment and b) Robigumer catchement

YEAR	Qmean(m^3/s)	Y=log(Q)
1995	152.16	2.18
1996	207.10	2.32
1997	153.63	2.19
1998	175.07	2.24
1999	169.38	2.23
2002	95.05	1.98
2003	68.96	1.84
2004	93.36	1.97
2005	72.95	1.86
2006	78.70	1.90
2007	125.70	2.10
2008	86.04	1.93
2009	70.34	1.85
2010	78.84	1.90
2011	83.90	1.92
2012	102.74	2.01
2013	123.93	2.09
2014	195.88	2.29
Xav	219.57	2.14
Std	303.73	2.48
XH	**936.69**	**2.97**
XL=	**-497.55**	**-3.72**
KN	**2.361**	
N	**19**	

YEAR	Qmean(m^3/s)	Y=log(Q)
1990	292.77	2.47
1991	210.31	2.32
1992	141.92	2.15
1993	294.53	2.47
1994	262.08	2.42
1995	171.84	2.24
1996	318.64	2.50
1997	187.49	2.27
1998	326.34	2.51
1999	348.64	2.54
2000	296.29	2.47
2001	295.18	2.47
2002	153.04	2.18
2003	382.23	2.58
2004	298.27	2.47
2005	267.31	2.43
2006	570.84	2.76
2007	309.34	2.49
2008	175.96	2.25
2009	208.70	2.32
Xav	274.68	2.41
std	97.81	1.99
XH	**505.60**	**2.70**
XL=	**43.76**	**-2.29**
KN	**2.361**	
N	**19**	

From the outlier test of hydrlogical data the Beressa catchemnt show high outlier in the 2000 and 2001 year data records. The two consecutive years of 2000 and 2001 significantly depart from the remaing data set trend. The value shows discharge depated from the higher outlier 937 m^3/s, this might be due to an extereme event (flood), however, compared to the historical record, there is no such case that could make the situtation reliable, and the error perphas could happen from either data measurment or processing. So these two years of data has deleted from the sample data set for calibration and sensitivity anlaysis. In Robigumer catchment the sample data set are within the high and low outlier, there is no such data that depart from the other sample data set. So the data used for calibration and sensitive analysis without any adjustment. In both catchements the maxmiunm flow is recorded in July and August. Since the rainy season are within these months a maxmium rainfall intensity recorded in most parts of the country.

3.4. Methodology to determine the surface water potential

3.4.1. SWAT model Setup

The SWAT Project Setup menu contains items that control the setup and management of SWAT projects that used for storing temporary GIS datasets, and SWAT input files. The Watershed Delineator used to import topographic maps and delineate the watershed commands to perform sub basin delineation and evaluate the results. The HRUs Distribution commands to define the number of HRUs created within each sub basin in the watershed. The Write SWAT Input Tables commands to manage the creation of Arc SWAT geodatabase tables that store values for SWAT input parameters. After all this steps are correctly done the final one is swat simulation allows to run the model(Winchell et al., 2013).

To run the swat model properly the interface will need to access ArcGIS compatible raster (GRIDs) and vector datasets (shapefiles and feature classes) and database files which provide certain types of information about the watershed. The necessary spatial datasets and database files need to be prepared prior to running the interface(Akoko et al., 2021; Winchell et al., 2013).

3.4.2. Watershed Delineation

The watershed delineation performed for both Beressa and Robigumer watersheds using the DEM that was downloaded from USGS. The download DEM projected to UTM-37^{0}N and masked with a watershed point that helps to save the proccessing time of delineation. Based on the threshold stream defines the size and number of watershed have calculated. The stream network definition and outlet added depend on the hydrologic coordinate points of both rivers. The Beressa watershed outlet point is taken on Debre birhan and Robigumer outlet on Lemi. Then the whole watershed delineation tasks was performed by calculating the sub-basin geomorphic parameters. Finally,a report having all sub basin topographic parameters were generated. The report provides a statistical summary and distribution of discrete land surface elevations in the watershed and all the sub watersheds.

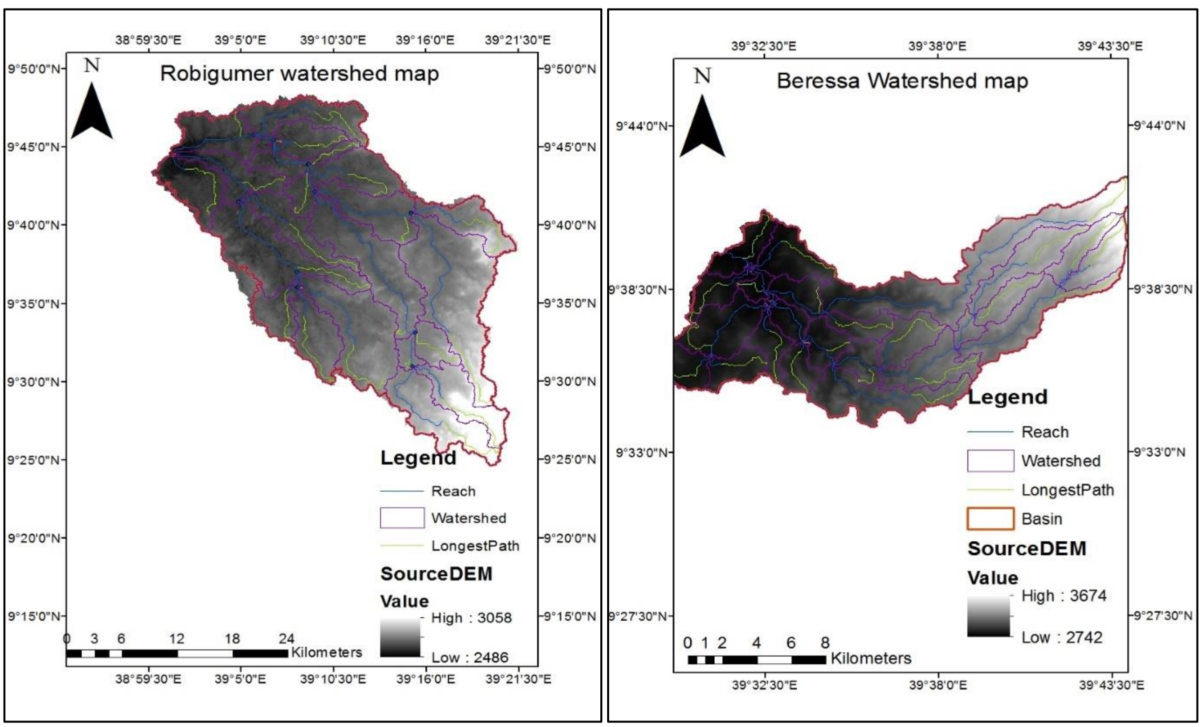

Figure 3: 7 The DEM of study are

3.4.3. HRU analysis

The Beressa and Robigumer watershed landuse, soil and slope map was prepared according to the swat database format. The maps and their look up table was prerared in txt format. The prepared maps with a look up table loaded into the HRU analysis tool. The three maps classified and overlayed to form a HRU report. The slope was classified with multiple slope option under three class interval. A recommended ratio taken into consideration 10,10 and 20% of land use, soil and slope used to define HRU definition. The HRU defintion enables Subdividing the watershed into areas having unique land use and soil combinations.

3.4.4. Land cover map

It the actual reflection of the earth's surface. The physical features of each land parts are represented in standardized format each color has meaningful relationship with the actual feature on the surface it exists. The land cover is the definition of the land in which it is belong to. Whereas land use refers to the actual usage of that land for some specific purpose.The LULC was done using SWAT supervised classification and maximum likelihood option in making LULC available for HRU swat input. The major LULC in Beressa are agricultures, plantations, and urban. Agricultures is the dominant LULC in Robigumer watershed.

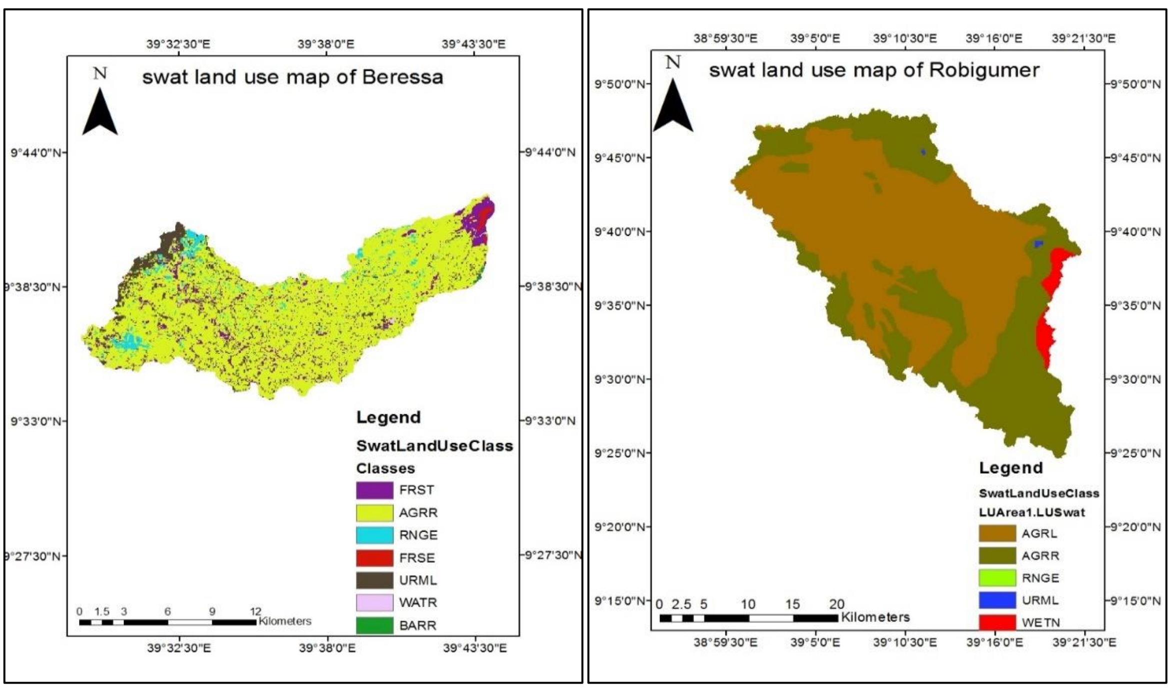

Figure 3: 8 The land use land cover map of study area

3.4.5. Soil map

The soil data is basic input in ARC swat HRU response determination. The soil data used to define the movement and process of water and air within the watershed. This makes it significant to understand the HRU of watershed. The soil data was obtained from MOWE and

FAO world digital harmonized soil. The major soil types in Beressa watershed are Eutric vertisol and Eutric cambisols. Eutric vertisols and Calcic vertisols in Robigumer watershed.

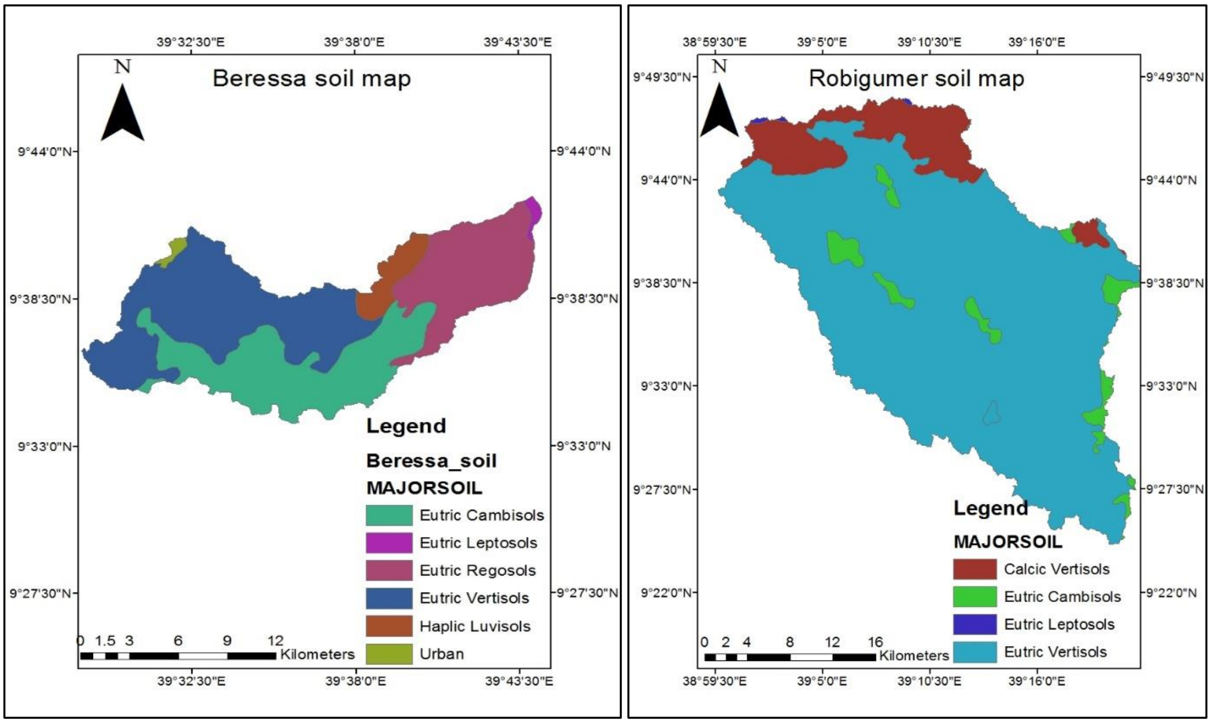

Figure 3: 9 The soil map of study area

3.4.6. Slope map

It is the one and most significant input in Arcswat that derived from a given study area DEM. The slope used to determine the surface steepness and gentless which greatly affect the kinetic energy of the river flow within the watershed. The Arc swat allow to classify the slope up to 5 under multiple slope option. The Beressa and Robigumer watershed used multiple slope category of 3 classes. Both catchments have a majority of steep slope.

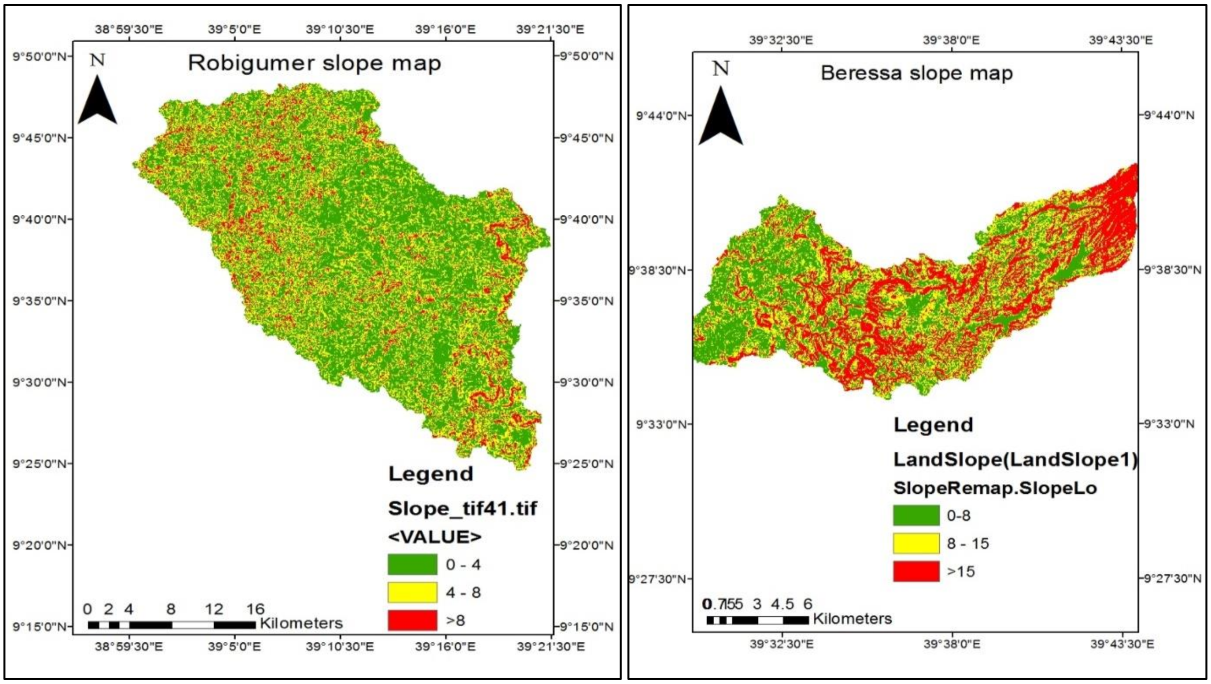

Figure 3: 10 The slope map of study area

After the HRU analysis is performed the final LULC, soil, and sloe was prepared according to swat database. Each unique code represnts a specifc land use on the actual ground.

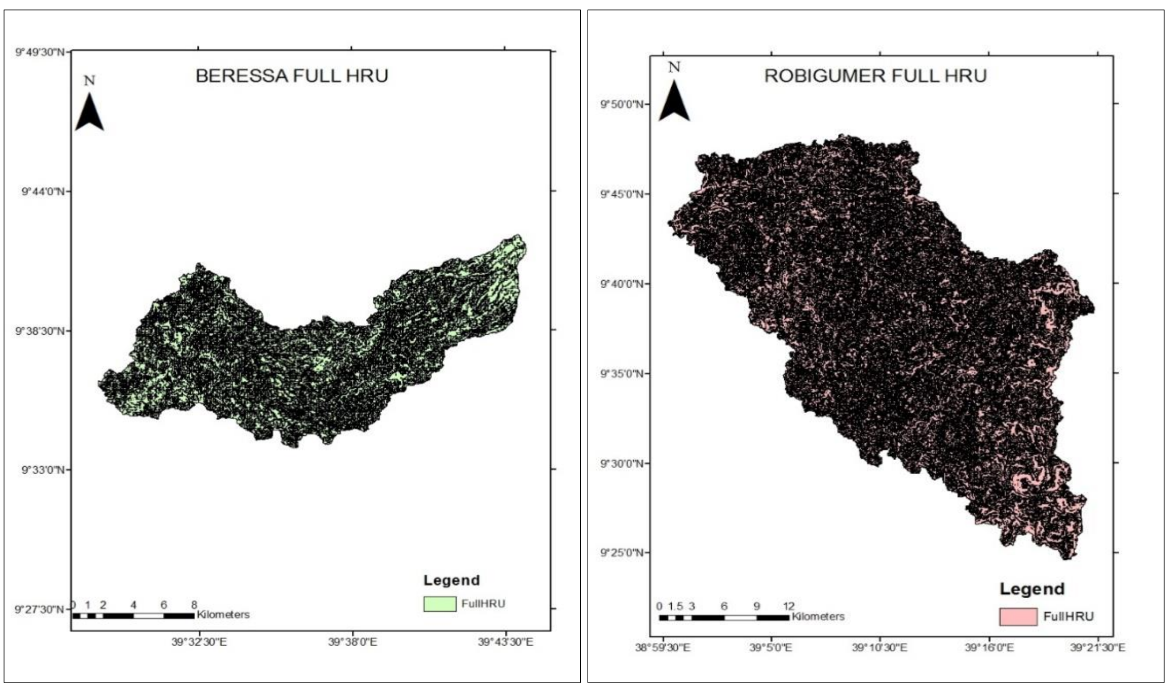

Figure 3: 11 Full hydrologic reponse unit of study area

3.4.7. SWAT hydrological process analysis

The prepared climatic data of all the six climatic station long periods of recorded data in a swat standard format. The data inserted into the swat weather database using the Wather generator swat software package. It helps to calculate and prepare all the necesscary parameters according to the swat database format. The weather generator station manages to fill the other missing climatic data of gauging stations. For both Beressa and Robigumer the weather generator was Debre birhan station that have all the climatic data of long periods of time.

The hydrologic cycle that occurs on the land is processed in SWAT depend on water balance equation is shown below(Neitsch, 2005):

$$SWt = SW0 + \sum(Rday - Qsurf - Ea - Wseep - Qgw) \qquad \text{3.5}$$

Where: -SW_t = final water content of soil (mm)

SW_o = initial water content of soil on day I (mm)

R_{day} = Rainfall amount on day I (mm)

Q_{surf} = Amount of surface runoff on day I (mm)

Ea = Amount of evaporation on day I (mm)

W_{seep} = Amount of water entering the vadose zone from the soil profile on day I(mm)

Q_{gw} = Amount of return flow on day I (mm)

3.4.8. Runoff simulation

SWAT is used to estimate runoff using soil conservation service curve number method (SCS-CN). The equation of SCS-CN is as follows:

$$Q = \frac{(P-Ia)^2}{(P-Ia)+S} \qquad \text{3.6}$$

where: Q = depth of runoff in (mm),

P = effective precipitation in (mm),

Ia = initial abstraction of water in (mm),

S = maximum potential retention. But initial abstraction of water

(Ia) is the function of maximum potential retention S.

Therefore, $Ia = \lambda s$..3.7

where λ= a constant value, usually 0.2 or 0.5 (a value of 0.2 is mostly used).

$$Q = \frac{(P-0.2S)^{2}}{(P+0.8S)}$$ 3.8

The runoff generates when P >0.2S. Depending on soil types, topography and slope of the catchment, and land use practices, maximum potential retention is variables. Therefore, the maximum potential retention of S is correlated with dimensionless parameter curve number expressed in the following equation(Chow et al., 1988; Neitsch, 2005):

$$S = \left(\frac{25400}{CN}\right) - 254$$ 3.9

SWAT manages to estimate evapotranspiration, infiltration and percolation, water balance, interception storage and surface runoff. The potential evapotranspiration (PET) in SWAT model is estimated using the most common known emperical methods. These are Hargreaves, Penman-Monteith, and Priestley-Taylor methods. The pennman-moneith is most accurate and FAO recommends for PET comptuation. The final step in swat model after the above mentioned steps are completed is swat simularion. This is to finalize the setup of input and run the SWAT model. This allows to perform sensitivity analysis, read swat output, manual calibration and save the final result.

3.4.9. Sensitivity analysis

The swat model has numerous parameters that significantly affect the output. Sensitivity analysis is essential before calibration and validation performed. SUFI-2 algorithm has been adopted to identify the sensitive parameters. The highest sensitive parameters which have smaller p-value and larger t-stat will be selected(Aragaw & Mishra, 2022; Gashaw et al., 2017; Singh & Saravanan, 2022; Worku et al., 2021; Worku et al., 2018).

It is a means of identifying the siginficant parameters that used to define and affect the result of the simulated data. The parameters that manages to represent the actual data of the study area physical features and hydrologic elements. The considerable parameters control the value of simulated data with regard to alter and modify the specific ranges. The senstivity analysis is performed in repeated iterative process. After a series of considerable iterations the simulated value be close enough with the observed data. This good fit between the simulated versus observed data is defined by the limit of considered parameters range.

A number of various parameters were taken into the process. After a sreies of iterations have done a few significant parameters identified that manages to give a good fit between the simulated value and observed data. For the Beressa and Robigumer catchments a recommended parameters have selected that have a siginficant relation and representaion with the physical and hydrologic condtion of the study area. Among the large number of parameters taken for both watersheds a few were identifed based on smaller p-value and t-stat.

3.4.10. SWAT parametrization

In SWAT, watershed is divided into HRUs based on elevation, soil, and land use. The parameters are dependent on important influential factors such as: hydrological group, soil texture, land use, elevation, and slope. The sensitivity of each parameter is identified through the global and local analysis based on the t-stat and p-value(Abbaspour, 2013).

In SWAT , most researchers considers the siginificant parameters. These important parameters are CN2 (moisture condition curve number), SOL_K (saturated hydraulic conductivity of the first layer), CH_K2 (effective hydraulic conductivity in the main channel alluvium,mmh^{-1}), ALPHA_BF (baseflow recession constant), GW_REVAP(groundwater 'revap' coefficient), ESCO(soil evaporation compensation factor) and EPCO (plant evaporation compensation factor)(Abbaspour, 2013; Ashine, 2021; Chen & Wu, 2012; Megebo, 2020; Mengasha, 2015; Worku et al., 2017).

The parameters represent the characteristics of the catchment's physical and hydrological conditions. CN2 is the most significant parameter that defines the surface flow of water on different land use conditions, ALPHA_BF affects the speed of flow to the aquifer response to recharge, GW_DELAY is the lag between the time water exits the soil profile and enters the shallow aquifer, SOL_AWC is the difference in soil water content between field capacity and the wilting point. SOL_K links soil water flow rate to hydraulic conductivity(Gholami et al., 2016; Neitsch et al., 2011). OV_N (Manning's "n" value for overland flow) and CH_N2 (Manning's "n" value for the main channel)(Worku et al., 2021). BLAI.plant.dat and GWQMN (threshold depth of water in the shallow aquifer required for return flow)(Mengasha, 2015).SLSUBBSN.hru(average slope length), SURLAG.bsn(Surface runoff lag time)(Megebo, 2020). The parameters conidered in this study in swat parametrization has based on the above conditions and literature(Appendix table 1:6).

3.4.11. Model calibration and validation

Calibration is a mandatory process whereby adjusting and modifying the sensitive parametes to make sure good fit between the simulated and observed data over a sevreal iterative process. The techinique is to ensure that the result obtained from model is enough to predict the actual hydrologic process of a given study area. There are three distinguished methods of calibration. The first and most used one is manual trial and error method that recommended to obtain a good graphical representation of models output with the observed data. While it's strongly requires much time, good knowledge and experieance, indeed difficult task to perform. The automatic calibration method uses a numerical algothim that helps to find the best parameters and optimization of numerical objective function under a series of iterative process. The third method comibines the above two calibration methods.

The SWAT-Calibration Uncertainty Programs (SWAT-CUP) tool developed to bring more The reliability of the calibration and the uncertainty of the prediction are decided of the p-factor to 100% and an r-factor close to zero (Aragaw & Mishra, 2022; Singh & Saravanan, 2022; Tudose et al., 2021). The main function of the interface is to provide sensitivity analysis, calibration and link to SWAT database format. The file exchange is through txt format. The parameters need to link the model input with the measured data that desired to meet the objective function. The parameters are with a set range value used to keep within a resonable value. The objective function is based on R^2, NS, and PBIAS acceptable values. The calibration is performed until the desired objective function is met. The calibration for Beressa and Robigumer is done from 2002-2009 and 1992-2000, respectively. The validation is performed with an independant set of observed data that are not used for the calibration process. The parameters on validation are those used for final calibration without any further adjustment of values. The validation for Beressa and Robigumer is done from the period of 2010-2014 and 2001-2009, respectively.

3.4.12. Model performance evaluation

Model performance evaluation is evaluated with statistical methods, i.e., percentage of bias (PBIAS), Nash–Sutcliffe model efficiency coefficient (NSE), and coefficient of determination (R^2). The NSE varying between − ∞ and 1 and its optimal value is 1. The value from 0.50 to 1 is generally acceptable and 0 value unacceptable performance that means observed data is an enhanced predictor than simulated data. The percent of bias (PBIAS) is a numerical error-index uses to assess model output performance. A negative and positive value indicate overestimation and underestimation, respectively , and zero is the best simulation(Aragaw & Mishra, 2022; Singh & Saravanan, 2022; Tudose et al., 2021).

The performance SWAT model is assessed using statistical criteria. The evaluation techiniques are used to decide wheather the output is enough to predict the actual data. The performance evaluations are various but, the most commonly used within the scientific community are Coeficient of Determination(R^2), Nash-Sutcliffe Effiecency(NSE), and Percent of Bias (PBIAS). The statical criteria used for this study are disscussed below:

Coefficient of Determination (R^2): it indicates how well observed outcomes are replicated by the model. The range of R^2 lies between 0 and 1. A value of 0 means no correlation at all; while 1 means that simulated value is perfectly correlated with the measured data.

$$R^2 = \frac{\sum[\![(Qm-Qs)(Qs,i-Qs)]\!]^2}{\sum(Qm-Qs)^2 \sum_i(Qs,i-Qs)^2} \quad \text{..........3.10}$$

Where:m and s stand for measured and simulated, i is the i^{th} measured or simulated data

Nash-Sutcliffe Effiecency(NSE) : it indicates the efficiency of the model how well the simulated data reprsented and plotted against the measured data. The NSE varying between − ∞ and 1 and its optimal value is 1. The value from 0.50 to 1 is generally acceptable and 0 value unacceptable performance that means observed data is an enhanced predictor than simulated data(Singh & Saravanan, 2022; Tudose et al., 2021).

$$NS = 1 - \frac{\sum_i(Qm-Qs)^2}{\sum_i(Qm,i-Qm)2} \quad \text{..........3.11}$$

Percent of bias (PBIAS): it measures the average tendency of the simulated data to be larger or smaller than the observations. A negative and positive value indicates overestimation and underestimation, respectively and zero is the best simulation(Singh & Saravanan, 2022; Tudose et al., 2021).

$$PBIAS = 100 * \frac{\sum_i (Qm - Qs)i}{\sum_i Qm,i} \text{ ....3.12}$$

Where:m and s stand for measured and simulated, i is the i^{th} measured or simulated data

3.5. Methodology to the water demand analysis in the sub-basin

3.5.1. Water demand analysis

WEAP is structured as a set of five different "views" of your area. The first step in WEAP is define the data set where the supply and demands are located. The catchment is loaded into the WEAP in GIS layer WGS-1984 format. The selected demands are identified based on their priority and connected with the supply by the tansmission link and the demand assumed to be return into the river flow after consumption. The result obtained from SWAT model is inserted in montly time step.

The baseline year of this study is 2022 and projected upto 2035 considering the GTP-II of the country. The default scenario “reference scenario” is built from 2023-2035. WEAP performs a monthly analysis from the first month of the Current Accounts Year through the last month of the Last Year. The model manges to calculate the supply and demand according to the water use data and priority order of the demands. The model first calculate the higher order and then prcoceed to lower one. Each selceted demand is placed on the river line and connected one with other by transmission link.

schematization of the study area is the starting point and central feature of WEAP is its easy-to-use "drag and drop" graphical interface used to describe and visualize the physical features of the water supply and demand system. This helps to add, edit and view the data defined on the selected demands. The data inserted into each demand site according to the type of data required by the demand. The annual water use, consumption, cost and other parameters are added to the demands. Create and link each demand node to manage the supply and demand of the catchment. Transmission links can deliver wastewater outflows from demand sites to other demand sites for reuse. Return flow water that is not consumed at a demand site can be directed to one or more demand site(Sieber & Purkey, 2015).

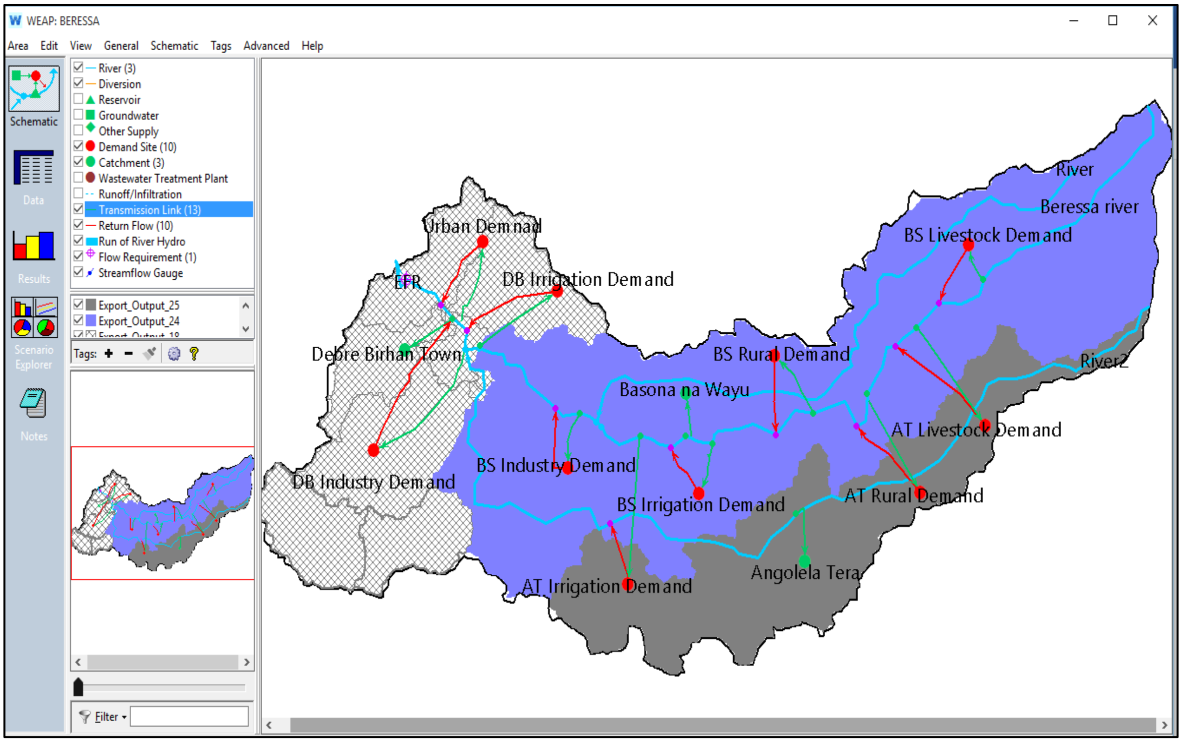

Figure 3: 12 Schematic view of Beressa catchment

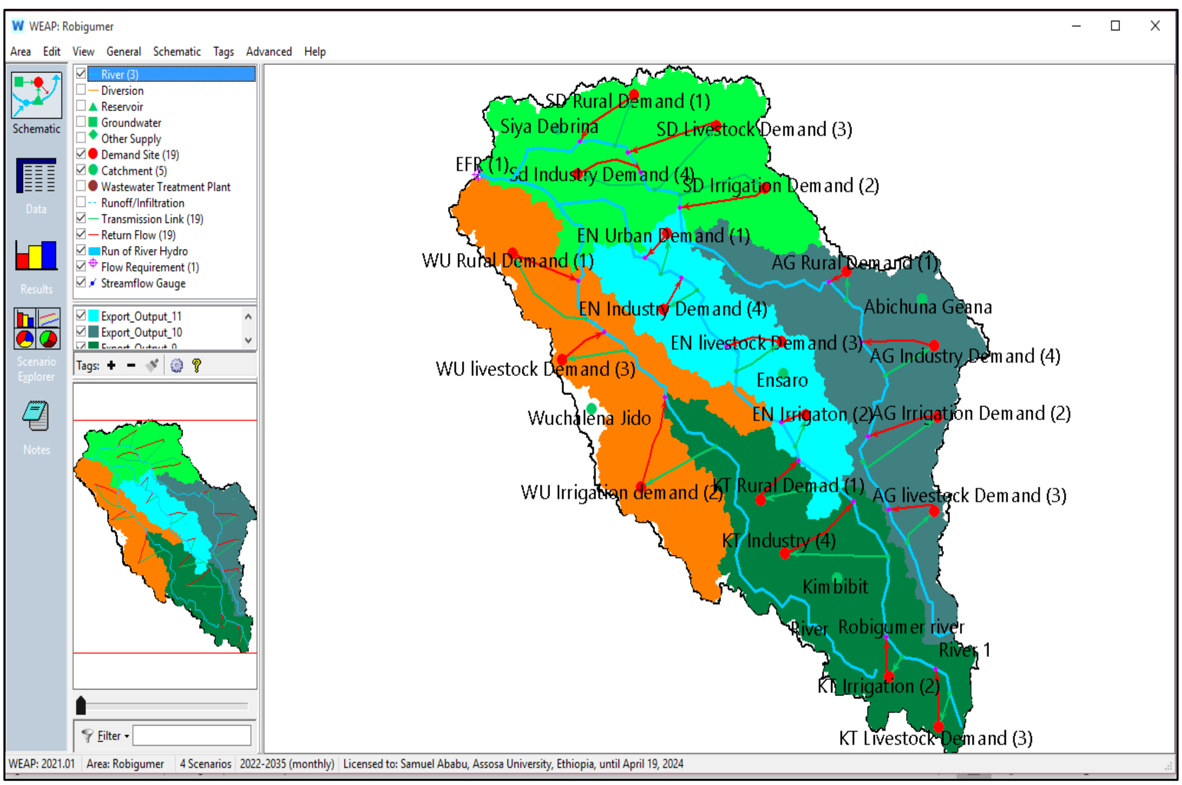

Figure 3: 13 Schematic view of Robigumer catchment

Annual water demand

The WEAP uses a linear programing algorithm in the analysis of the total annual and monthly water demand. A demand site's (DS) demand for water is calculated as the sum of the demands for all the demand site's bottom-level branches. The total activity level is the product of the activity levels in all areas of the catchment(Sieber & Purkey, 2015).

$$\text{Annual water demand} = \sum(\text{Total activity level} * \text{water use rate}) \qquad \text{.............................3.13}$$

Monthly water demand

$$\text{Monthly water demand} = \text{monthly variation} * \text{adjusted annual demands} \qquad \text{...............3.14}$$

Supply requirment

supply requirement is the actual amount needed from the supply sources. The supply requirement takes the demand and adjusts it to account for internal reuse, demand side management strategies for reducing demand, and internal losses(Sieber & Purkey, 2015).

$$\text{Supply requirment} = \frac{(\text{monthly demand}*((1-\text{reuse rate})*(1-\text{DSM}))}{(1-\text{loss rate})} \qquad \text{.......................................3.15}$$

In water demand analysis, the consideresd demands are domestic, livestock , irrigation, industrial and environmental. These demands are considered depend on the current and future trend of socio-economic and environmental changes of the area. The Beressa catchment are within urban and rural areas. The larege area of Beressa catchments is rural areas. The urban area is small and consits of different infrastructures such industry, commerical and residential. The demand analysis is based on the guidelines of Minsitry offices and countrys' growth and transformational plan set for the comming years.

1. Domestic demand

The domestic water demand is water required for all household activities. The major activities are cooking, washing, drinking and hygine. These demands are various and different depending on the life style and standard of the living condtion. The demand is basically affected by the water availability, supply system and socio-economic condtion of the area. The UN reccomends 100l/c/d for all basic domestic activies in standard living condtion. Ethiopia is currently working on water resources development projects to addres the changing demands of country with urbanization, socio-economic and environmetal changes.

Considering the GTP-II of the country the domestic demand analysis is done using 25l/c/d for rural and 50l/c/d for urban areas(Commission, 2016). Since the study area have both rural and uban areas both demand are taken into account. The Beressa catchment is 75% rural and the rest is urban with highly populated and urbanized areas. While, the robigumer catchment is 87% rural areas and urban with low density(CSA, 2020).

Population data

The demographic data is the significant input in demand analysis. The supply delivered to satisfy the basic needs of human beings. In the demography data the population number is basic element that defines the charactersics of humans. The population data is obtained from the 2007 census data of CSA. The poulation data of both catchments are obtained from the woreda statistics. The Beressa catchments is found on Basona wayu(Debri Berhan zuria), Angolela tera, and Debre berhan town. The populatuion data of the Beressa was 268, 510 in 2007 census data. The population number of Robigumer catchment was 398,370. The growth rate of both catchments approximated to is 2.5%. The population is projected to 2035 for both catchments. The projected population estimated by the Geometric method below:

$$Pn = Po * (1 + k)^{n} \qquad (3.21)$$

Where; Po=initial population,

Pn= Population at n decade or years,

n =decade or year

K = percentage (geometric) increase, k=2.5%

Table3: 5 Current and projected population data of study area

Table3: 4 Current and projected population of the study area

Year	2007	2018	**2022**	2025	2030	2035
Beressa	268, 510	352,308	**388,882**	418,784	473,815	536,078
Robigumer	398,370	522,695	**576,958**	621,320	702,967	795,342

Annual Water use rate

Inorder to analyse the demand determing the annual water use rate is a key element in WEAP demand comptuation. So the annual water use rate is estimated by multiplying the projected population with the per capita demand. Based on the MOWE and GTP-Π of the country the per capita demand of urban is 40-100l/c/d depending the socio-economic and life standard of the area(Commission, 2016).

Table3: 5 Per capita per water demand of urban settlement

Town	Population	Per capita per demand
Level- 1	> 1 million	80 l/c/day
Level- 2	1million - 100,000	60 l/c/day
Level- 3	50,000-100,000	50 l/c/day
Level- 4	20,000 - 50,000	40 l/c/day
Level- 5	<20,000	25l/c/day

Therefore, for this study the per capita demand is 25l/c/d for rural and 50l/c/d for urban in both catchments have adopted. The curent estimated population is 388,882and 576,958 in Beressa and Robigumer respectively. The population density of rural areas in Beressa and Robigumer is 75% and 87% respectively(CSA, 2021).

The per capita demand of rural areas is 25l/c/d= 0.025 m^3/d*365=9.13 m^3/c/yr

The per capita demand of urban area is 50l/c/d=0.05m^3/d*365= 18.25 m^3/c/yr

Table3: 6 Annual water use rate of domestic demand

Catchment	settlement	Population	Consumption (%)	Annual per capita (m^3/yr)	Annual water use rate (C_4*C_5) (m^3/yr)	Annual demand (C_3*C_6) (MCM)
Beressa	Urban	97,220	25	18.25	4.56	0.44
	Rural	291,662	75	9.13	6.85	2.0
Robigumer	Urban	75,005	13	18.25	2.4	0.2
	Rural	501,953	87	9.13	7.94	4.0

Therefore, the annual estimated water use rate is 12m^3/yr and 11m^3/yr in Beressa and Robigumer catchments respectively.

2. Livestock demand

Ethiopia is believed to have the largest livestock population in Africa. This livestock sector has been contributing considerable portion to the economy of the country, and still promising to the economic development of the country(CSA, 2021). Ethiopia's livestock population estimated is about 35 million tropical livestock unit (TLU), and on average, one TLU requires about 25 liters of water per day(Bosire et al., 2022; Sileshi et al., 2003). As the demand of the individual animal for water is variable, only the average estimation of water requirements used in a specific climatic environment(Pfeifer et al., 2021; Sileshi et al., 2003). In both catchments the livestock population is significant and plays great role in the livelihood of the areas. The livestock population in both catchments are cattle, sheep, goat, donkey, mule, horses, and camel species.

Assesing the livestock demand is significant element in demand analysis. It provide the needed animal protein that contribute to the improvement of the nutritional status of the people. It plays an important role to earn foreign exchanges to the country. The animals also used in cultivation and transportation. Since both catcments are experiancing an increase rate of graizing land and pasturalis way of life, the analysis of this demand is significant and mandatory. The recent population density is obtained from CSA annual report(CSA, 2021).

Table3: 7 Livestock water demand

Catchment	Livestock	Population number	Conversion factor	Average water requirment (l/d) of TLU	Annual water use (m^3/TLU/yr)	Annual water demand (MCM/yr)
Beressa	Cattle	152,203	0.7	17.5	5.475	0.84
	Sheep/ Goat	282,287	0.1	2.5	0.913	0.26
	Equine	30,371	0.4	10	3.65	0.11
Robigumer	Cattle	261,522	0.7	17.5	5.475	1.43
	Sheep/ Goat	351,762	0.1	2.5	0.913	0.32
	Equine	64,453	0.4	10	3.65	0.24

The estimated annual water use rate of livestock in both catchments is 10.95m^3/TLU/yr. The total livestock population are 464,861 and 677,737 in Beressa and Robigumer, respectively

3. Irrigation water demand

Agriculture is the dominant sector of the Ethiopian economy and its performance is the major determinant of overall GDP growth rate. Rain fed agriculture provides the largest proportion of the total production. However, over the past few decades, irrigated agriculture has become more important. Local farmers, however, had already been practicing irrigation by diverting water from rivers in the dry season for the production of subsistence food crops(Eshete et al., 2020).

The irrigation water requirment (IWR) is determined as follows(FAO, 1998)

IWR = ET crop – Pe..3.16

ET crop = ETo × Kc..3.17

ET_O of the Penman-Monteith method is recommended by FAO to estimate reference ET_O according to FAO from the other calculating methods. The method is applicable wherever possible given that there is enough metrological data. The following equation is used to calculate reference evapotranspiration(Allen et al., 1998):

$$ETo = \frac{0.08\nabla(Rn-G)+\ \gamma\frac{900}{T+273}U2(es-ea)}{\nabla+\gamma(1+0.34U2)} \quad \text{.......3.18}$$

Where: ET_o reference evapotranspiration (mm day^{-1}),

R_n net radiation at the crop surface (MJ m^{-2} day^{-1}),

G soil heat flux density (MJ m^{-2} day^{-1}),

T mean daily air temperature at 2 m height (°C),

u_2 wind speed at 2 m height (m s^{-1}),

e_s saturation vapour pressure (kPa),

e_a actual vapour pressure (kPa),

e_s - e_a saturation vapour pressure deficit (kPa),

∇ slope vapour pressure curve (kPa °C^{-1}),

γ psychrometric constant (kPa °C^{-1})

The estimation of effective precipitation is essential to identify the available rain water which meet the crop water requirement completely or partially.

$$Peff = \left(0.6 * P - \frac{10}{3}\right) \text{ for } P \leq 70/3mm \quad \text{.......... 3.19}$$

$$Peff = \left(0.8 * P - \frac{24}{3}\right) \text{ for } P > 70/3mm \quad \text{.......... 3.20}$$

The crop water requirment and irrigation water requirment was estimated using CROPWAT. There are different types of crops adopted in the area, but the major crops are selected in both catchments according to the area of coverage and production unit. The selected crops grown for dry season only, due the farmers used rainfed system in other seasons. The irrigated area is 11.3% and 4.5% of total catchment area of Beressa and Robigumer, respectively. The irrigation command area in both catchment is gained in woreda scale. The gross irrigation area is 3300ha and 4550ha in Beressa and Robigumer catchments, respectively. The acctual irrigated area is 2390.48ha and 4050ha in Beressa and Robigumer, respectively.

Annual water use rate

Table3: 8 The CWR and IWR of existing irrigation demand of the study area

Catchment	Crop	Irrigated area(ha)	Stage (days)	CWR (mm)	IWR (mm)	Annual demand (MCM)
Beressa	Carrot	500	100	433.7	433.6	2.2
	Potato	400	130	589.1	581.7	2.3
	Garlic	105	145	631.3	623.1	0.6
	Cabbage	85.48	165	759.4	747.6	0.64
	Barley	700	120	497.9	492.2	3.4
	Wheat	600	130	523.1	506	3.0
Robigumer	Carrot	800	100	433.7	433.0	3.5
	Potato	900	130	585.1	581.3	5.2
	Garlic	250	145	654.7	640.0	1.6
	Cabbage	300	165	786.4	758.5	1.9
	Sorghum	1000	125	508.9	477.3	5.2
	Wheat	800	130	467.1	441.1	3.5

The irrigation Demand = Total irrigation command area(ha) x Annual water use rate(m^3/ha). The major irrigation method in the catchments is furrow system.Therefore, the annual water use rate is 4304.9m^3/ha and 5,160m^3/ha in Beressa and Robigumer catchments, respectively.

4. Industrial Demand

The industrial demand is variable due to the type and scale of investment. The industries uses different amount of water depending on the type and manifacturing process of the industry. This demand considered for both catchments. The Beressa consists of various types of indusrty from small to large ones. This industrial demand is estimated on rough estimation considering the experiance of other cities. Lack of proper data on water consumption made it difficult to assess the right demand. The MOWE recomends 5% -10% DW water supply for the sector, depending on the standard and scale of the industries on the area(Andualem, 2020). Considering the development opportunity of the town in the future 10% of the average domestic demand is taken. The estimated annual water use rate expected to be 1.2m^3/yr and 1.1 m^3/yr in Beressa catchment and Robigumer catchment, respectively.

5. Environmental flow requirment(EFR)

The enviromental is the basic element in maintaing and baancing the ecosystem of the area. The study considers this demand as significant in preserving and controling the minimum flow of the river. The ecosystem is collection of different biotic and abiotic lives, this needs a certain amount of flow to sustaion the usual living process. The downstream users also be kept within thier minimum consumption, that helps to facilitate the overall benefit of the watershed and balance the enivironment. The EFR in most studies taken 10-20% of the annual runoff(Ashine, 2021; Harun, 2021; Megebo, 2020; Yates et al., 2005). Therefore, the EFR for Bersa and Robigumer estimated using thier 20% of annual runoff. The EFR is estimated 7.4MCM and 29.81MCM in Beressa and Robigumer cachments respectively.

3.6. Development of sceanrio

The WEAP model allows the user to define and develop different scenarios, the scenario are based on the assumption and consideration of different factors which will affect the demand of the study area within current and future time frames. The scenarios helps to see and analyse the effect and response of the supply for the differnt assumed factors of the demand due to the dymanic socio-economic changes of the study area. The scenario ables the policy maker's and other stakeholders to know and identify the potential and problems of the resources. This makes easy to manage and find the best solution for wateshed managment.

3.6.1. Reference Scenario

This scenario is the intial and most siginficant for the other scenarios too. This scenario accounted the hydrologic, climatic, technological and socio-economic changes for long period of time without any ploicy intervation in the coming years. The reference scenario is taken from the current accont year to the projected to identify the basic trends which will occur on the assumed basic demands. The current account year in the study is 2022, due to the surface water potential be the same throughout the projected years. The refernce scenario assesed from 2023-2035. The basic demands are selected for both catchments according to thier enivronmental condtion. As the name implies the other scenario compared to this scenario for further analysis. This scenario only considers a linear change of population growth of 2.5%. The total poulation in the Beressa and Robigumer are 388,382 and 576,958, respectively.

3.6.2. Scenario one: Projection of population growth

This scenario is developed to asses the effect in the demands by assuming high growth rate in both human and livestock population. The human population is projected in the refernce scenario is using the 2.5% growth rate. The annual growth rate for both domestic users and livestock population is taken as 3.0% and 3.2%, respectively(CSA, 2021). Since the poulation growth affects the overall demand of the area, this makes the scenario imoprtant in determing the impact on the selected demands. The livestock demand is the basic element in this study due to the livelihood economy of the area is depend on livestock production.

3.6.3. Scenario two: Projection of irrigation command area

Irrigation is an essential and necesscary apsect of agricaltural sector to prevail food secutity. Most of the Ethiopian economy is rely on rainfed system, this doesn't satisfy the demand of the scoiety and famine and drought are the problems of most parts of the country. Therefore, develop scenario in this issue is siginificat to know the potential and capcity of the area in accordance with the socio-economic changes will occur in the future. The irrigation command area is projected to be more than double of the existing irrigated area. The anticipation of major irrigation projects will be proposed for the future in the area to solve the critical issues related to food securiy and improvement of livelihood of the society. Therefore, the irrigation demand in both catchments are expected to be 150% and 250% increase according to woreda bureau in Beressa and Robigumer, respectively. The irrigation application effeciency for the employed furrow system will be achieved at its maximum desirable point and advanced irrigation system also be adopted in future time.

3.6.4. Scenario three: Increased domestic demand

Domestic demand is mandatory one that provide the basic human needs for the day to day activities. In this scenario the per capita demand for rural and urban considered as 40l/c/d and 60l/c/d, respectively. This demand is curently have devloped due to different factors related to it. The demand is still high and unable to meet the basic needs of the society. So, without understanding the current and future demand, either the existing or proposed project will not meet their objective. Anlysing the fututre condtion of this demand is critical for the overall growth and development of the study area.

3.7. Methodology

3.7.1. Flow chart of the activites undertaken

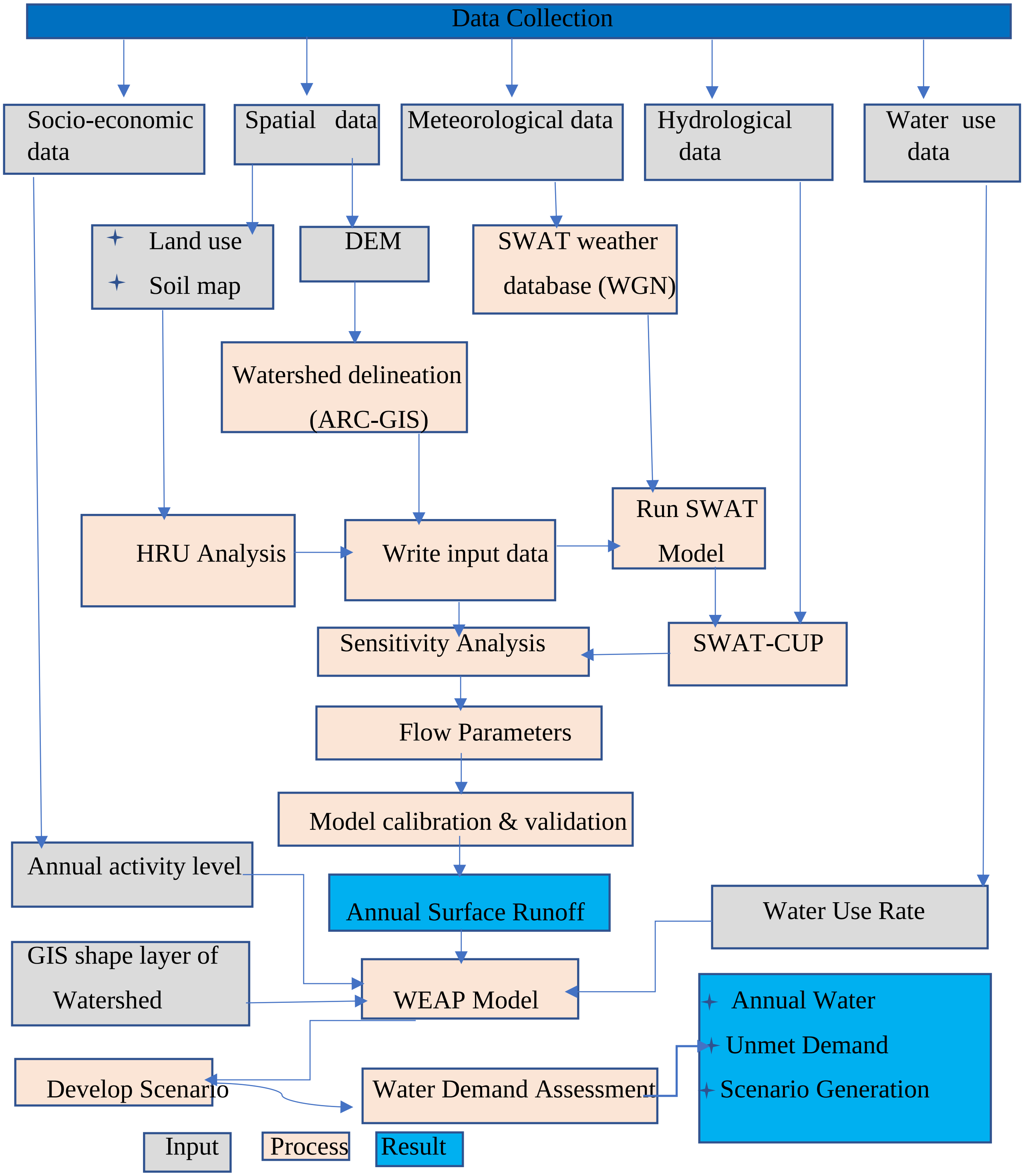

Figure 3: 14 Flow chart representation of the study

4. RESULTS AND DISCUSSION

4.1. SWAT model results

Watershed Delineation

The watershed delineation that performed in Arcswat model gives the result for both Beressa and Robigumer watersheds. The Beressa watershed has 213 sq.km. The elevation ranges from 2742-3662 m.a.s.l. The watershed have 27 sub-watersheds. The Robigmer watershed has an area of 893sq.km. The watershed delineated to 24 sub-watersheds. The catchment's elevation ranges from 2486-3057 with an average elevation of 2656 m.a.s.l.

HRU Analysis

The threshold value of 10%,10%, and 20% was taken for land use, soil, and slope, resectively. The HRU analysis for Beressa is performed and 135 HRU is obtained from the LULC, soil and slope data of the watershed loaded into HRU analysis. The Robigumer watershed has132 HRU.

Table 4: 1 The spatial chatacterstics of study area

Catchment's Name	Land use	Area (%)	Soil	Area (%)	Slope (%)
Beressa	Agricalture->AGRR	78.45	Eutric Vertisols->EuVe	41.43	0-8
	Plantation->FRST	7.35	Eutric Cambisols->EuBe	30.04	8-15
	Baren land->BARR	0.33	Eutric Regosols->EuRe	22.52	>15
	Waterbody->WATR	1.31	Halpic Luisols->HaLu	4.739	
	Urban->URML	7.97	Urban ->Rock	0.59	
	Natural Vegetation->FRSE	0.42	Eutric Leptsols->EuLe	0.6	
	Grassland->RNGE	4.17			
Robigumer	Bushland->WETN	2.05	Calcic Vertisols->CaVe	10.7	0-4
	Moderetly Cultivated->AGRL	57.49	Eutric Vertisols->EuVe	85.38	4-8
	Dominantly cultivated->AGRR	40.35	Eutric Leptsols->EuLe	0.05	>8
	Grassland->RNGE	0.015	Eutric Cambisols->EuBe	3.82	
	Urban->URML	0.09			

4.1.1. Sensitivity analysis

The parameters that used for sensitivity analysis are 23 which seleted from different scientific literature and related to the physical and hydrologic condtion of the study area. Among the 23 parameters a few shows siginificant effect on the simulated output. The significant parameters selected is based on the p and t-stat values. The smaller the p-value the higher sensitive the parameter. The SWAT-Cup is used for the process of sensitivty analysis using the SUFI-2. The first siginificant parameter in Beressa catchment was CN2.mgt, depends mainly on land use and obtained as an important factor in surface runoff generation.The second significant parameter is ALPHA_BF.gw, a direct index of groundwater flow response to changes in recharge. The third parameter (GW-DELAY.gw), it linked with the time to recharge aquifers

Table 4: 2 The significant sensitive parameters of Beressa catchment

Parameter Name	t-Stat	P-Value	Rank	Fitted value	Min. value	Max. value
CN2.mgt	36.58	0.0	1	79.53	35	98
GWQMN.gw	-31.3	0.0	2	447.5	0	5000
GW_REVAP.gw	-13.31	0.0	3	0.2	0.02	0.2
CANMX.hru	-9.71	0.0	4	0.13	0	100
SOL_K(..).sol	6.78	0.0	5	7.26	0	2000
SOL_Z(..).sol	-5.65	0.0	6	243	0	3500
SOL_AWC(.).sol	-4.98	0.0	7	0.16	0	1
ALPHA_BF.gw	4.9	0.0	8	0.75	0	1
GW_DELAY.gw	-4.28	0.0	9	31	0	500
BIOMIX.mgt	-1.24	0.21	10	0.59	0	1
SURLAG.bsn	-0.62	0.54	11	4.21	0.05	24
EPCO.hru	-0.26	0.79	12	0.89	0	1
CH_K2.rte	0.14	0.88	13	2.24	-0.01	500
REVAPMN.gw	0.03	0.98	14	475.75	0	500

The most siginficant parameters in Robigumer catchments are curve number(CN2.mgt), baseflow alpha factor(ALPHA_BF.gw), affects the speed of flow to the aquifer response to recharge, a reduction in the parameter will slow the flow of aquifer response to recharge and reduce the annual runoff peak. (GW_DELAY.gw) expresses the lag between when water pulls out the soil profile and enters the shallow aquifer and treshold depth of water in the shallow aquifer required for return flow to occur (GWQMN.gw), respectively.

Table 4: 3 The significant sensitive parameters of Robigumer catchment

Parameter Name	t-Stat	P-Value	Rank	Fitted value	Min.Value	Max.Value
GWQMN.gw	-22.1	0.0	1	1457.5	0	5000
GW_REVAP.gw	-4.99	0.0	2	0.15	0.02	0.2
SOL_AWC(.).sol	4.05	0.0	3	0.08	0	0.1
CN2.mgt	-3.6	0.0	4	78.61	35	98
ESCO.hru	-3.42	0.0	5	0.75	0	1
ALPHA_BF.gw	0.68	0.0	6	0.83	0	1
SOL_Z(..).sol	2.48	0.01	7	294	0	3500
EPCO.hru	2.25	0.02	8	0.24	0	1
SLSUBBSN.hru	2.21	0.03	9	99.45	10	150
CH_K2.rte	1.07	0.29	10	8.57	-0.01	500
GW_DELAY.gw	-0.94	0.35	11	31	0	500
SOL_K(..).sol	0.86	0.39	12	5.31	0	2000
SOL_ALB(.).sol	-0.09	0.93	13	0.1	0	0.25

4.1.2. Calibration and validation

The calibration is done based on the parameters that obtained from the sensitivity analysis. The siginificant parameters in both catchments are used to perform the calibration. The calibration is performed for several number of iteration until the best fit obtained between the simulated and observed data. some simulated data overestimate the stream flow during high-flow periods and underestimated during low-flow periods. This could be from the parameters considered in swat model and data analysis. The performance evaluation criteria used to identify the best fitted parameters that meet the desired objective function. The NS, R^2 and PBIAS are used to manage the best fitted parameters of calibration process.

Table 4: 4 Model performance evaluation result of Beressa catchment

Goal_type= Nash_Sutcliff No_sims= 1000 Best_sim_no= 674 Best_goal = 8.917168e-001							
Variable	p-factor	r-factor	R^2	NS	$_bR^2$	PBIAS	Calibration period
FLOW_OUT_1	0.76	0.51	0.89	0.87	0.77	2	**2002-2008**

Based on the criteria stated in methodology section, the NS value between 0.8 and 0.9 tells that the model performs well and a value between 0.9 and 1 indicates that the model performs extremely well, and also the range of R^2 lies between 0 and 1 which described how much of the observed data is explained by the simulated. A value of zero means no correlation at all and 1 is desired.

The SWAT model simulated from 1990-2018. Three years of data was used as warm-up periods. The rest of data used for calibration and validation purposes. The stream flow data obtaied from MOWE in 2000 and 2001 shows extreamly large values compared to the other historical data. So using hydrological outlier test the two years of data are in high outlier ,due to that the two years of data excluded from the process. Therefore, the calibration period is done from 2002 to 2008 and the rest for validation purpose.

The Beressa catchement Simulated monthly average flow shows good correlation with the measuered flow. The simulated data and measured flow in Beressa catchment have good correlation with each other. The PBIAS value obtained suggested that Some values of the simulated data are overestimated than the measured data. The graph showed that there are some under estimation and overestimation in the simulated data due to the quality of used data and other parameters taken into the model simulation.

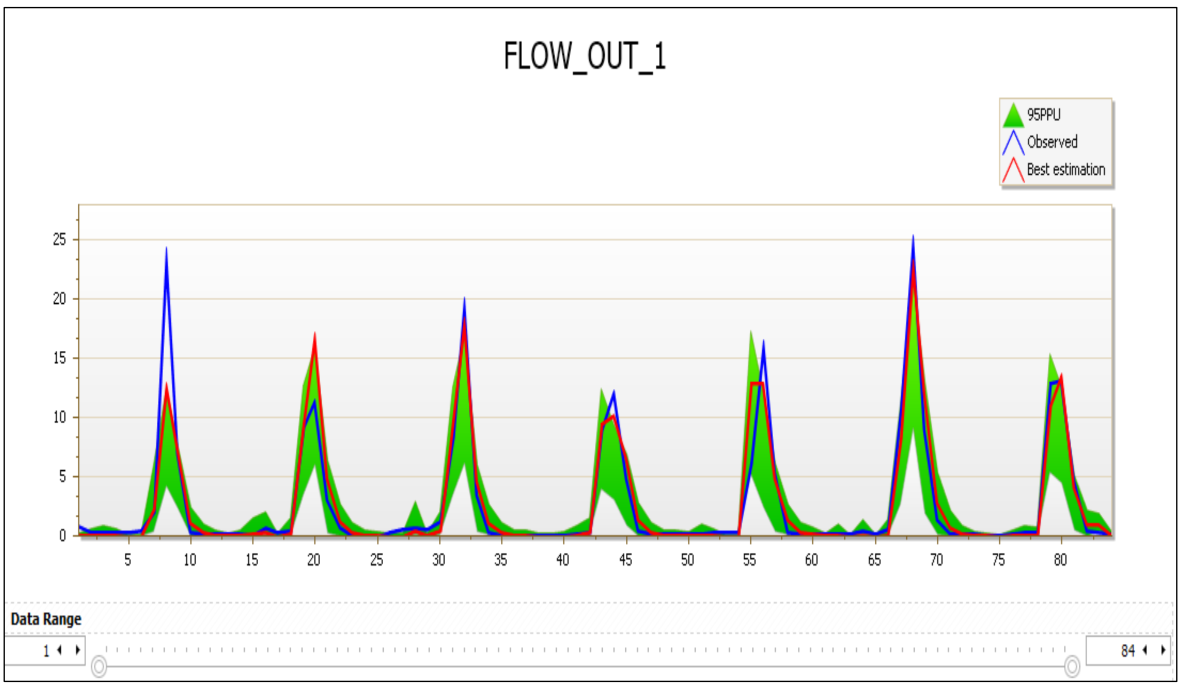

Figure 4: 1 Mean monthly flow of simulated Vs observed data of Beressa Catchment (2002-2009)

The SWAT model simulated for Robigumer catchment was for 29 years of data. Two years of data used for warm-up periods. The other years of data used for both calibration and validation process. The calibration performed from 1992-2001. The higher P-value close 1 is desired that indicates the percent of prediction uncertainity bracketed by 95(ppu). The 80 percent prediction uncertainity is obtained in Robigumer catchment,i.e the observed data bracketed by the 95ppu. The value obtained from the SWAT-Cup after a sries of iterations were 0.76, 0.74 and -15.2 of R^2,NS and PBIAS, respectively. The NS value shows a good aggrement is found between the simulated monthly flow and measured data.

Table 4: 5 Model performance evaluation result of Robigumer catchment

Goal_type= Nash_Sutcliff	No_sims= 1000 Best_sim_no= 5 Best_goal = 7.395548e-001						
Variable	p-factor	r-factor	R^2	NS	$_bR^2$	PBIAS	Calibration period
FLOW_OUT_1	0.8	0.7	0.76	0.74	0.67	-15.2	**1992-2001**

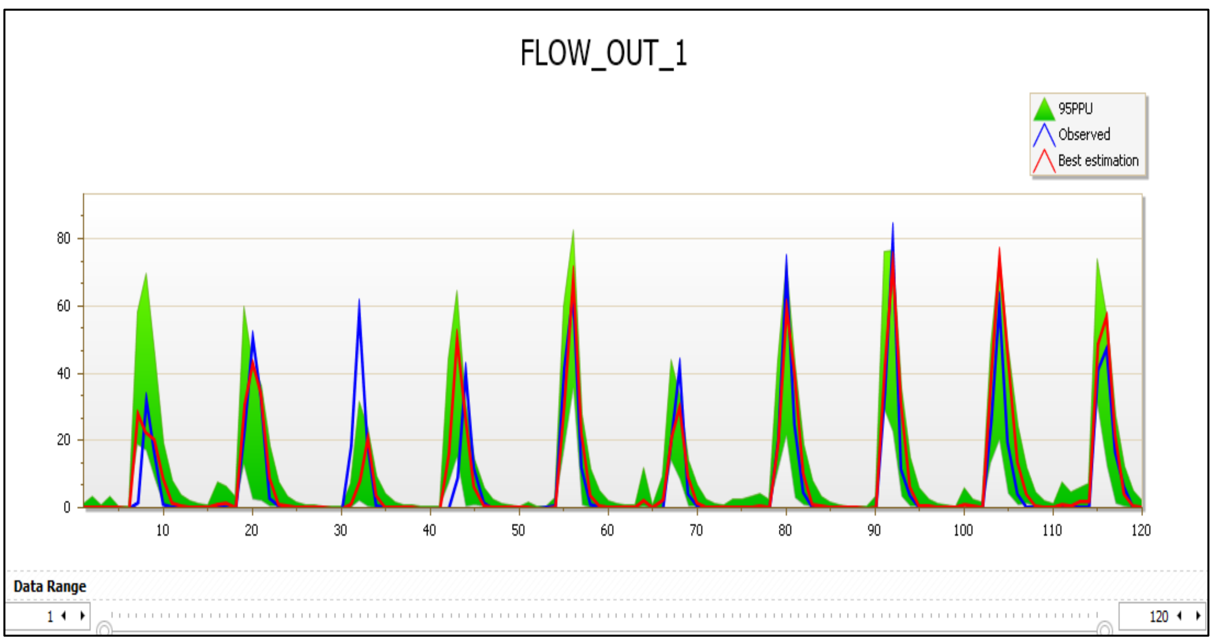

Figure 4: 2 Mean monthy flow of simulated Vs observed data of Robigumer Catchment (1992-2001)

Validation is done with an idependent set of data that have not used for the calibration prcoess. The validation is performed after the calibration is suceesfuly completed. The fitted parameters obtained from the calibration used for the validation too without any adjustment. The significant model performance evaluation criterias are used in validation process to determine the efficency of the SWAT model.

The validation for Beressa catchment is done from 2009-2014. The result obtained from swat-cup indicates that the simulated data is enough to predict the observed data. The three significant performance evalation criterias are within thier good range. A 0.71,0.70, and 0.3 R^2,NS, and PIBAS values obtained respectively that shows good correlation of both datas.

Table 4: 6 Model performance evaluation result of Beressa catchment

Goal_type= Nash_Sutcliff No_sims= 1000Best_sim_no= 847Best_goal = 7.040309e-001							
Variable	p-factor	r-factor	R^2	NS	$_bR^2$	PBIAS	Validation period
FLOW_OUT_1	0.82	0.66	0.71	0.70	0.46	0.3	**2009-2014**

The 82% of observed data is bracketed by the 95PPU. The p-value is close enough to 1 that implies the model result is good. The higher p-value the more the perfection of the model. A value the r-factor close to 0 is highly desirable with a p-factor also close to 1, that implies the better the thickeness of 95PPU and less uncertainity.

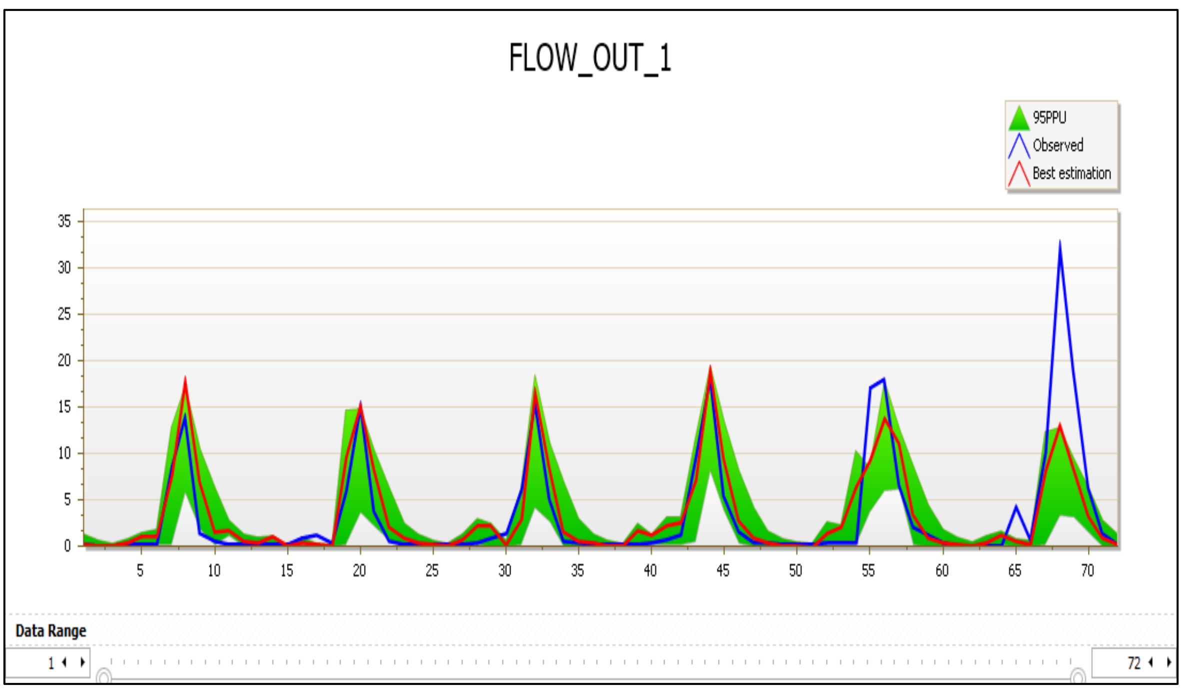

Figure 4: 3 Mean monthly flow of simulated Vs observed data of Beressa Catchment (2009-2014)

From the validation graph there are some under and overestimated values of the model output. This might due the factors taken into the SWAT model. However, the correlation beween the simulated and observed data is good.

Table 4: 7 Model performance evaluation result of Robigumer catchment

Goal_type= Nash_Sutcliff No_sims= 1000Best_sim_no= 154Best_goal = 6.649799e-001							
Variable	p-factor	r-factor	R^2	NS	$_bR^2$	PBIAS	Validation period
FLOW_OUT_1	0.69	0.61	0.72	0.66	0.6431	-13.4	**2002-2009**
Recommended	1	1	>0.6	>0.5	1	±25	

The result obtained from the validation somehow indicates the simulated data is significantly correlated with the observed data. The three values of performance evaluation criteria are within their good range. The 69% of observed data is bracketed by the 95ppu.This implies the model is enough to predict the observed data.

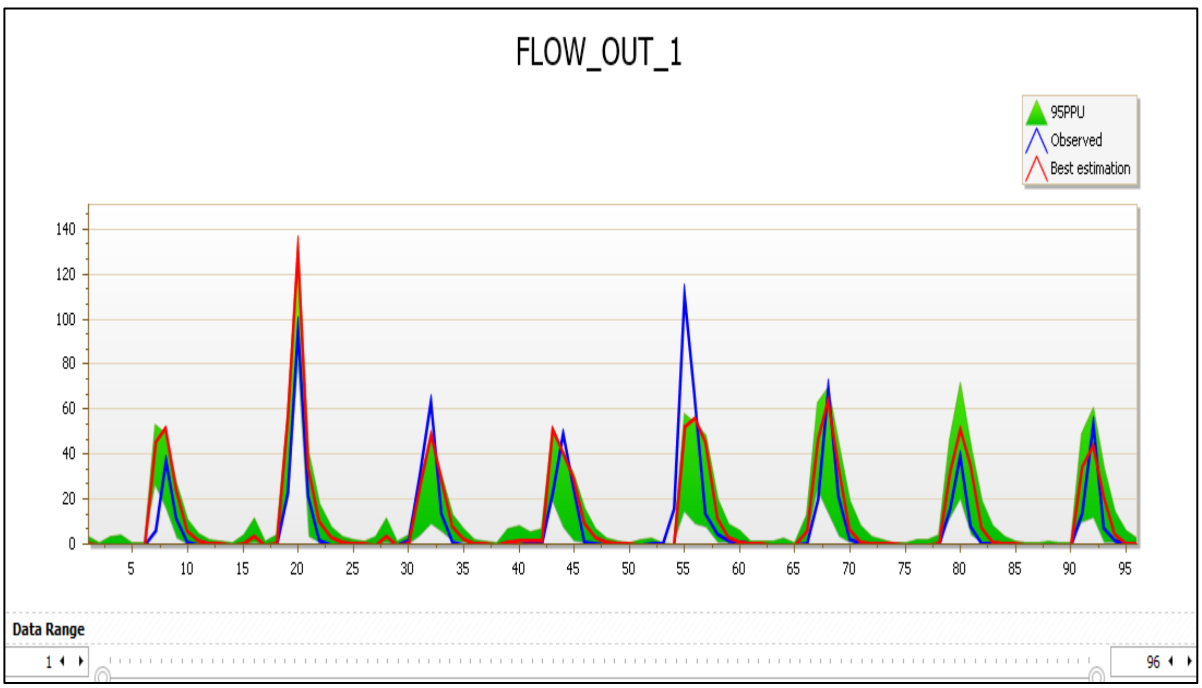

Figure 4: 4 Mean monthly flow of simulated Vs observed data of Robigumer catchment (2002-2009)

4.1.3. Surface water potential result

The SWAT model run after all the above mentioned process sucessufly completed. The best fitted paramters obtained from the calibration process used for rerun the SWAT model to quantify the reliable simulated data.The important hydrologic parameters were identified from SWAT model. The water balance repsentation of flow are soil water mositure content(SWC), evapotranspiration(ET), infiltraion, deep percolation and sufrace runoff. The evapotransipration is the function of crop growth, soil moisture and weather condition of a river catchment. It is the significant factor in hydologic process detemination. The evapotranpiration is primarly depends on air teamprature and soil water content.

According to final SWAT model run from the period of 1990-2018 the Beressa catcment recives an estimated mean annual precipitation of 941.5mm.The estimated mean surface runoff depth from the watershed area of 213km^2 was about 174.4 mm and this generates a total surface runoff voume of the entire area was around 37.2MCM. That implies 18.52% of the mean annual preciptiation falling to the area is converted directly into the surface runoff.

The remainaing precipitated water that infiltrated into the soil layer and percolated to the ground aquifer is 293mm, about 31.11% of annual precipitation recieved on the entire catchment. The percolated water used for ground water recharge and contibutes to the baseflow of the river. The shallow aquifer contibutes to the surface runoff through lateral flow of ground water , about 2.13% of the mean annual rainfall.

The water infilaterd into the soil layer returns to the surface with 278.34mm amount. A significant amount of water deep percolates to recharge the aquifer with an amount of 14.65mm. The Beressa catchment lost 48% of precipitated water through evapotranspiration process,i.e the evapotranspiration hydrologic parameter is significant factor in the Beressa catchment. The total water yield estimated as 10.83 MCM of the collective flow of surface, lateral, shallow aquifer, and minus losses in the catchment.

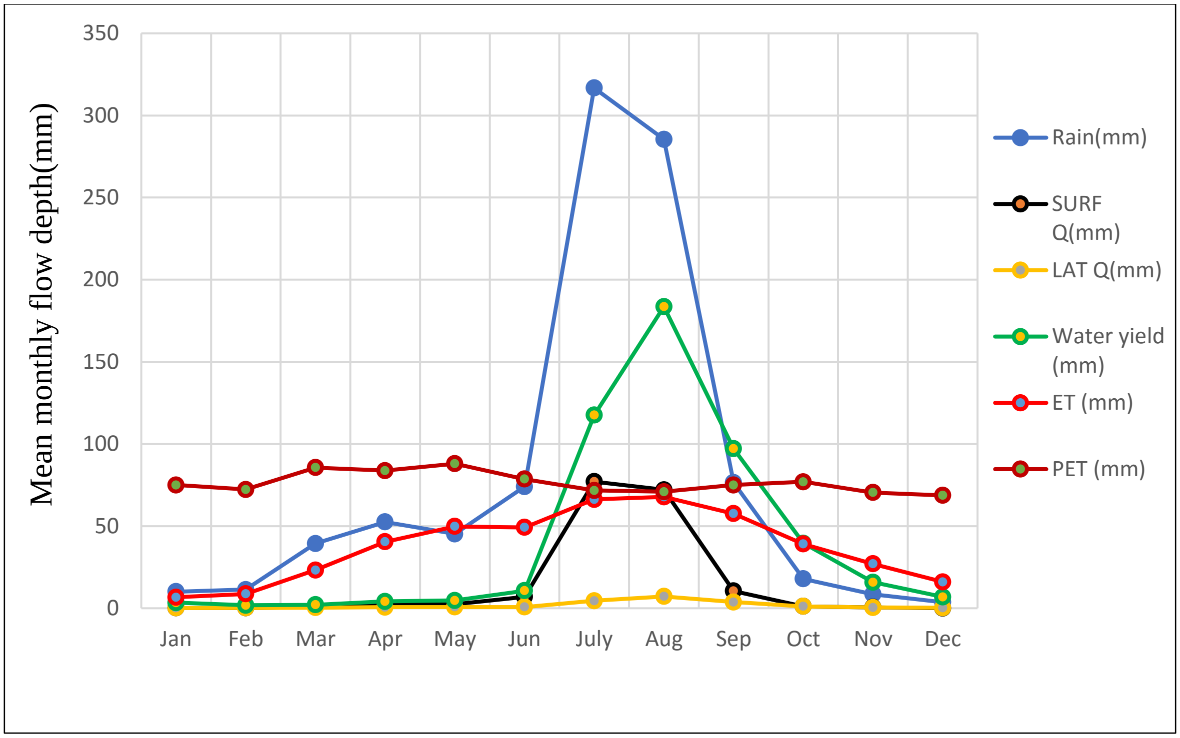

Figure 4: 5 Mean monthly water balance of Beressa catchment

The maximum surface runoff volume occured in July(16.26MCM),and August(15.22MCM) months.While, the minimum flow was in December(0.004MCM), January(0.032MCM), and Febrauary(0.038MCM), respectively. Since the kirmet season(June- September) in Ethiopia is charaterized by high rainfall intensity and cold teamprature. The rain falling to the surface more of converted to direct surface runoff, due to less evapotranspiration rate. While the bega season(October-Febraury) well known with high teamprature and evapotranspiration. The surface runoff obtained from the rainfall was minimum due to the water lost through evapotranspiration.

The Robigmuer catchment simulated from 1990-2018. After all the calibration and validation sucessfuly completed and the best fitted parameters have identified, then the SWAT model was retrun to obtain the reliable simulated data. The volumetric surface water potential of the Robigumer catchment was 149.05MCM. The lateral flow contributed to the suraface runoff was 10.82MCM and the water lost through evapotransipiration was 374.1MCM, about 43% of the precipitaton. The water that infiltrated the soil layer accounts to 337.43MCM. The infiltrated water that deep percolates to the aquifer to recharge the ground water was 16.87MCM. The mean annual rainfall over the river catchment was 976.4mm depth.

The maximum surface runoff occurred in July(67.56MCM) and August(56.68MCM). While January(0.036MCM) and December(0.13MCM) months are the minimum surface runoff volume recorded. These months are experianced with high evapotranspiration rate and low or no precipitation rate. the increase of temprature and decrease of precipitation results a reduction in surface water volume. the belg seasons showed relatively better increment in surface volume than dry periods. The Robigumer catchment have moderate to cold weather condtion and recivied a moderated amount of average annual rainfall.

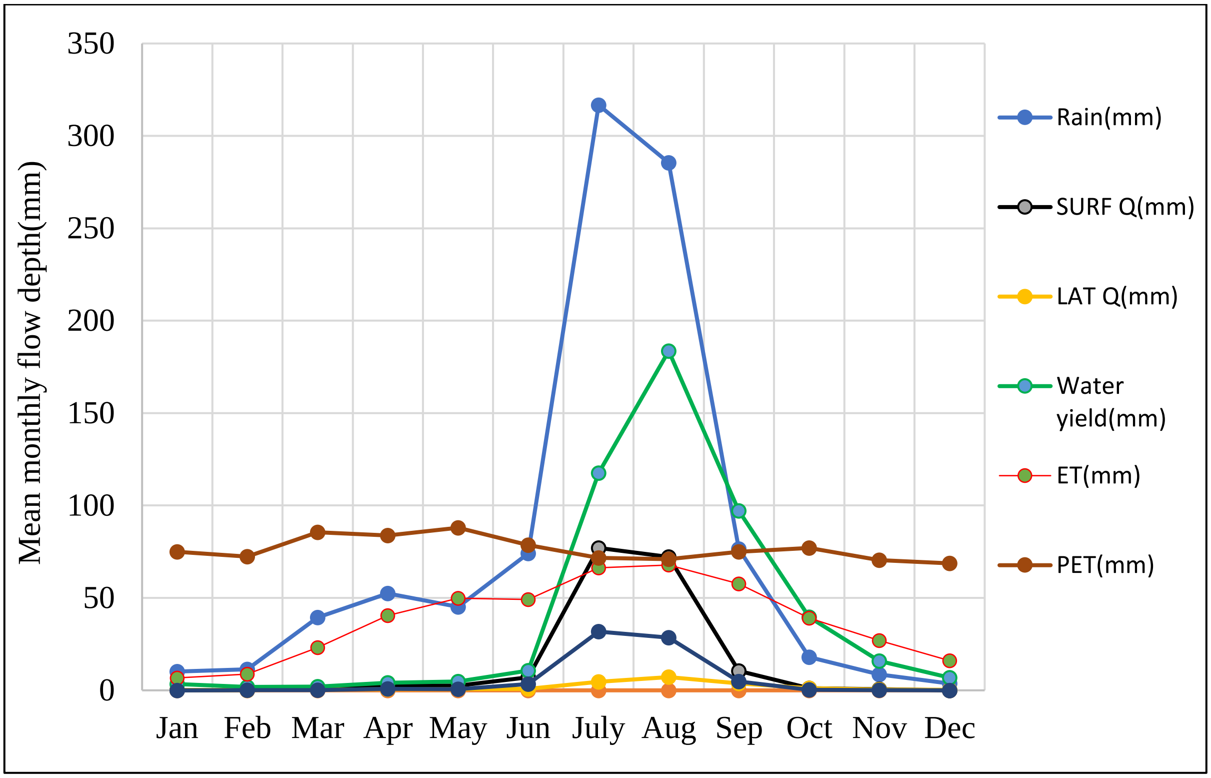

Figure 4: 6 Mean monthly water balance of Robigmer catchment

4.2. Demand analysis results

4.2.1. Current account water demand

The water demand analysis is done on current account year of 2022, this is because the surface water potential quantified assumed to be constant throughout the entire projected years. The Beressa catchment have high urban socio-economic activities relative to Robigumer catchment. The Beressa catchment subdived into three(Debre birhan town, Basona na Wayu, and Angolela tera) and Robigumer catchment divided into Five (Siya Debrina, Abichu Genna, Ensaro, Wuchalena Jido, and Kimbibit) sub-catchments.

In Beressa catchment the total annual water demand estimated to be 10.45MCM(28.24%) of the surface water potential. The maxium demand showed in Basona na Wayu sub-catchment estimaed as 7.17MCM(68.6%) of the total annual demand in Beressa catchment. The livestock demand revealed as the leading demand of all demands in the sub-catchments. The total consumptive demand estimated to be 2MCM(19.13%) and 0.41MCM(0.04%) in Angolela Tera and Debre Birhan Town of the total annual current demand in the catchment, respectively. The EFR of Beressa catchment is 7.4MCM(20%)of the total surface water potenial of Beressa river. The total water demand with EFR in the base period assessed as 17.85MCM(48.2%)of the total surface water potential of Beressa river.

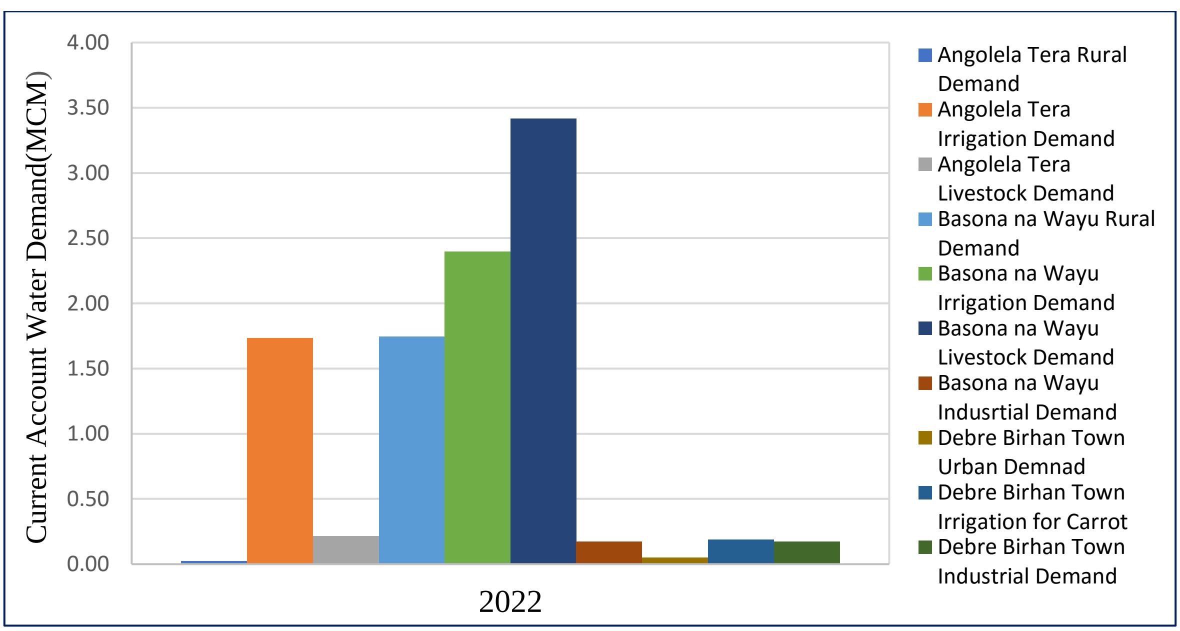

Figure 4: 7 Current account annual water demand in Beressa catchment

The estimated water demand to be 1.8MCM(22.22%), 0.64MCM(7.9%), 1.76MCM(22.2%), 2.4MCM(29.63%), and 1.43MCM(17.6%) in Abichu Genna, Ensaro, Kimbibit, Siya Debrina, and Wuchalena Jido of the total current account annual water demand, respectively.The Robigumer estimated total annual demand in the baseline year of 2022 as 8.1MCM(5.4%) of the total surface water potenial of Robigumer catchment. The irrigation demand showed high value in each demand site. The maximum estimated irrigation demand showed in the three large demand site of the catchment with 1.06MCM. Since the catchment majorly experienced with pasturalist and rural living way of life, the livestock and rural demand have significant demand in most sites. The maximum livestock demand and rural demand estimated about 0.7MCM and 0.63MCM in Siya Debrina site, respectively.

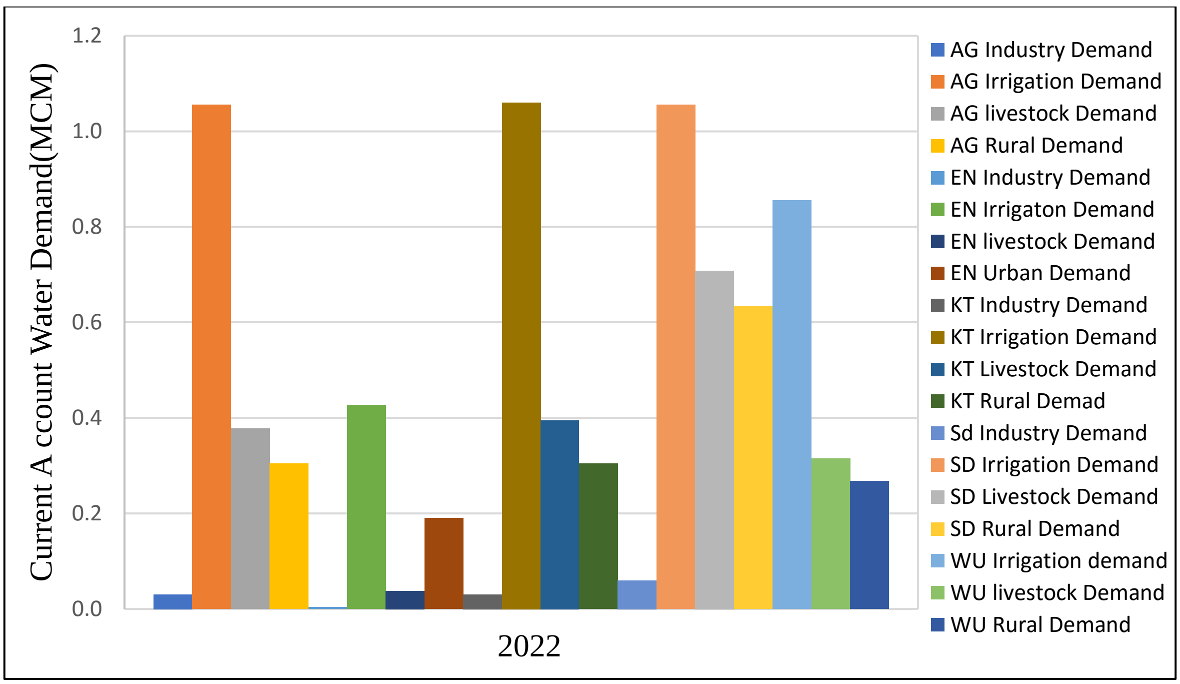

Figure 4: 8 Annual total water demand in 2022 of Robigumer catchment

4.2.2. Reference scenario(2023-2035)

This scenario is the important scenario in identifying the demands from the current year of 2022-2035. This scenario takes only the change of population growth without considering the changes in policy and other demands of the area. The scenario developed with the constant population growth of 2.5% in both catchments according to the CSA cenus report. The per capita demand of rural and urban domestic demand considered of GTP-II are 25l/c/d and

50l/c/d, respectively. From the accounted demands the annual water use rate of Beressa and Robigumer catchments estimated 4.3Mm^3/yr and 5.75Mm^3/yr, respectively. The other demands assumed to be constant through out the reference period due to no significant policy measure would be taken.

Table 4: 8 Total projected water demand of reference scenario in Beressa catchment

Year	Angolela Tera			Basona na Wayu				Debre Birhan Town			Sum (MCM)
	Irrigation	Livestock	Rural	Industry	Irrigation	livestock	Rural	Industry	Irrigation	Urban	
2023	1.73	0.21	0.02	0.17	2.40	3.42	1.82	0.05	0.19	0.54	10.55
2024	1.73	0.21	0.02	0.17	2.40	3.42	1.89	0.05	0.19	0.57	10.65
2025	1.73	0.21	0.02	0.17	2.40	3.42	1.97	0.05	0.19	0.60	10.76
2026	1.73	0.21	0.02	0.17	2.40	3.42	2.05	0.05	0.19	0.63	10.87
2027	1.73	0.21	0.02	0.17	2.40	3.42	2.13	0.05	0.19	0.66	10.98
2028	1.73	0.21	0.02	0.17	2.40	3.42	2.21	0.05	0.19	0.69	11.10
2029	1.73	0.21	0.03	0.17	2.40	3.42	2.30	0.05	0.19	0.73	11.23
2030	1.73	0.21	0.03	0.17	2.40	3.42	2.40	0.05	0.19	0.76	11.36
2031	1.73	0.21	0.03	0.17	2.40	3.42	2.49	0.05	0.19	0.80	11.50
2032	1.73	0.21	0.03	0.17	2.40	3.42	2.59	0.05	0.19	0.84	11.64
2033	1.73	0.21	0.03	0.17	2.40	3.42	2.70	0.05	0.19	0.88	11.78
2034	1.73	0.21	0.03	0.17	2.40	3.42	2.81	0.05	0.19	0.93	11.94
2035	1.73	0.21	0.03	0.17	2.40	3.42	2.92	0.05	0.19	0.98	12.10

In this scenario the result shows the Basona na Wayu livestock demand is the major demand with 3.42MCM (28.3%) of the total water demand 12.1MCM in the projected year 2035. The 2035 total estimated demand in including both the EFR and consumptive demands in the catchment is 19.4MCM(52.4%) of the total surface water potential of Beressa river. In refernce scenario, the total estimated annual water demand in Basona na Wayu, Angolela Tera, and Debre Birhan about 8.91MCM(73.6%), 2.11MCM(17.4%), and 1.22MCM(10%) of the total demand in Beressa catchment, respectively. The irrigation demand also the major demand in each projected year of sub-catchments, even if no major change was considered in the major crops and irrigation area. The domestic demand have significant factor with respect to industrial demands in more urban area of the sub-catchments. This scenario showed the siginficant effect of human population growth in the domestic demand. So, this helped to identify the possible solution to escalating demand due to population growth.

Table 4: 9 Total annual water demand of Robigumer catchment in Refercnce scenario

Demand Site	2023	2025	2030	2033	2034	2035
Abichuna Geana						
Industry Demand	0.03	0.03	0.03	0.03	0.03	0.03
Irrigation Demand	1.06	1.06	1.06	1.06	1.06	1.06
livestock Demand	0.38	0.38	0.38	0.38	0.38	0.38
Rural Demand	0.32	0.36	0.47	0.55	0.58	0.62
Ensaro						
Industry Demand	0.02	0.02	0.02	0.02	0.02	0.02
Irrigaton	0.43	0.43	0.43	0.43	0.43	0.43
livestock Demand	0.04	0.04	0.04	0.04	0.04	0.04
Urban Demand	0.20	0.23	0.32	0.38	0.41	0.44
Kimbibit						
Industry Demand	0.04	0.04	0.04	0.04	0.04	0.04
Irrigation Demand	1.04	1.04	1.04	1.04	1.04	1.04
Livestock Demand	0.40	0.40	0.40	0.40	0.40	0.40
KT Rural Demad	0.32	0.36	0.47	0.55	0.58	0.62
Siya Debrina						
Industry Demand	0.06	0.06	0.06	0.06	0.06	0.06
Irrigation Demand	1.08	1.08	1.08	1.08	1.08	1.08
Livestock Demand	0.71	0.71	0.71	0.71	0.71	0.71
Rural Demand	0.67	0.75	0.98	1.15	1.22	1.28
Wuchalena Jido						
Irrigation demand	0.86	0.86	0.86	0.86	0.86	0.86
livestock Demand	0.31	0.31	0.31	0.31	0.31	0.31
Rural Demand	0.28	0.32	0.41	0.49	0.51	0.54
Sum(MCM)	**8.21**	**8.42**	**9.06**	**9.54**	**9.72**	**9.97**

In the Robigumer catchment the reference scenario revealed, the Siya debrina rural demand showed the maximum estimated demand as 1.28MCM compared to other demand site in the projected year 2035. The total annual water demand in 2035 projected year estimated to be 2.1MCM, 0.93MCM, 2.1MCM, 3.13MCM, and 1.71MCM in Abichu Genna, Ensaro, Siya Debrina, and Wuchalena Jido, respectively. The total consumptive demand with EFR estimated about 39.87(29.67%) of the surface water potential of the Robigumer catchmet. The reference scenario in this catchment is developed considering 2.5% population growth and no policy change will occur through the entire projected years. The domestic demand showed significant change in the projected year 2033 and respective years. That makes it the significant demand in the catchment that directly linked to the change of population density and anthropogenic activities.

4.2.3. Scenario one: Projection of population growth

This scenario is the analysis of the significant imact of poulation growth of both domestic users and livestock. The growth of these two major elelemnts in the area affects the supply system and demand management. The population growth rate of 3% and 3.2% takes into cosideration for domestic users and livestock poulation in accordance to the recent annual report of CSA, repectively. The population growth rate considered on the basis of current and future socio-economic activities and changes occured in the area.

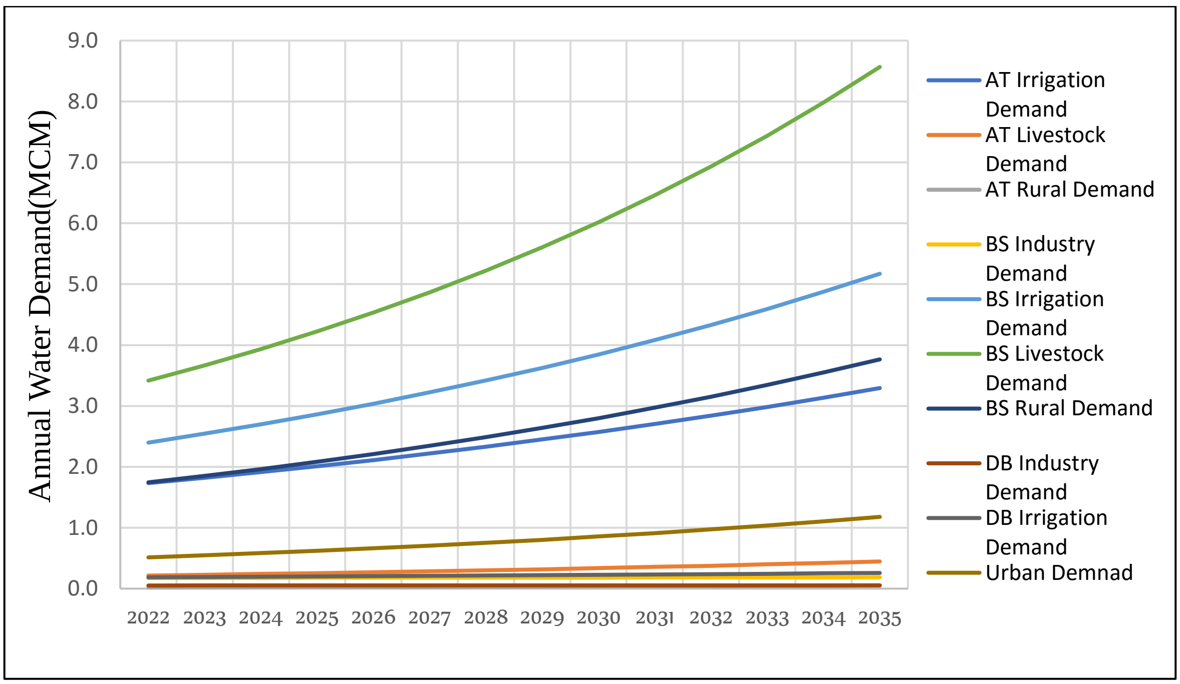

Figure 4: 9 Annual total water demand of Projected population growth in Beressa catchment

The scenario shows how the population growth of both domestic users and livestock affects the supply system. In this scenario, the Basona na Wayu livestock demand showed tremendous increment from 3.42MCM to 8.57MCM in 2035. That makes it the livestock demand the major demand compared to other demands. The livestock demand estimated about 37.3% of the total water demand of 23.5MCM in the year 2035. The total estimated annual demand to be 17.5MCM(76%), 3.79MCM(16.5%), and 1.5MCM(6.5%) of the total annual water demand of 2035in Basona na Wayu, Angolela Tera, and D/Birhan, respectively. In this scenario, both urban and rural demand showed radical changes compared with the reference scenario total demand. The growth rate of domestic user and livestock population revealed that significant effect of rapid population growth, socio-economic and urbanization on the supply system. The scenario gave basic understanding on how to satisfy the water demand of growing livestock population for the significant interest to engage on livestock production and related activities. This indeed makes easy to manage the future conditon of the demand and potenial of the catchment related to livestock production. Since the livelihood in the area is depend on livestock and pasturalist way of life and understanding the effect is mandatory. The total estimated demand considering EFR as 30MCM(82%) of the supply capacity in the projected year 2035.

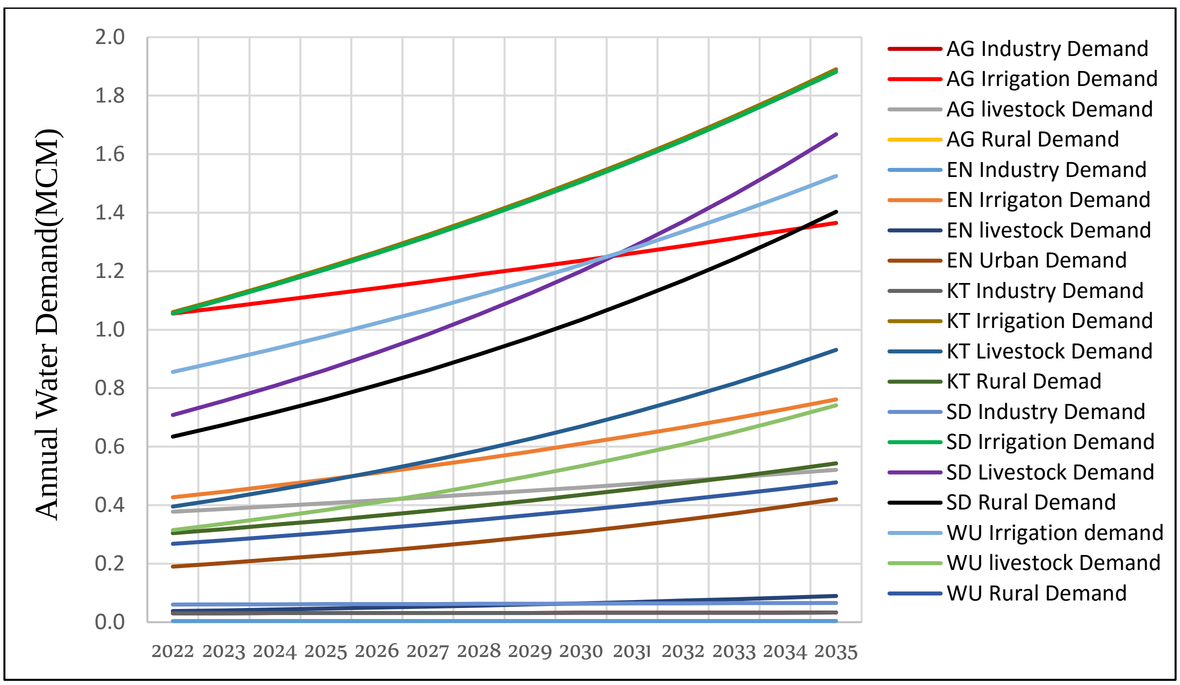

Figure 4: 10 Annual total water demand in projected popualtion growth of robigumer catchment

In this scenario, the Siya Debrina irrigation demand revealed as the maximum demand of all demands in other demand site with estimated value of 1.88MCM in 2035 projected year. The total annual water demand in Abichu Genna, Ensaro, Kimbibit, Siya Debrina, and Wuchalena Jido estimated as 2.43MCM(16.2%), 1.2MCM(7.95%), 3.36MCM(22.6%), 4.95MCM(33.3%), and 2.74MCM(18.4%) of the total water demand of 2035, respectively. The maximum livestock and rural demand showed in Siya Debrina demand site estimated as 1.64MCM and 1.4MCM, respectively. The total annual demand with EFR estimated about 44.6MCM(29.8%) of surface water potential.

4.2.4. Scenario two: Projection of irrigation command area

This scenario helps to identify the future proposed irrigation projects effect and response of the catchments surface water potential. The increase in command area from the exising irrigated area will clearly shows how the area will able to manage drought and food insecurity. Even if the study catchments get significant amount of rainfall during rainy and wet season, adopting irrigation in dry period enable to increase yield and enhance economic status and statisfy food security. Considering such scenario help to know the future effect and result of agriculture with the changing socio-economic and environmental changes. The scenario takes into account significant expansion of the irrigation area from the base line account year of 2022 irrigated area for both catchments. Since the irrigation demand depends on the type of crop and system of irrigation, the best possible assumption is considered in this scenario. The irrigation command area in Beressa catchment projected to 150% of the catchment's actual irrigated area and able to achieve the best irrigation application efficency of above 70% to the adopted furrow irrigation system and future advanced system be employed.

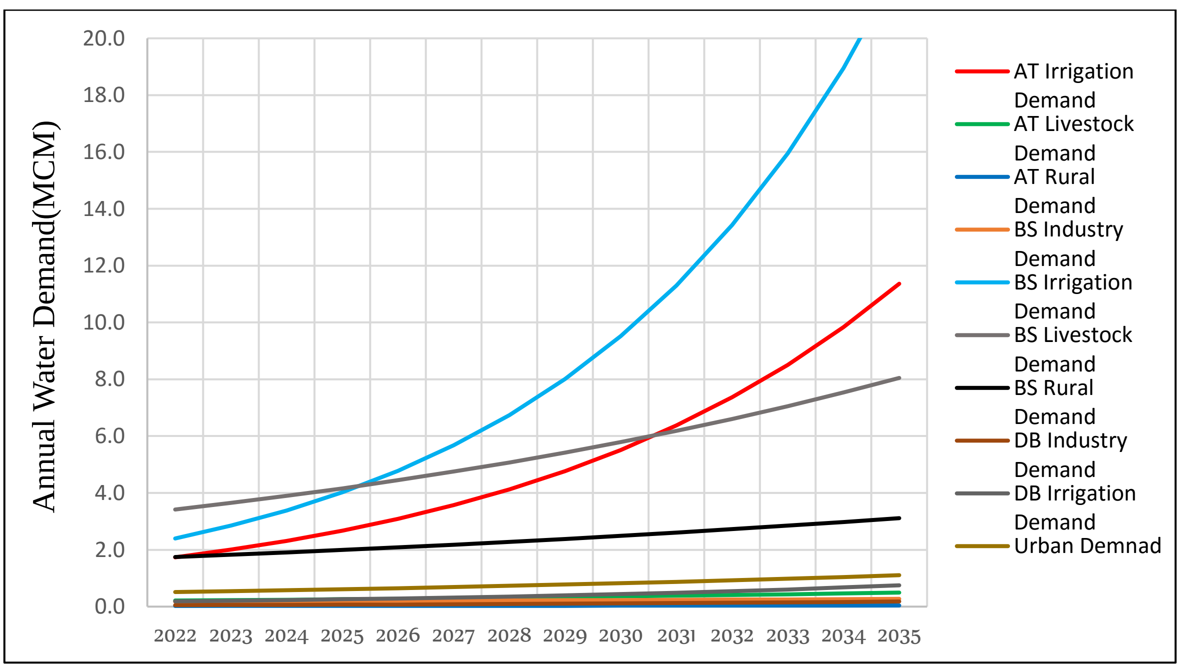

Figure 4: 11 Total annual water demand of projected irrigation area in Beressa catchment

The scenario showed that a tremendous increment of irrigation demand in each projected year. The Basona na Wayu irrigation demand showed the highest demand of the total demads in the catchment an estimated amount of 22.55MCM(46.9%) of the total water demand 48.31MCM in 2035. The total annual water demand estimated to be 33.7MCM(70.5%), 11.8MCM(24.6%), 2.3MCM(4.8%) in Basona na Wayu, Angolela Tera, and D/Birhan sub-catchments of total annual water demand of 2035, respectively. The Angolela Tera irrigation demand increment revealed that there should be some advancement on the irrigation system, palnted crops and appliction efficieny in order to manange the substaintial effect of demand on the supply system. Since the total water demand including EFR is 55.2MCM in 2035, which is beyond the potential of Beressa river. Therefore, the projection of irrigation area and other considered demands are unmet by the surface water potential in the projected years of 2034 and 2035. The estimated unmet demand estimated as 3.8MCM and 10.5MCM in the 2034 and 2035, respectively. This would cause an imbalance of supply and demand, which will negatively affect the envirnoment.

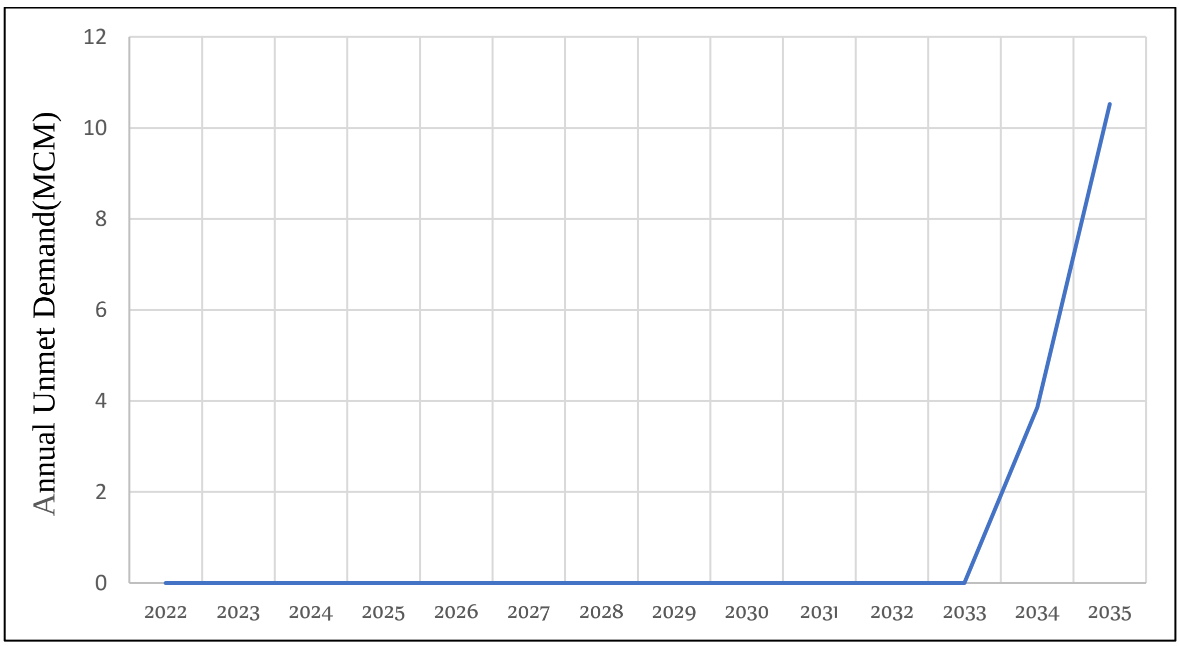

Figure 4: 12 Unmet demand of projected irrigation area in Beressa catchment

The irrigation demand showed radical change in Robigumer catchment with a considereable assumed irrigable land of 250% of the total acctual irrigated catchment's area. The estimated irrigation demand estimated about 121.65MCM(96.8%) of the total annual water demand in the 2035. This makes the irrigation demand the significant element in all demand site of Robigumer catchment. The maximum irrigation demand showed in Siya Debrina with 35.7MCM compared to other demand site. The total annual water demand estimated to be 32.48MCM(25.85%), 2.9MCM(2.3%), 29.16MCM(23.21%), 37.3MCM(29.69%), and 23.55MCM(18.74%) in Abichu Genna, Ensaro, Kimbibit, Siya Debrina, and Wuchalena Jido of the total annual water demand of 2035, respectively. In this scenario, the estimated total annual water demand to be 125.64MCM(84%) of total surface water potential.

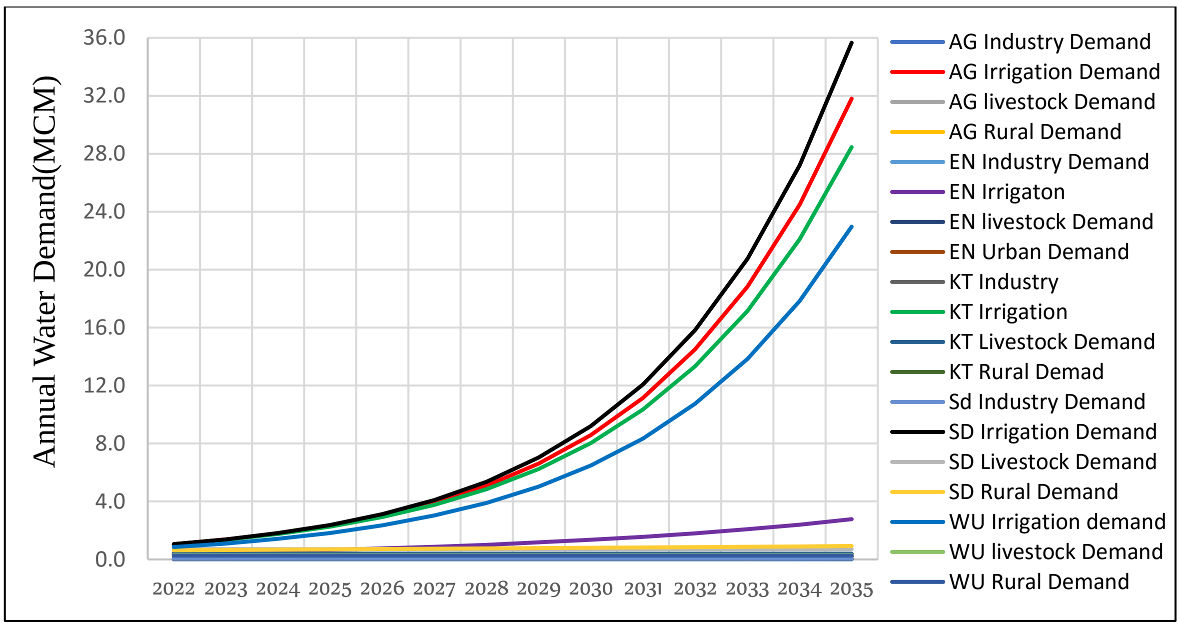

Figure 4: 13 Total annual water demand of projected irrigation area in Robigumer catchment

4.2.5. Scenario three: Projection of domestic demand

This scenario is taken to demonstrate the future condtions of the study area due to the changes of enviromental, living standard and urbanization effect of the future time. Since most of the rural area now adays are changed into urban related to the drastic socio-economic and environmental changes. This scenario considers the rural and urban demand of both catchments 40l/c/d and 60l/c/d, respectively. The domestic demand is the basic element in this scenario, the demand showed significant increment in each projected years. This scenario takes into account the change in per capita demand of urban and rural area considering the effect of urbanization, living standard, socio-economic and environmental changes. The scenario identify the essential impact of projected domestic demand in the future trend of the surface water potential of Beressa river. The considered demands in the projected years increased in tremendous way and results water stress in the catchment.

The per capita demand of rural areas is 40l/c/d= 0.04 m^3/d*365=14.6 m^3/c/yr

The per capita demand of urban area is 60l/c/d=0.06m^3/d*365= 21.9 m^3/c/yr

Therefore, the annual water use rate of 16.5m^3/yr and 15.73m^3/yr in Beressa and Robigumer catchment respectively.

In this scenario, the Basona na Wayu irrigation demand considered as the leading demand with estimated amount of 17.33MCM(40.1%) of the total estimated demand in 2035 in Beressa catchment. The estimated total water demand in Basona na Wayu about 31.44MCM(72.8%), Angolela Tera is 8.5MCM(19.7%), and D/Birhan about 3.11MCM(7.2%), of the total water demand of 43.15MCM of 2035. The total water demand in the projected year 2035 to be 50.55MCM considering both consumptive and EFR, which is beyond the potential of the catchment.

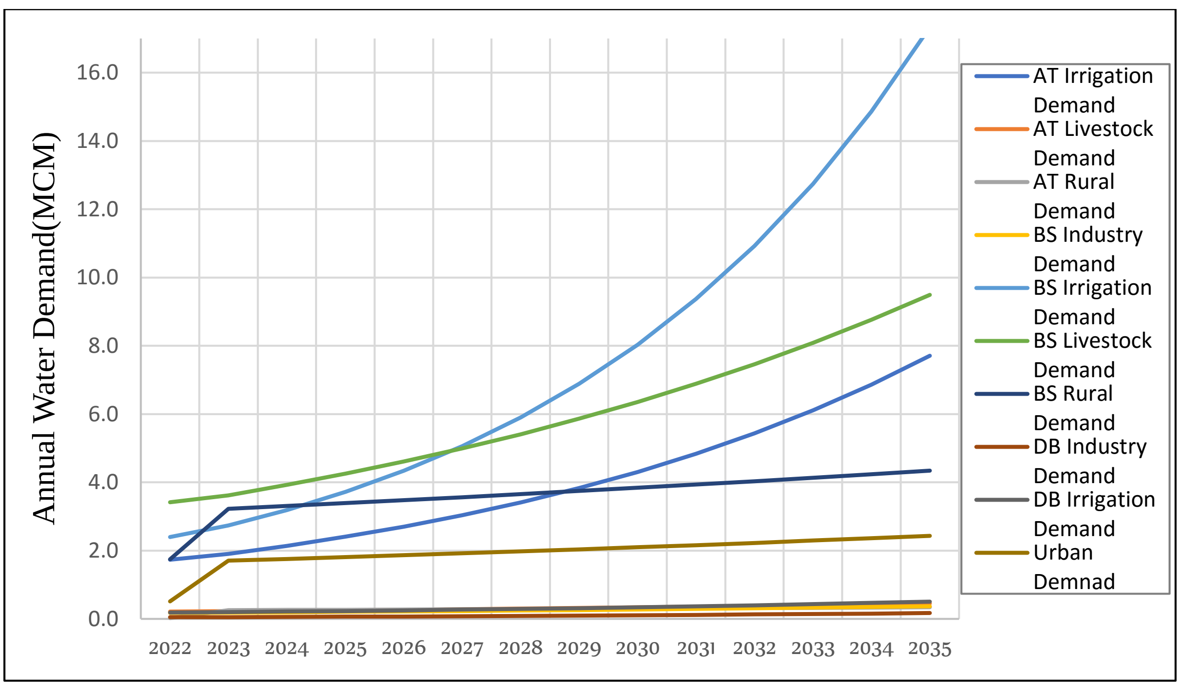

Figure 4: 14 Total annual water demand of projected domestic demand in Beressa catchment

In this scenario, there was an estimated unmet demand between the projected year 2034 and 2035. The estimated unmet demand is 2.25MCM and 10.1MCM in the two projected years, respectively. This shows that the Beressa river will not meet the demand of the area. That will result water stress on the water potential of the Beressa river, the imbalance of supply and demand wiil affect the socio-economic activities of the area. That will affect the livelihood and growth of the cathment. So, to manage the supply and demand in the catchment, water management mechanisms, and other water sources should be adopted for sustainable utilization of resources.

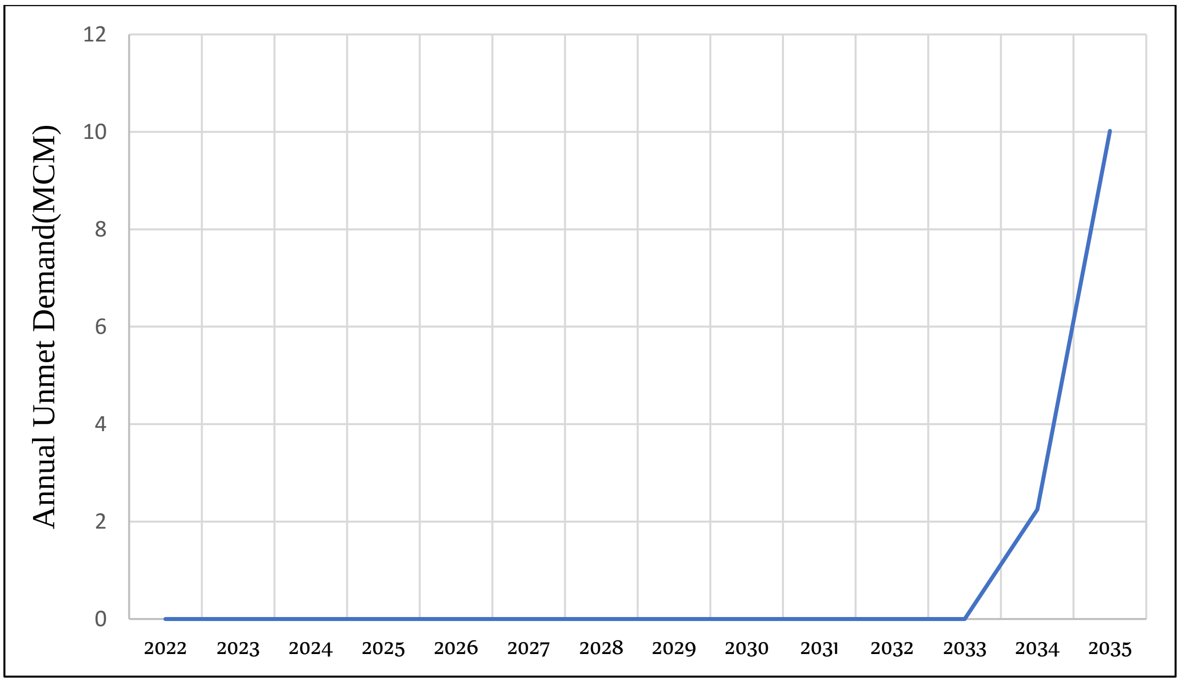

Figure 4: 15 Annual total unmet projected domestic water demand in Beressa catchment

This scenario helps to identify the significant effect of domestic demand change in related to the urbanization, living standard and socio-economic changes. The increment of both rural and urban domestic per capita demand reveals the potential consequence of domestic demand on the supply system. This makes easy to figure out water allocation systems effeciency and wise utilization of resources in the future trend.

Under this scenario, the total annual water demand estimated to be 18.43MCM(22.9%), 7.4MCM(9.2%), 15.45MCM(23.1%), 23.97MCM(26.1%), and 14.88MCM(18.5%) in Abichu Genna, Ensaro, Kimbibit, Siya Debrina, and Wuchalena Jido of the total annual water demand of 2035, respectively. The Siya Debrina irrigation demand showed the maximum demand with 15,9MCM of the other irrigation demand in demand site. The rural demand showed substantial change in this scenario, the maximum rural demand occurred in Siya Debrina with 3.02MCM(41.9%) of the total rural water demand 7.2MCM of 2035. The total water demand including EFR estimated about 110.25MCM(74%) of the surface water potential of Robigumer catchment. No unmet demand in this scenario, this implies that the Robigumer river will able to satisfy the future demand. The catchment is experieancing good ecological condtion, even if some changes take place in the area in the projeted years. Therefore, the catchments' potential for escalating domestic, irrigation, livestock, and industry demands due to population growth and urbanization is significantly enough for the demand site in the catchment.

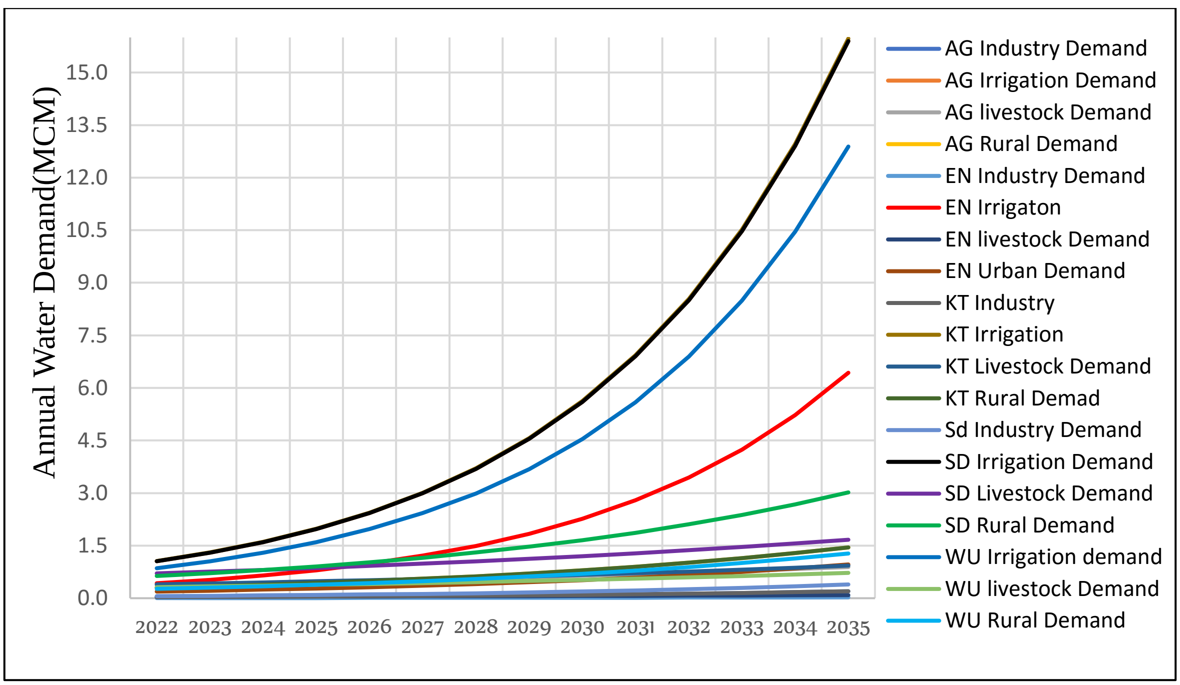

Figure 4: 16 Annual water demand in projected domestic demand of Robigumer catchment

4.3. The impact of developed scenarios on demand variation and supply requirement

4.3.1. Scenarios in Beressa catchment

The Beressa catchment subdivded into Basoa na Wayu, Angolela Tera , and Debre Birhan. The basic considered demands are domestic, irrigation, livestock and industry in descending priority, respectively. This demands taken into account regarding the socio-economic and environmental status of the catchment. In order to analyse the future trend of each demands effect on the surface water potential of the catchment some relevant scenarios developed. This considered scenarios are based on the common understanding and well known nature of the elements. Then the effect of each scenario is analysed from the baseline year of 2022-2035. The scenarios helps to undertsand their specific effect on the potential of supply. Their effect is expressed in each projected years according to their order of significance.

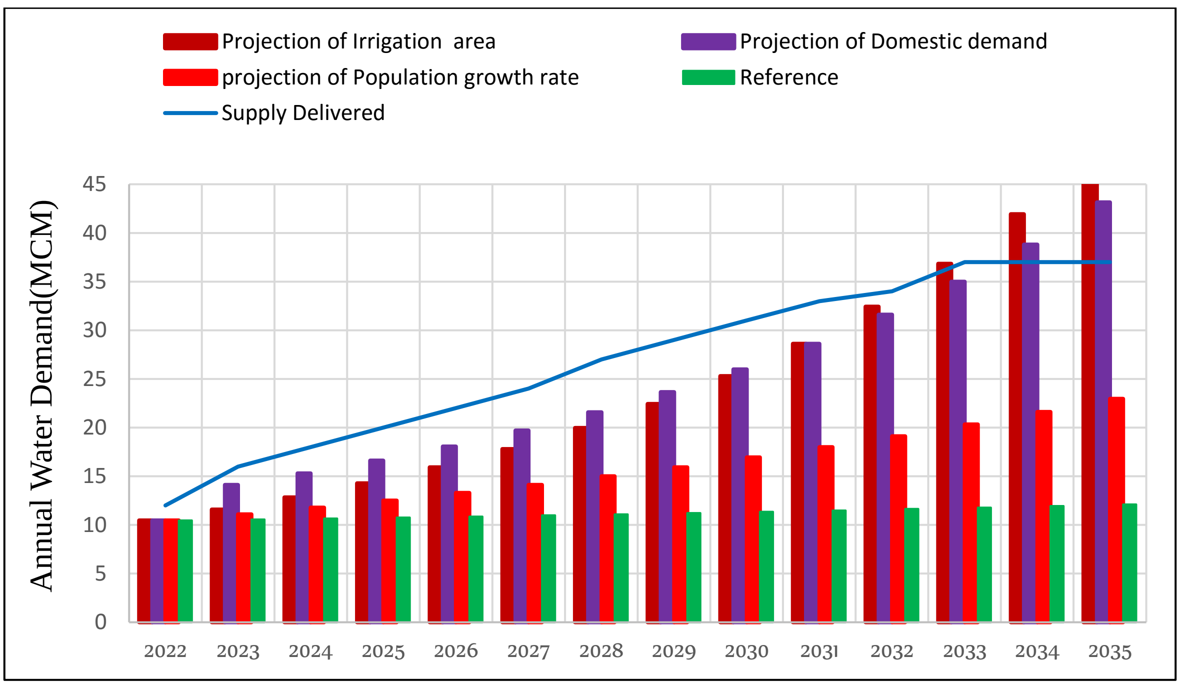

Figure 4: 17 Anual total water demand of all scenrios in Beressa catchment

In the analysis of each scenario significant results obtained, this makes the scenario relevant to manage the supply with the demand. Some scenario revealed significant effect on the surface water potential of the catchment. The simulated surface water potential of the the catchemt is 37MCM and 20% of the surface water potential is given the minimum flow requirment(EFR) to manage the catchment's ecological balance. The total water demand in projected irrigation area showed unmet demand in the year 2034 and 2035 projected years, this will negatively affect the supply potenial if the scenario is adopted in the future. The total estimated unmet demand in the projection of domestic demand to be 10MCM and 11MCM in projection irrigation area.

In addition the projected domestic demand also showed significant effect in many of projected years. Therefore, adopting this two scenario will result imbalance of supply and demand. This makes the catchment imcompatible to the socio-economic and enivronmental changs. The best option is to find other relevant mechanisms to manage the supply with the demand by changing some considerations and assumptions. The best possible options, improving public awareness, modernizing agricultural practices, adopting other water sources, and rainwater harvesting could be significant measures.

4.3.2. Scenarios in Robigumer catchment

In Robigumer catchment all the scenarios gave relevant infomation on the significant effect of each projected years. The simulated surface water potential of the catchment is 149.06MCM and 20% is considered to EFR. In each scenario the basic demands revealed significant changes with respect to the status and condtion of the catchment. The catchment in each scenario is compatible to the demand including the EFR.

The significant changes observed in projected irrigation demand with a total estimated demand as 125.64MCM(84.04%) of the total suply potential. Even if the supply will statify each basic demands in all scenarios some relevant water resource managment should be adopted for the sustainble utilization of catchment's resource. Therefore, if such scenarios are adopted rain water harvesting, other source and effective techniques should be used to manage the catchment's ecological balance. The scenarios are developed on the scio-economic, radical population growth, projection of irrigation command area, enivronmetal changes to understand future trends of the catchment.

The catchment will satisfy the basic demands with the ongoing known and prediced conditios without causing imbalance between supply and demand. So, all scenarios are the best option to enhance agricuture yield, improve livelihood of scoiety, increase livestock production and industrial output. Inorder to alleviate water stress and maintain the sustainbility of catchment, water resources mangement measures are significant such as constructing resrvoir, hydraulic structures, rain water harvesting and soil conservartion stuctures are mandatory.

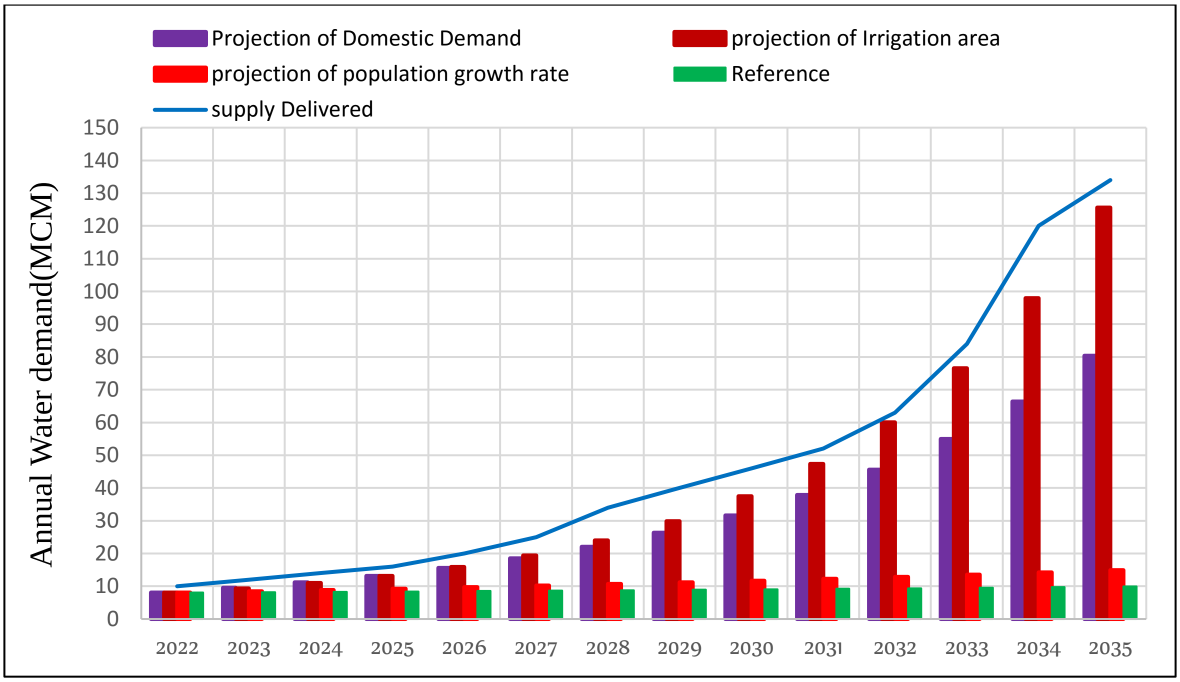

Figure 4: 18 Annual water demand of all scenarios in Robigumer catchment

5. SUMMARY, CONCLUSION AND RECOMMENDATION

5.1. Summary and conclusions

The assessment of surface water potential at catchments level is significant for the exsiting and planned water resources development projects of developing countries like Ethiopia. That helps to stimulate the agricultural, economic, and social growth of the country through utilization of the available potential of water for irrigation, livestock, and water supply. Surface water is the dominantly used source of water due its accesbility and simple application. In the utiliztion of surface water, there should be a proper plan, design, implementation, and operation of the water resources project. Indeed, integrated surface water potential and demand analysisa is important to have reliable information on policy-making process. This facilitates the maximum potential utilization of available resources, allocation and development of water resources projects.

This study applied different hydrlogic models used for assessing the surface water potenial and analysis of demand in the poorly gauged catchments of Jemma sub-basin, the applied SWAT model predict the available surface water potenial over a period of 1990-2018. The significant parameters was identified, that alters the model performace using the SWAT-CUP. The SWAT model helps to understand the water balance of the catchments and able to estimate the mean flow depth of hydrologic elements. The calibrated and validated model evaluated with a performance evalution criteria and showed good correlation with the observed flow data.

The swat model requires daily climatic, DEM, LULC, and soil data of the study area, so using the necessary parameters, the quantified surface water potential of the Beressa and Robigumer catchment was 37MCM and 149MCM, respectively. The mean surface annual flow depth is 174.4mm and 166.91 in Beressa and Robigumer catchments, respectively. The Beressa catchment receives mean annual precipitation of 941.5mm, while the Robigumer is about 976.4 mm mean annual precipitation. The maximum amount of recived precipitation lost through evapotranspirarion in both catchmnets, 48% and 43% in Beressa and Robigumer catchmets, respectively.

The developed “ what if” sceanrios hepls to identify the cuurent and future annual water demand variation in the the projected time period. The scenarios are based on the socio-economic, enviromental, poulation growth, living standard and ecological balance of the study area. These scenarios showed the potenial current supply reuirement, annual water demand an unmet in the accounted short term period.

The WEAP model analyzed the basic consumptive demands, supply requiremnt, unmet water demands in each sceanrios. The estimated total annual water demand in the Beressa catchment was 46MCM, 38MCM, 27MCM, and 23MCM in the projection of domestic, agriculture, population, and reference scenarios, respectively. In the two developed "what if " scenarios, there were unmet demand in most projected years. That showed the Beressa river could not meet the future demand if such a scenario is adopted. The total annual water demand estimated about 9.91MCM(6.63%), 14.90MCM(10.24%), 80.35MCM(53.74%), and 125.64(84.04%) in reference, projected population growth, projected domestic demand, and projected irrigation demand scenarios of the total surface water potential of Robigumer catchment, respectively. This implied the Robigumer catchment have a significant water supply and demand balance and could meet the considered demands under accounted scenarios.

So, regarding the assessment of surface water potential and demand analysis, this work could be taken to manage, satisfy and allocate accordingly to the natural and manmade condtions, which significantly alter and modify the hydrologic cycle of catchments.

- Integrating surface water potential with the existing and future demand plays an essential role in the better and wise use of water resources. Understanding the surface water potential and demand at a basin level is a mandatory task for the sustainable and reliable management of the water resources in current and future time.
- The impact of escalting demand due to urbanization, poulation growth, socio-economic, and environmental changes could imbalance supply and demand, results water stress and scarcity. That will affect the economic, agricultural and livelihood of the society in the catchments.

5.2. Recommendations

This study assessed the surface water potential and demands for the current and future periods on the two poorly gauged catchments of the Jemma sub-basin. From the conducted works in the area, the following point has recommended for further analysis:-

- The two gauged catchments have insufficient organized and recent data in quantifying the surface water availability and demand analysis. So, monitoring and time inspection of the catchments is essential for an accurate and reliable result in policy formulation and decision-making activities.
- In satisfying the rapidly escalating demands of society, another water source has to be adopted, and a rainwater harvesting system also is applied for sustainable utilization of water potential in both catchments.
- Even if the existing irrigated potential is satisfactory, much more is to be done for the livelihood of society through creating awareness, adopting advanced technologies, and introducing modified crops.
- In both catchments, concerning utilizing and proposing new projects at the sub-basin level, special consideration is vital to address to the significant impact of climate, socio-economic and environmental changes.
- The environmental flow requirement of surface water resources should be studied in detail in a catchment to prevail the ecosystem balance and sustainability on the upstream and downstream sides.
- Finally, In the study area, further research needs to be done to estimate accurate and reliable data on the water potential and demands at a basin level, and special care has to apply for other researchers to use this study.

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7. APPENDICES

Appendix Table 1: 1 Mean monthly rainfall of stations in the study area

Month	Debre Berhan	Gudoberet	Deneba	Lemi	Sheno	Mendida
Jan	9.49	13.06	14.93	8.16	6.76	7.13
Feb	15.19	12.30	22.82	28.75	14.03	15.14
Mar	35.13	36.42	60.01	53.59	33.37	33.05
Apr	53.00	55.78	57.91	61.54	54.59	57.73
May	39.06	62.05	36.89	53.66	31.63	33.42
Jun	64.60	85.69	82.32	84.76	95.32	99.71
Jul	295.75	372.38	295.23	377.86	296.14	304.95
Aug	263.80	375.82	276.51	378.72	266.15	260.02
Sep	78.92	135.63	79.89	106.48	85.51	87.42
Oct	17.43	49.00	11.28	18.43	13.34	13.11
Nov	7.15	23.29	7.33	8.77	5.89	5.43
Dec	3.27	6.14	3.84	4.93	5.98	5.98

Appendix Table 1: 2 Mean annual rainfall of stations in the study area

year	Debre Berhan	Gudoberet	Deneba	Lemi	Sheno	Mendida
1990	71.03	48.78	72.69	144.03	65.28	65.20
1991	72.08	26.41	70.51	73.79	60.78	60.78
1992	75.13	22.23	73.62	87.56	85.16	85.16
1993	80.21	39.38	88.70	91.16	86.35	86.35
1994	72.02	126.77	72.33	82.46	47.75	86.35
1995	62.72	118.58	70.73	115.25	69.43	69.43
1996	82.00	127.03	98.63	192.60	79.23	79.23
1997	75.42	119.45	74.52	84.63	69.02	69.02
1998	71.59	124.07	88.74	72.23	88.53	88.53
1999	78.08	127.48	78.83	108.96	77.32	77.32
2000	82.11	116.78	67.63	107.28	70.35	70.35
2001	77.51	119.13	72.76	128.41	83.39	83.39
2002	69.18	110.95	49.43	63.43	75.11	75.11
2003	83.79	102.25	107.74	94.78	105.49	105.49
2004	85.27	129.04	77.67	97.96	81.53	81.53
2005	77.70	77.47	75.42	79.60	80.75	80.75
2006	79.28	136.84	95.77	109.85	86.64	86.64
2007	90.29	159.03	98.18	108.06	86.61	86.61
2008	78.89	132.57	72.44	204.95	83.58	83.58
2009	75.52	91.49	75.23	118.17	72.78	72.78
2010	76.32	130.43	97.43	121.13	71.98	71.98
2011	88.36	145.69	76.36	78.63	75.49	75.49

2012	87.58	145.78	94.28	110.71	136.09	136.09
2013	73.74	127.68	65.39	100.23	82.99	82.99
2014	75.49	137.26	75.48	95.58	117.51	117.51
2015	63.64	79.79	60.27	59.61	54.74	54.74
2016	97.56	119.19	91.58	111.47	70.84	70.84
2017	77.90	122.78	69.07	90.82	51.30	48.86
2018	79.53	78.86	81.92	101.59	108.05	108.05

Appendix Table 1: 3 Average annual maximum and minimum teamratures of Stations

	DebreBerhan		Gudoberet		Lemi		Sheno		Mendida	
Year	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin
1990	19.52	5.51	18.62	8.45	17.68	7.74	18.92	6.58	20.57	7.87
1991	20.38	5.97	17.96	7.90	19.28	8.77	18.30	6.71	21.54	8.31
1992	19.16	6.61	17.73	7.53	21.10	9.57	18.51	7.22	20.95	8.70
1993	19.23	6.12	17.96	7.55	22.16	9.15	19.33	7.28	20.38	8.24
1994	19.70	5.97	16.64	8.08	22.97	8.82	20.14	6.59	21.03	8.48
1995	20.30	5.88	17.33	8.64	20.25	8.39	20.06	6.45	21.11	8.77
1996	19.55	5.93	17.09	8.39	21.31	9.23	18.71	7.05	20.45	8.33
1997	19.60	6.30	16.79	8.58	21.61	10.43	18.75	5.94	20.99	8.63
1998	19.91	6.36	16.88	8.56	21.27	10.37	19.27	7.61	20.67	8.42
1999	19.66	4.79	16.29	7.64	22.21	9.74	19.40	6.67	20.84	8.08
2000	19.81	4.88	16.67	7.42	22.78	9.85	19.48	6.74	21.26	8.02
2001	19.87	6.03	16.98	8.06	21.73	9.76	19.07	7.29	20.69	8.41
2002	20.41	6.80	17.03	8.31	20.60	9.56	19.14	7.75	21.50	9.05
2003	20.04	6.57	17.27	7.87	22.22	10.73	19.49	7.81	21.42	8.66
2004	20.09	6.27	17.49	6.73	22.19	11.25	19.53	7.81	21.50	8.65
2005	20.05	6.78	17.62	7.11	22.18	10.08	19.59	7.59	21.73	8.05
2006	19.90	7.35	17.03	7.56	22.52	10.32	19.02	8.20	20.84	8.35
2007	19.84	6.82	17.37	7.43	22.52	9.98	19.33	7.99	20.55	8.30
2008	19.96	6.54	17.49	7.36	21.95	6.18	19.40	7.56	20.90	8.58
2009	20.18	7.08	17.86	8.01	21.85	10.08	19.58	7.72	18.51	8.85
2010	19.98	7.45	18.54	8.26	21.71	10.00	19.45	7.92	20.78	8.89
2011	20.05	6.51	18.05	7.49	21.73	10.02	19.65	7.69	22.49	9.75
2012	20.37	5.61	18.57	7.58	22.62	9.86	20.21	7.11	21.51	8.23
2013	20.16	6.06	18.92	8.15	22.54	9.76	20.83	7.60	21.49	8.75
2014	20.20	6.33	18.23	7.67	22.42	9.72	19.84	8.04	21.30	8.55
2015	20.93	5.52	18.44	8.20	23.28	10.13	20.62	7.90	22.15	8.73
2016	20.27	6.15	19.19	8.27	22.77	10.61	20.48	8.00	21.36	8.71
2017	20.40	6.69	18.61	7.41	22.93	9.86	20.46	7.46	21.79	8.29
2018	20.87	7.12	18.85	8.21	23.31	10.80	20.27	8.17	28.83	15.40

Appendix Table 1: 4 Rainfall outlier test of Stations

Year	DB	y=log	Gudo	y=log	Den	y=log	Lemi	Y=log	Mend	y=log	Sheno	y=log
1990	71.00	1.85	48.78	1.69	72.69	1.86	144.03	2.16	65.20	1.81	65.28	1.81
1991	72.10	1.86	26.41	1.42	70.51	1.85	73.79	1.87	60.78	1.78	60.78	1.78
1992	75.10	1.88	22.23	1.35	73.62	1.87	87.56	1.94	85.16	1.93	85.16	1.93
1993	79.30	1.90	39.38	1.60	88.70	1.95	91.16	1.96	86.35	1.94	86.35	1.94
1994	72.00	1.86	126.77	2.10	72.33	1.86	82.46	1.92	86.35	1.94	47.75	1.68
1995	62.70	1.80	118.58	2.07	70.73	1.85	115.25	2.06	69.43	1.84	69.43	1.84
1996	82.00	1.91	127.03	2.10	98.63	1.99	192.60	2.28	79.23	1.90	79.23	1.90
1997	75.40	1.88	119.45	2.08	74.52	1.87	84.63	1.93	69.02	1.84	69.02	1.84
1998	71.60	1.85	124.07	2.09	88.74	1.95	72.23	1.86	88.53	1.95	88.53	1.95
1999	78.10	1.89	127.48	2.11	78.83	1.90	108.96	2.04	77.32	1.89	77.32	1.89
2000	82.10	1.91	116.78	2.07	67.63	1.83	107.28	2.03	70.35	1.85	70.35	1.85
2001	77.50	1.89	119.13	2.08	72.76	1.86	128.41	2.11	83.39	1.92	83.39	1.92
2002	69.20	1.84	110.95	2.05	49.43	1.69	63.43	1.80	75.11	1.88	75.11	1.88
2003	83.80	1.92	102.25	2.01	107.74	2.03	94.78	1.98	105.49	2.02	105.49	2.02
2004	85.30	1.93	129.04	2.11	77.67	1.89	97.96	1.99	81.53	1.91	81.53	1.91
2005	77.70	1.89	77.47	1.89	75.42	1.88	79.60	1.90	80.75	1.91	80.75	1.91
2006	79.30	1.90	136.84	2.14	95.77	1.98	109.85	2.04	86.64	1.94	86.64	1.94
2007	90.30	1.96	159.03	2.20	98.18	1.99	108.06	2.03	86.61	1.94	86.61	1.94
2008	78.90	1.90	132.57	2.12	72.44	1.86	104.**95**	2.31	83.58	1.92	83.58	1.92
2009	75.50	1.88	91.49	1.96	75.23	1.88	118.17	2.07	72.78	1.86	72.78	1.86
2010	76.30	1.88	130.43	2.12	97.43	1.99	121.13	2.08	71.98	1.86	71.98	1.86
2011	88.40	1.95	145.69	2.16	76.36	1.88	78.63	1.90	75.49	1.88	75.49	1.88
2012	87.60	1.94	145.78	2.16	94.28	1.97	110.71	2.04	116.09	2.13	116.09	2.13
2013	73.70	1.87	127.68	2.11	65.39	1.82	100.23	2.00	82.99	1.92	82.99	1.92
2014	75.70	1.88	137.26	2.14	75.48	1.88	95.58	1.98	117.51	2.07	117.51	2.07
2015	63.60	1.80	79.79	1.90	60.27	1.78	59.61	1.78	54.74	1.74	54.74	1.74
2016	97.60	1.99	119.19	2.08	91.58	1.96	111.47	2.05	70.84	1.85	70.84	1.85
2017	77.90	1.89	122.78	2.09	69.07	1.84	90.82	1.96	48.86	1.69	51.30	1.71
2018	79.60	1.90	78.86	1.90	81.92	1.91	101.59	2.01	108.05	2.03	108.05	2.03
KN		**2.534**										
Std	7.54	0.04	36.02	0.22	13.14	0.07	32.44	0.12	17.94	0.09	18.82	0.10
X (mm)	77.91	1.89	108.39	2.00	79.08	1.89	104.65	2.00	81.38	1.90	80.14	1.89
XU (mm)	97.00	2.00	199.67	2.55	112.37	2.08	186.86	2.31	126.85	2.13	127.83	2.14
XL (mm)	58.81	1.78	-2740	1.45	45.79	1.71	22.44	1.70	35.92	1.67	32.45	1.64
Skew	0.37	0.01	-0.20	-0.36	0.26	-0.27	0.37	0.34	0.13	0.24	0.22	0.13

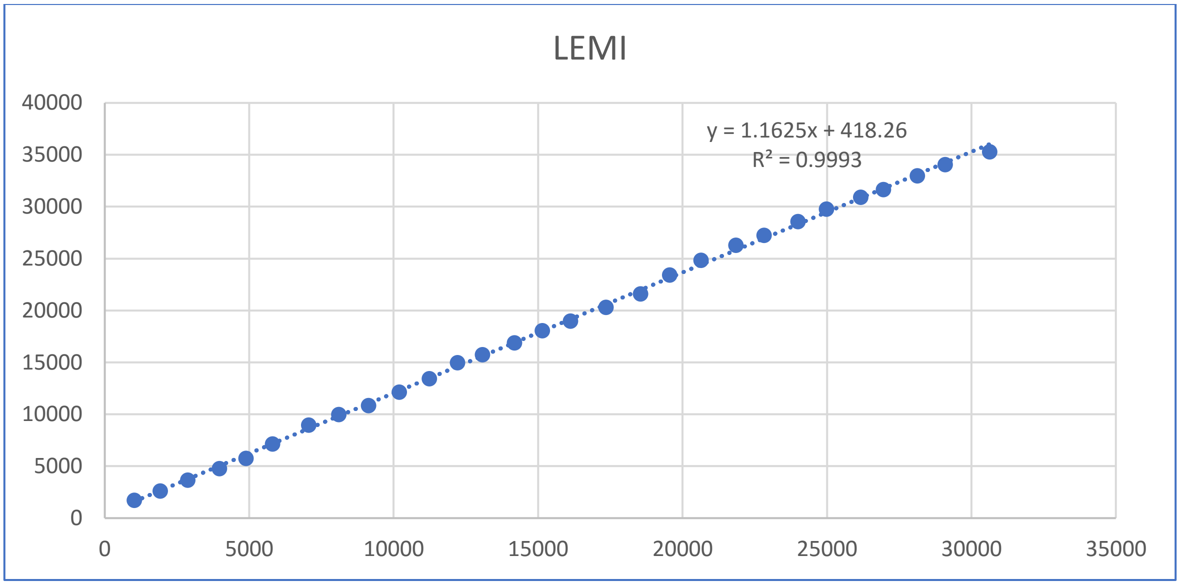
Appendix Table 1: 5 Normal distribution of KN values

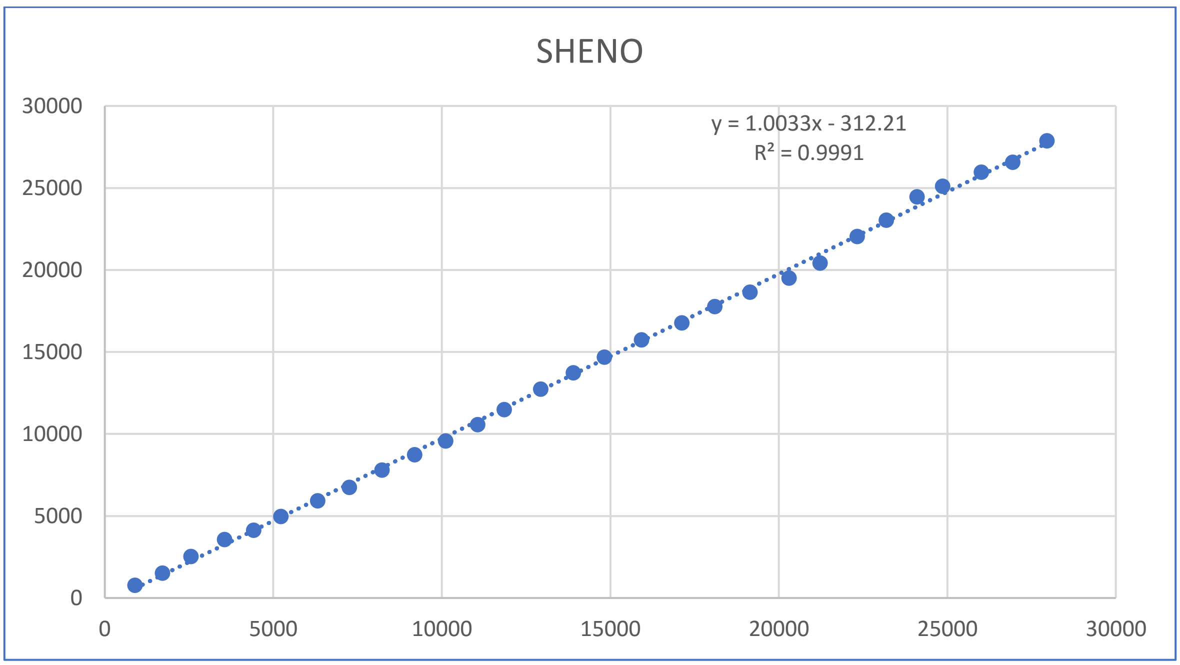
OUTLIER TEST K VALUES

10 PERCENT SIGNIFICANCE LEVEL K VALUES

The table below contains one sided 10 percent significance level vvalues for a normal distribution (38). Tests conducted select the outlier detection procedure used in report Indicate these values are applicable to log—Pearson type distribution over tested range of values.

Sample size	KN value	Sample size	KN value	Sample size	KN value	Sample size	KN value
10	2.036	45	2.727	80	2.940	115	3.064
11	2.088	46	2.736	81	2.945	116	3.067
12	2.13	47	2.744	82	2.849	117	3.070
13	2.175	48	2.753	83	2.953	118	3.073
14	2.213	49	2.760	84	2.957	119	3.075
15	2.247	50	2.768	85	2.961	120	3.078
16	2.279	51	2.775	86	2.966	121	3.081
17	2.309	52	2.783	87	2.970	122	3.083
18	2.335	53	2.790	88	2.973	123	3.086
19	2.361	54	2.798	89	2.977	124	3.089
20	2.385	55	2.804	90	2.981	125	3.092
21	2.408	56	2.811	91	2.984	126	3.096
22	2.429	57	2.812	92	2.989	127	3.097
23	2.448	58	2.824	93	2.993	128	3.100
24	2.467	59	2.831	94	2.996	129	3.102
25	2.486	60	2.837	95	3.000	130	3.104
26	2.502	61	2.842	96	3.003	131	3.107
27	2.519	62	2.849	97	3.006	132	3.109
28	2.534	63	2.854	98	3.007	133	3.112
29	2.549	64	2.860	99	3.014	134	3.114
30	2.563	65	2.866	100	3.017	135	3.116
31	2.577	66	2.871	101	3.018	136	3.119
32	2.591	67	2.8173	102	3.026	137	3.122
33	2.604	68	2.883	103	3.027	138	3.124
34	2.616	69	2.888	104	3. 029	139	3.126
35	2.628	70	2.893	105	3.033	140	3.129
36	2.639	71	2.897	106	3.037	141	3.131
37	2.650	72	2.903	107	3.040	142	3.133
38	2.661	73	2.908	108	3.043	143	3.135
39	2.671	74	2.912	109	3.046	144	3.138
40	2.682	75	2.917	110	3.049	145	3.140
41	2.692	76	2.922	111	3.052	146	3.142
42	2.700	77	2.927	112	3.055	147	3.144
43	2.710	78	2.931	113	3.058	148	3.146
44	2.711	79	2.93	114	3.061	149	3.148


LEMI
y = 1.1625x + 418.26
R² = 0.9993
40000
35000
30000
25000
20000
15000
10000
5000
0
0
5000
10000
15000
20000
25000
30000
35000


SHENO
y = 1.0033x - 312.21
R² = 0.9991
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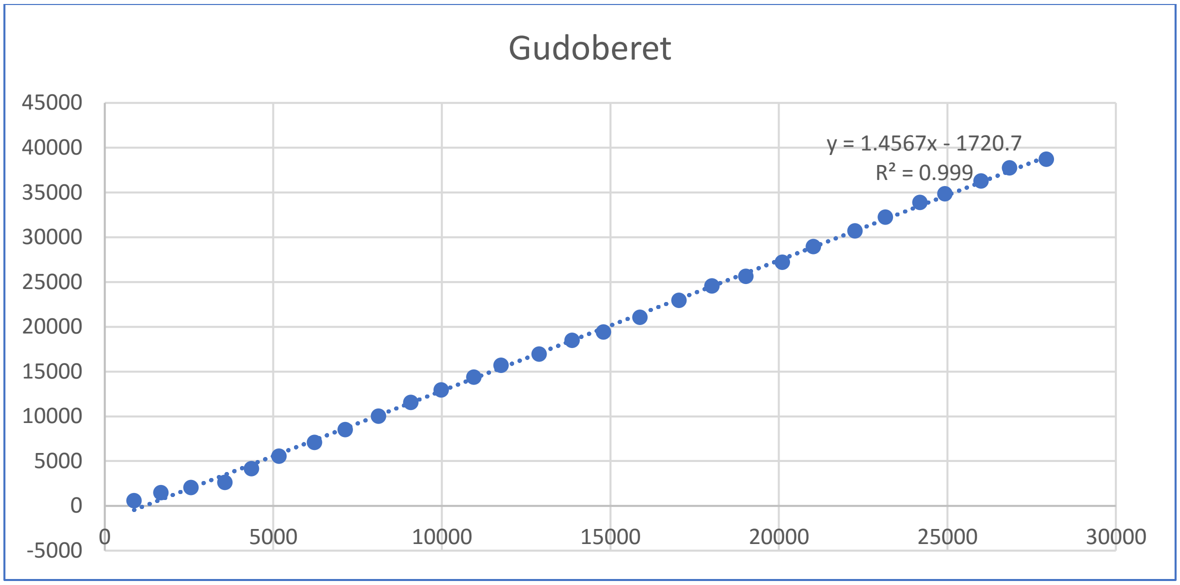
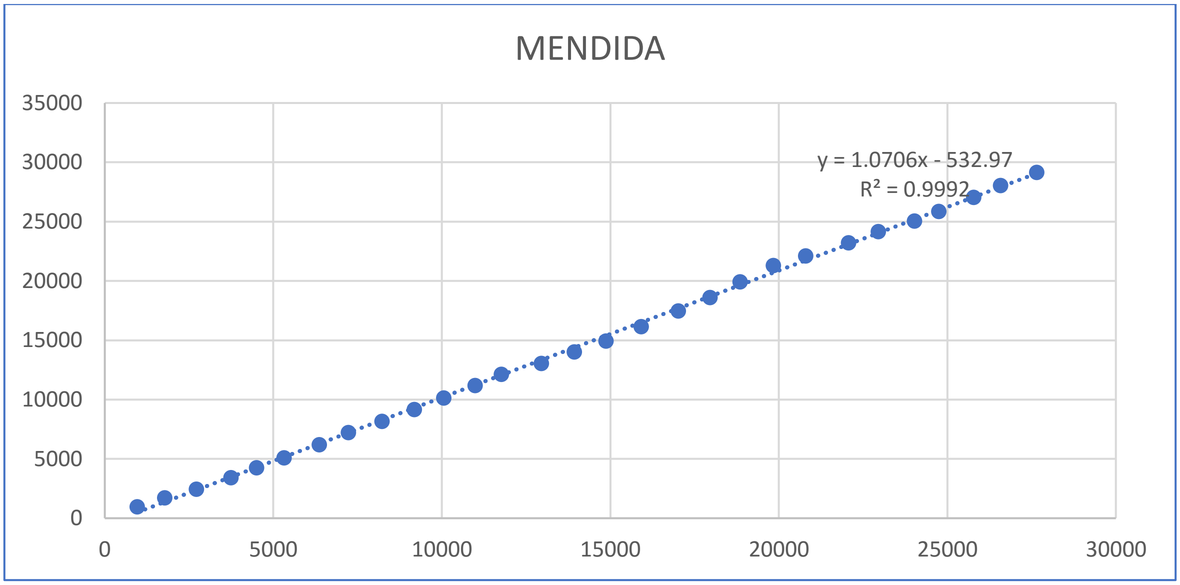
25000
20000
15000
10000
5000
0
0
5000
10000
15000
20000
25000
30000





Appendix Figure 1: 1 Consistency rainfall data test of stations

Appendix Table 1: 6 Parameters used in sensitive anaalysis test in SWAT-CUP

23 : Number of Parameters (the program only reads the first 4 parameters or any number indicated here) code, Name of Parameters and thier range

Code	**Name of parameters**	**Range used**	
r__CN2.mgt	Initial SCS runoff curve number for moisture condition II	-0.1	0.1
v__ALPHA_BF.gw	Base flow alpha factor (days)	0.0	1.0
a__GW_DELAY.gw	Groundwater delay (days)	-10	10
v__GWQMN.gw	Treshold depth of water in the shallow aquifer required for return flow to occur(mm)	0.0	5000
v__BIOMIX.mgt	Biological mixing efficiency	0.0	1.0
a__CANMX.hru	The maximum amount of water that can be trapped in the canopy when the canopy is fully developed(mm)	0.0	10.0
v__CH_K2.rte	Effective hydraulic conductivity (mm h-1)	0.0	10.0
v__CH_N2.rte	Manning's "n" value for the main channel	0.01	0.20
v__EPCO.hru	Plant evaporation compensation factor	0.0	1.0
v__ESCO.hru	Soil evaporation compensation factor	0.0	1.0
v__GW_REVAP.gw	Groundwater re-evaporation coefficient	0.02	0.20
v__REVAPMN.gw	Threshold depth of water in the shallow aquifer for “re-vamp" to occur(mm)	0.0	500
r__SLSUBBSN.hru	Average slope length (m)	-0.20	0.20
r__SOL_ALB().sol	Soil albedo	-0.25	0.25
r__SOL_AWC().sol	Available water capacity of the soil (mm H2O mm soil)	-0.30	0.30
r__SOL_K().sol	Saturated hydraulic conductivity of the soil (mm h-1)	-0.90	0.90
r__SOL_Z().sol	Soil depth (mm)	-0.30	0.30
v__BLAI{4.plant.dat	Potential maximum leaf area index for the plant	0.5	10.0
r__OV_N.hru	Manning's "n" value for overland flow	-0.20	0.20
r__SOL_ZMX.sol	Maximum rooting depth of soil profile	-0.1	0.30
r__SLSOIL.hru	Slope length for lateral subsurface flow	-0.2	0.30
v__SURLAG.bsn	Surface runoff lags coefficient	0.05	24.0
r__HRU_SLP.hru	Average slope steepness	0.0	0.20

Appendix Table 1: 7 SWAT model simulation output

SWAT Dec 23 2016 VER 2016/Rev 664

General Input/Output section (file.cio):

8/10/2022 12:00:00 AM ARCGIS-SWAT interface AV

Annual Summary for Watershed in year 5 of simulation

UNIT TIME	PREP (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERCO LATE (mm)	SW (mm)	ET (mm)	PET (mm)	WATER YIELD (mm)
1	0	0	0.1	1.85	0	64.74	3.24	77.12	3.08
2	0	0	0.05	0.64	0	63.07	1.68	78.01	1.47
3	95.6	1.88	0.85	0.39	0.33	119.75	35.31	74.77	3.76
4	0	0	0.45	0.22	0	92.28	27.48	77.58	1.13
5	23.2	0.32	0.27	0.1	0.03	78.64	36.26	83.66	1.04
6	92.7	0.55	0.49	0.06	0.24	99.21	70.04	85.7	1.35
7	281.7	72.49	3.98	18.94	90.43	146.44	65.13	67.17	95.68
8	222.9	49.25	5.73	78.96	101.04	150.18	63.34	65.66	134.83
9	101.7	18.76	3.93	73.94	39.75	132.39	58.65	73.38	98.59
10	9.9	0.01	0.94	30.37	0	97.03	45.19	78.01	33.37
11	36.5	3.68	0.64	11.01	0.1	97.2	32.14	60.08	17.03
12	0	0	0.24	4.27	0	72.79	24.42	74.25	5.91
1994	864.2	146.95	17.68	220.75	231.91	72.79	462.88	895.38	397.24

SWAT Dec 23 2016 VER 2016/Rev 664

General Input/Output section (file.cio):

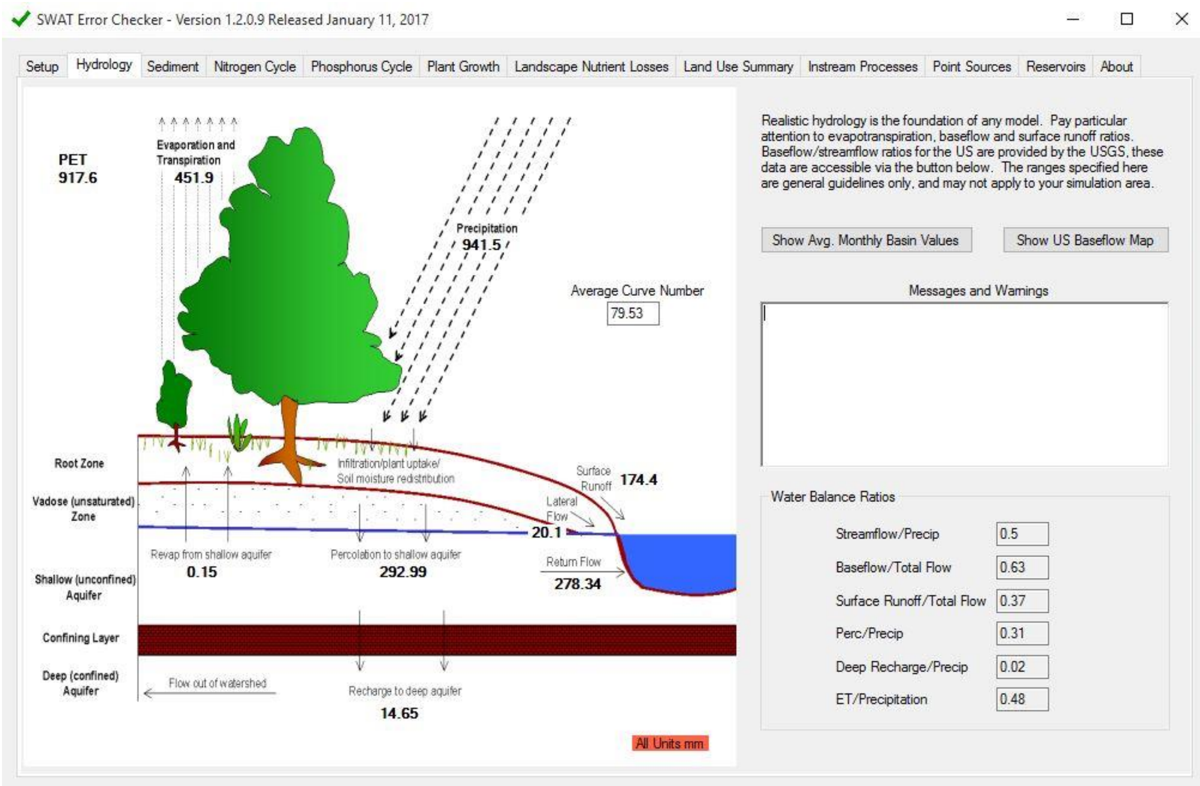
8/10/2022 12:00:00 AM ARCGIS-SWAT interface AV

Annual Summary for Watershed in year 29 of simulation

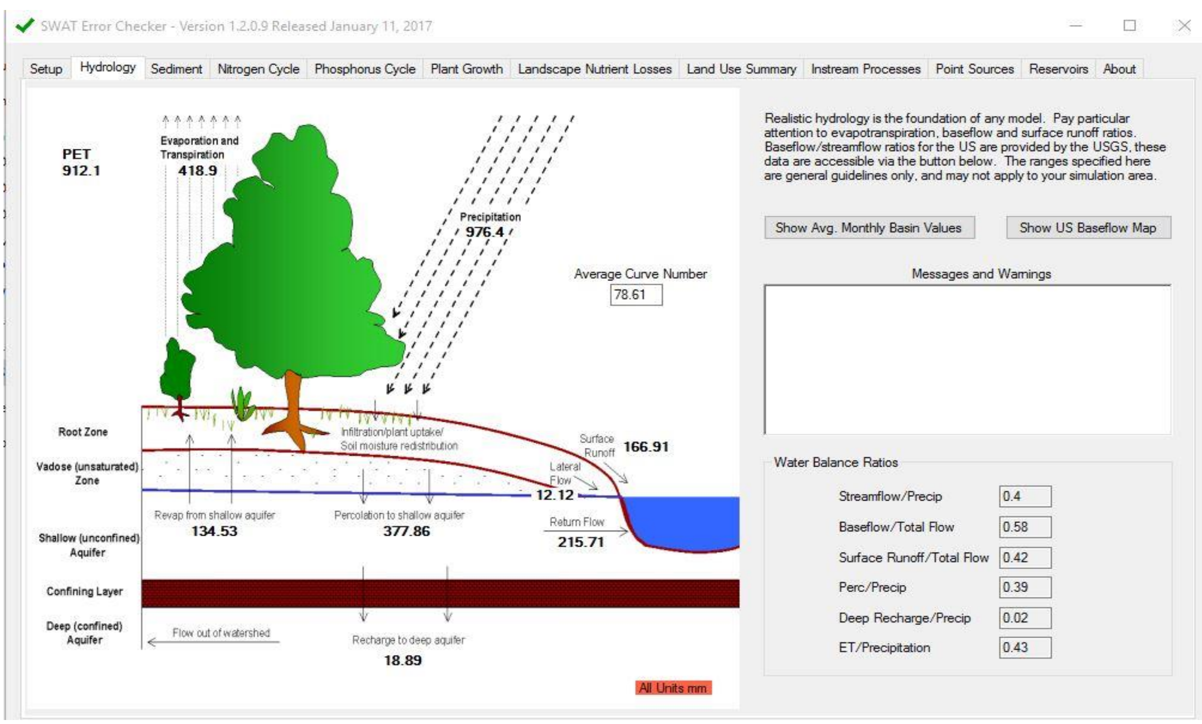
UNIT TIME	PERC (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERCO LATE (mm)	SW (mm)	ET (mm)	PET (mm)	WATER YIELD (mm)
1	0	0	0.1	1.7	0	81.81	2.84	67.7	2.98
2	0	0	0.05	0.59	0	78.84	2.98	70.2	1.45
3	11.5	0.02	0.1	0.25	0	80.93	9.31	83.97	1.04
4	70.1	0.24	0.41	0.12	0.08	96.97	53.12	90.85	1.24
5	28.9	0.07	0.39	0.07	0	68.45	57.1	94.77	0.89
6	96.3	0.54	0.71	0.09	0.23	99.69	63.01	82.81	1.6
7	326.7	73.75	4.93	33.42	115.33	148.08	81.51	85.54	112.42
8	314.2	74.21	6.97	95.69	153.3	146.82	79.83	87.63	178.16
9	62.5	4.12	4.14	86.35	18.86	134.26	50.82	81.57	96.89
10	37.7	3.65	1.27	36.58	0.07	136.52	31.28	74.37	44.01
11	6.5	0.01	0.52	13.22	0	126.75	16.22	64.65	15.83
12	0	0	0.22	5.12	0	121.3	5.46	70.06	7.04
2018	954.4	156.6	19.79	273.19	287.88	121.3	453.46	954.13	463.56

Appendix Table 1: 8 SWAT model HRU sample statistics result

LULC	HRU	SUB	MON	AREA km2	PET mm	ET mm	SW_INIT mm	GW_RCHG mm	LATQ_ mm	GW_Qmm	WYLD_Qmm	DAILYCN
AGRR	1	1	1	1.0353	76.263	1.901	46.681	2.065	0.09	2.021	3.337	72.435
AGRR	2	1	1	0.74	76.263	1.893	46.689	2.039	0.179	1.995	3.383	72.437
BERM	3	1	1	0.47304	76.263	0.185	0.009	2.674	0.013	2.616	4.251	60.889
BERM	4	1	1	0.93726	76.263	0.198	0.01	2.779	0.011	2.72	4.414	60.898
BERM	5	1	1	2.5066	76.2	2.271	57.132	2.092	0.09	2.047	3.387	65.828
BERM	6	1	1	1.4135	76.263	2.267	57.105	2.065	0.177	2.02	3.432	65.82
AGRR	7	2	1	0.021615	76.162	1.908	46.83	2.044	0.168	2	3.381	72.474
AGRR	8	2	1	0.046473	76.162	1.915	46.82	2.07	0.082	2.025	3.335	72.473
RNGE	9	2	1	0.0075654	76.162	4.244	70.67	2.582	0.197	2.526	4.264	71.196
RNGE	10	2	1	0.0064846	76.162	4.25	70.694	2.613	0.08	2.557	4.205	71.203
WATR	11	2	1	0.0075654	183.917	128.742	0	0	0	0	0	0
WATR	12	2	1	0.0086462	183.917	128.742	0	0	0	0	0	0
AGRR	13	3	1	2.3648	76.397	1.876	46.49	2.035	0.179	1.991	3.377	72.384
AGRR	14	3	1	3.9304	76.397	1.885	46.48	2.062	0.09	2.017	3.33	72.382
RNGE	15	3	1	1.1356	76.397	4.212	70.513	2.605	0.099	2.549	4.204	71.146
RNGE	16	3	1	0.70301	76.397	4.206	70.491	2.573	0.206	2.518	4.26	71.139
BERM	17	3	1	0.25213	76.397	2.211	56.708	1.801	0.009	1.762	2.853	65.703
BERM	18	3	1	0.38168	76.397	2.249	56.955	2.059	0.182	2.015	3.428	65.776
BERM	19	3	1	0.55308	76.397	2.254	56.984	2.088	0.09	2.043	3.381	65.784
AGRR	20	4	1	2.8152	76.361	1.89	46.538	2.064	0.086	2.019	3.329	72.397
AGRR	21	4	1	1.3599	76.361	1.881	46.548	2.037	0.178	1.993	3.378	72.4
BERM	22	4	1	1.1072	76.361	2.259	57.029	2.09	0.086	2.045	3.38	65.798
BERM	23	4	1	0.4688	76.361	2.255	57.002	2.063	0.174	2.018	3.425	65.79
FRST	24	5	1	0.74705	78.122	7.371	111.266	2.113	0.022	2.068	3.351	73.352
AGRR	25	5	1	1.5858	78.122	4.063	79.257	1.565	0.2	1.532	2.661	79.569
AGRR	26	5	1	3.6656	78.122	4.07	79.011	1.301	0.015	1.273	2.067	79.523
FRST	27	6	1	1.2537	78.306	7.369	111.118	2.059	0.024	2.015	3.269	73.312
AGRR	28	6	1	1.5666	78.306	4.06	78.97	1.56	0.2	1.526	2.652	79.515
AGRR	29	6	1	4.7658	78.306	4.149	79.452	1.291	0.015	1.263	2.052	79.605
FRST	30	7	1	0.095788	76.234	6.302	78.403	2.929	0.221	2.866	4.843	66.271
FRST	31	7	1	0.24316	76.234	6.304	78.42	2.964	0.102	2.9	4.779	66.277
AGRR	32	7	1	1.5603	76.234	1.905	46.729	2.067	0.086	2.023	3.335	72.447
AGRR	33	7	1	0.5632	76.234	1.897	46.737	2.041	0.174	1.997	3.382	72.45
FRST	34	8	1	0.014281	76.221	6.301	78.409	2.924	0.241	2.861	4.857	66.274
FRST	35	8	1	0.031858	76.221	6.304	78.429	2.966	0.087	2.902	4.768	66.281
AGRR	36	8	1	0.10276	76.221	1.9	46.754	2.041	0.178	1.997	3.385	72.454
AGRR	37	8	1	0.1143	76.221	1.907	46.741	2.059	0.09	2.015	3.326	72.45



Appendix Figure 1: 2 Mean annual water balance of Beressa catchment



Appendix Figure 1: 3 Mean annual water balance of Robigumer catchment

Appendix Table 1: 9 Mean monthly water balance of Beressa catchment

Month	Rain (mm)	SURF Q (mm)	LAT Q (mm)	Water yield (mm)	ET(mm)	PET (mm)
Jan	10.13	0.15	0.18	3.42	6.72	74.97
Feb	11.36	0.18	0.16	1.85	8.76	72.29
Mar	39.37	0.72	0.34	2.08	23.2	85.61
Apr	52.5	2.45	0.65	4.13	40.43	83.79
May	45.21	2.47	0.71	4.78	49.76	87.97
Jun	74.01	7	0.75	10.67	49.23	78.6
July	316.7	77.05	4.58	117.51	66.27	71.73
Aug	285.49	72.12	7.15	183.61	67.8	70.89
Sep	76.47	10.5	3.76	97.09	57.55	75.01
Oct	17.92	1.18	1.15	39.62	39.1	76.97
Nov	8.56	0.56	0.44	15.81	27.02	70.46
Dec	3.68	0.02	0.23	6.87	16.01	68.71

Appendix Table 1: 10 Mean monthly water balance of Robigumer catchment

Month	Rain (mm)	SURF Q (mm)	LAT Q (mm)	Water yield (mm)	ET (mm)	PET (mm)
Jan	7.65	0.04	0.08	1.69	10.39	75.58
Feb	12.21	0.39	0.09	1.56	11.78	71.14
Mar	34.56	0.85	0.18	1.93	24.73	84.39
Apr	57.38	3.66	0.42	4.71	40.66	82.55
May	35.89	1.61	0.41	2.54	40.4	87.17
Jun	102.52	10.7	0.58	11.4	42.79	76.51
July	323.58	75.66	3.02	93.86	66	69.28
Aug	286.53	63.47	3.98	157.69	65.75	69.1
Sep	87.57	9.39	2.29	93.06	58.21	74.32
Oct	15.13	0.73	0.69	33.88	30.26	78.79
Nov	6.55	0.26	0.24	8.44	15.94	72.27
Dec	6.72	0.14	0.13	2.72	11.91	70.32

Appendix Table 1: 11 CROPWAT model result for Carrot

Month	Decade	Stage	Kc Coeff	Etc. mm/day	Etc. mm/dec	Eff rain mm/dec	Irri. Req. mm/dec
Oct	1	Init	0.7	3.88	11.6	0.2	11.6
Oct	2	Init	0.7	3.79	37.9	0	37.9
Oct	3	Deve	0.71	3.7	40.7	0	40.6
Nov	1	Deve	0.8	4.02	40.2	0.1	40.1
Nov	2	Deve	0.91	4.37	43.7	0	43.7
Nov	3	Mid	1.01	4.72	47.2	0.1	47.2
Dec	1	Mid	1.03	4.67	46.7	0	46.7
Dec	2	Mid	1.03	4.54	45.4	0	45.4
Dec	3	Late	1.02	4.67	51.4	0	51.4
Jan	1	Late	0.97	4.6	46	0	46
Jan	2	Late	0.93	4.57	22.8	0	22.8
Total					433.7	0.4	433.6

Appendix Table 1: 12 CWR and IWR for Barley

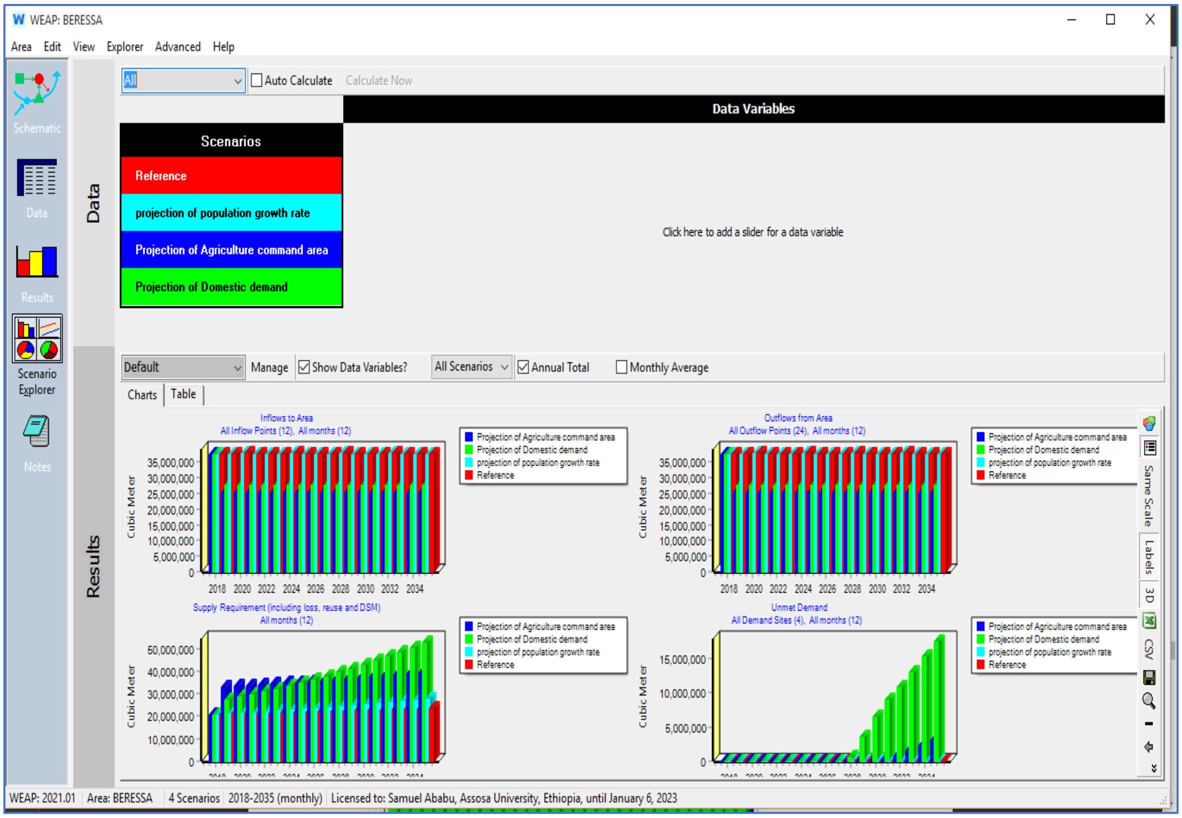
Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Oct	2	Init	0.3	1.62	11.4	0	11.4
Oct	3	Deve	0.32	1.66	18.2	0	18.2
Nov	1	Deve	0.58	2.9	29	0.1	28.9
Nov	2	Deve	0.91	4.36	43.6	0	43.6
Nov	3	Mid	1.12	5.24	52.4	0	52.4
Dec	1	Mid	1.12	5.11	51.1	0	51.1
Dec	2	Mid	1.12	4.97	49.7	0	49.7
Dec	3	Mid	1.12	5.15	56.6	0	56.6
Jan	1	Mid	1.12	5.32	53.2	0	53.2
Jan	2	Late	0.99	4.86	48.6	0	48.6
Jan	3	Late	0.69	3.51	38.6	0	38.6
Feb	1	Late	0.38	2.03	20.3	0	20.3
Total					472.8	0.2	472.6

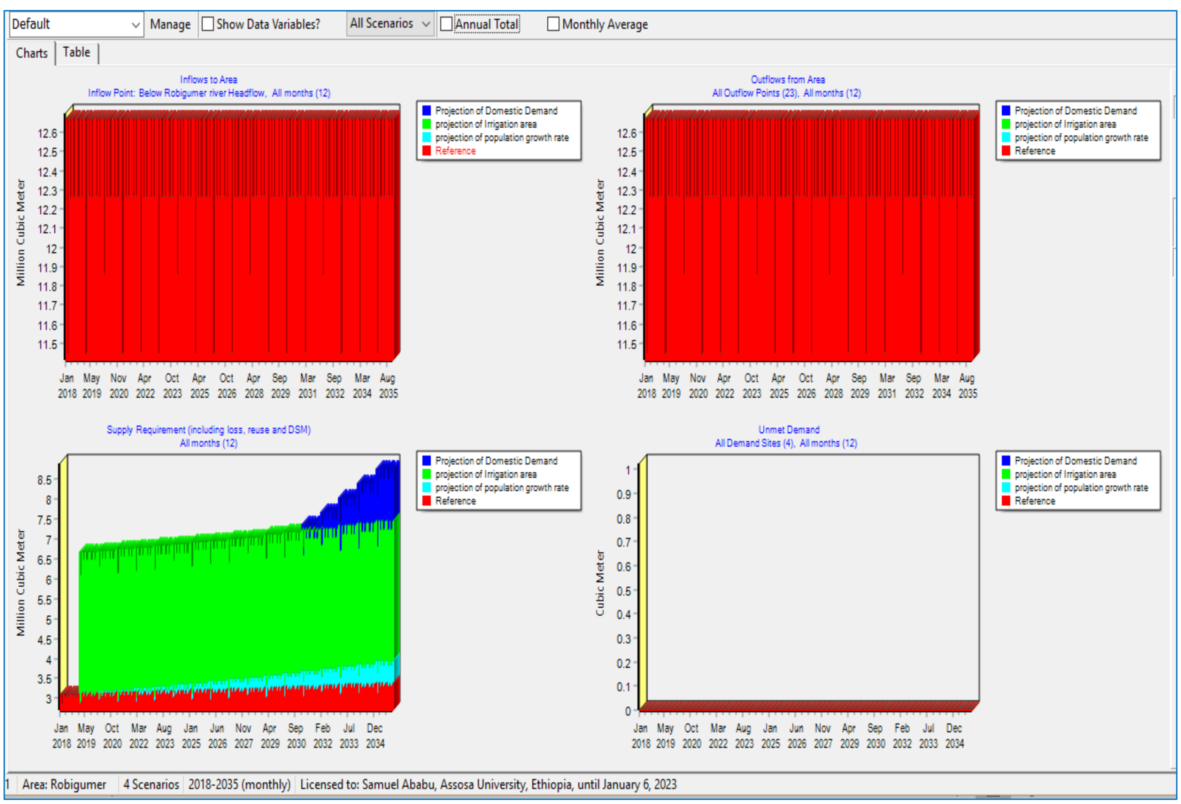
Appendix Table 1: 13 CWR and IWR for Wheat

Month	Decade	Stage	Kc Coeff	Etc. mm/day	Etc. mm/dec	Eff rain mm/dec	Irri. Req. mm/dec
Nov	3	Init	0.3	1.4	5.6	0	5.6
Dec	1	Init	0.3	1.36	13.6	0	13.6
Dec	2	Init	0.3	1.33	13.3	0	13.3
Dec	3	Deve	0.34	1.54	17	0	17
Jan	1	Deve	0.58	2.77	27.7	0	27.7
Jan	2	Deve	0.86	4.18	41.8	0	41.8
Jan	3	Mid	1.09	5.56	61.2	0	61.2
Feb	1	Mid	1.11	5.93	59.3	0	59.3
Feb	2	Mid	1.11	6.17	61.7	0	61.7
Feb	3	Mid	1.11	6.45	51.6	0.1	51.5
Mar	1	Late	1.09	6.57	65.7	3.2	62.5
Mar	2	Late	0.86	5.39	53.9	4.8	49.1
Mar	3	Late	0.57	3.62	39.8	5.6	34.2
Apr	1	Late	0.35	2.26	11.3	3.3	8
Total					523		506

Appendix Table 1: 14 CWR and IWR result for Garlic

Month	Decade	Stage	Kc Coeff	Etc. mm/day	Etc. mm/dec	Eff rain mm/dec	Irri. Req. Mm/dec
Oct	3	Init	0.7	3.65	29.2	0	29.2
Nov	1	Init	0.7	3.5	35	0.1	34.9
Nov	2	Init	0.7	3.36	33.6	0	33.6
Nov	3	Deve	0.72	3.39	33.9	0	33.9
Dec	1	Deve	0.79	3.61	36.1	0	36.1
Dec	2	Deve	0.86	3.82	38.2	0	38.2
Dec	3	Deve	0.94	4.29	47.2	0	47.2
Jan	1	Mid	0.98	4.63	46.3	0	46.3
Jan	2	Mid	0.98	4.78	47.8	0	47.8
Jan	3	Mid	0.98	4.99	54.9	0	54.9
Feb	1	Mid	0.98	5.21	52.1	0	52.1
Feb	2	Mid	0.98	5.42	54.2	0	54.2
Feb	3	Late	0.92	5.34	42.8	0.1	42.6
Mar	1	Late	0.81	4.91	49.1	3.2	45.9
Mar	2	Late	0.71	4.45	31.2	3.4	26.4
Total					631.3	6.8	623.1





Appendix Figure 1: 4 WEAP model results

Appendix Figure 1: 5 Pictures of study area