MODELING OF SURFACE WATER RESOURCES FOR WATER ALLOCATION: A CASE STUDY IN UPPER GIDABO WATERSHED, GIDABO SUB BASIN, ETHIOPIA

MSc. THESIS

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We, the undersigned, members of the Board of Examiners of the final open defense by Tamirat Shuke Kitawa have read and evaluated his thesis entitled "**Modeling of surface water resources for Water allocation: A Case Study in Upper Gidabo watershed, Gidabo Sub-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 of Master of Science in Water Resource Engineering and Management.

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DEDICATION

I dedicated this thesis document to my father: Ato SHUKE KITAWA and my mother: W/ro ARSHITU SIRATE for their amazing and continuous supports me with care and love for the success throughout my life.

DECLARATION

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 studies. 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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LIST OF ABBREVIATIONS AND ACRONYMS

BCM	Billion Cubic Meter
CIWD	Commercial and Institutional Water Demand
CSA	Central Statistical Agency
CWR	Crop Water Requirement
DEM	Digital Elevation Model
DFID	Department for International Development
DHI	Danish Hydraulic Institute
DMC	Double Mass Curve
DSS	Decision Support Systems
DWD	Domestic Water Demand
EFR	Environmental Flow Requirement
ETc	Crop evapotranspiration under standard conditions
ETo	Reference evapotranspiration
FAO	Food and Agricultural Organization
GIS	Geographic Information System
GWP	Global Water Partnership
ITCZ	Inter-Tropical Convergence Zone
IWD	Industrial Water Demand
IWR	Irrigation Water Requirement
IWRM	Integrated Water Resource Management
Kc	Crop coefficient
LULC	Land use/Land-cover
LWD	Livestock Water Demand
MCM	Million Cubic Meter
MoWIE	Ministry of Water, Irrigation, and Energy
MOWR	Ministry of Water Resource
MWSWAT	Map Window Interface for SWAT
NMA	National Meteorological Agency
NSE	Nash-Sutcliffe simulation efficiency
OECD	Organization for economic development and development
RVLBA	Rift vale lakes basin authority
SCS-CN	Soil conservation service curve number

SEI	Stockholm Environmental Institute
SNRSAFRA	Sidaama national regional state Animals and Fish resource Agency
SUFI2	Sequential uncertainty fitting version 2
SWAT	Soil water assessment tool
TLU	Tropical Livestock Unit
UN	United Nation
UNESCAP	United nations, Economic and social commission for Asia and pacific
USDA	United states Department of Agriculture
USGS	United states goggle survey
WEAP	Water Evaluation and Planning
WRAM	Water Resource Allocation and Management
WRMP	Water Resource Management Policy

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ABSTRACT

The processes of population increase, urbanization, industrialization, and dependency ratio has resulted in a rapid demand increase for water resources in the developing world. Water managers in the watershed of the developing world face the increasingly difficult task of allocating the limited water resources among competing users for fulfilling their demands due to difference in available resources and water demand increment. Water resources management has limited in the Upper Gidabo watershed and there is traditional water allocation are vastly practiced. This was due to lack of sufficient awareness about available water resources and management in watersheds. Understanding the potential and use of surface water in upper Gidabo would help to increase the productivity of Agriculture and other sectors, to improve the traditional water management system. Therefore the objective of this study was to Modeling of surface water resources for water allocation under developed scenarios for maximizing overall benefits without compromising ecological requirements in the Upper Gidabo watershed in Gidabo sub basin. To achieve the aim of this study soil and water assessment tool (SWAT) model was used to determine the available surface water resources of the watershed after sensitivity analysis, calibration and validation of the model by SWAT_CUP sufi-2 algorithm. The simulated result revealed that the total average surface water potential from the watershed was 773.5 MCM annually during the study period (2021). Both the calibration and validation result for Aposto and kolla gauging station showed a good performance with a value of R^2 and NSE of 0.83 and 0.65 for calibration and 0.81 and 0.6 for validation in Aposto and 0.79 and 0.62 for calibration and 0.78 and 0.61 for validation in Kolla gauging station, respectively. After this Water Evaluation and Planning (WEAP) model was used to assess water demands. To assess irrigation water requirement of the sixteen (16) crop types CROPWAT 8.0 software was used. After assessing the currently existing demands Different scenarios were also developed to determine the future water demand, and unmet demand from overall time period of 2021-2050, This scenarios namely: reference, population growth and increased water demand scenario was established to determine increasing demands under increasing human as well as Livestock population, agricultural areas and different industrial activities. The current (2021) utilization is about 110.4 MCM for consumptive use and non-consumptive (EFR) use, For EFR 10% considered from available flow to maintain ecological functioning and water resource development in the watershed. The current demands fully met with available flows and for scenarios the assessed total annual water demand may be expected to be 126 MCM, 195.1 MCM and 341.8 MCM for the reference, high population growth, and increased water demand scenarios, except increased water demand scenario the other scenarios is met fully, It is appropriate to shape more effective policies and regulations in the area for effective water resources management in reducing water shortage and achieving downstream water needs in the future.

Keywords: Priority, Demand, Scenarios, Simulation, Water availability, Water Allocation, CROPWAT, SWAT, WEAP

1. INTRODUCTION

1.1. Background of the study

Water is a precious natural resource required for the survival of all living beings (Jayasekera, 2013). And it is necessary for all forms of human, animal and plant life, it is essential for overall human well-being and supports all aspects of human livelihoods. Furthermore, water plays an important role in supporting productive human activities such as agricultural, energy and industrial production, sanitation, transportation services, fishing and tourism (UNEP, 2009).

Water resources are the critical components for the development of countries and we can understand that "water-based development" is significant to the growth and transformation of the country. The World Summit on Sustainable Development in 2002 drawing more attention to the importance of water resources management in meeting the Millennium Development Goals (UN, 2002). And the Ethiopian growth and transformation plan also considers and aims to increase the uses of the country's water resources (MOFED, 2010)

Nowadays, water resources development and management remain at the heart of the struggle for sustainable development, growth, and poverty reduction (Daniel et al., 2011) Even though it has been the case for all industrial and developing countries, developing countries such as Ethiopia, for unmet challenge managing our water legacy is almost without precedent Unless we are unable to overcome our unmet problem, sustainable growth and poverty reduction.

(OECD, 2018) was indicated that the demand will rise by 55% in 2050; over-abstraction and contamination of water resource worldwide will pose significant challenges to food security, the health of ecosystems and water supply, and can increase the risk of subsidence. Therefore, necessitates equitable and reasonable utilization of water resource which can implement through properly instituted water governance system. (Zbelo & Achameleh, 2022)

Water governance relates to the rules, structures and powers of Management and regulation of water is the system that regulates the determination of "who gets what water ,when and how, and who has the right to water and its related services and their benefits" generally governance implies management and regulation of the public good that goes beyond the centralized nation-state due to this governance is dynamics and can be affected by plurality that means allocation water resources for all sectors was impossible so, in a water governance

system, prioritization of water use rights is considerd as one of the key principle. (Zbelo & Achameleh, 2022)

Ethiopia's surface water potential is large and it is the key for development of the country, but very little of it had developed or utilized for the irrigation development, hydropower plant development, municipality, Domestic water supply, and other purposes (MoWIE, 2012) As we know, Ethiopia has twelve major river basins, including the Rift valley lakes basin, combined with its eleven major lakes, make Ethiopia the "water tower" of Northeast Africa However, the country cannot fully mitigate the impact of hydrological variability through water infrastructure and management investments alone.

Water demand is increasing as a result of the rapid population growth, agricultural expansion, Industrial development, and higher standards of living in addition to climate change. The current world population is 7.9 billion as of December (worldometer, 2021), based on (Worldometer, 2020) estimates elaborates in 2020 World population growing rate is about 1.05% annually, we expect the total population to rise from 7.8 billion to over 10 billion in 2057. Virtually, all of the increase will be located in the developing countries like Ethiopia.

Ethiopia is a country with a high population number in the continent of Africa second to Nigeria, in which 85% of the population lives in rural areas and they are depend on Agriculture and most of them are in highland areas (Bekele et al., 2021) and a country which belongs to with increasing number of population, Based on (UN, 2022) estimation in Ethiopia on July is 123 million, growth rate is 2.7% per annum and population density 123 per km^2 and According to (RVLBA, 2010) in the RVLB as well as the Upper Gidabo sub-basin is also known by high population density and population dependency ratio (90 to 10), and furthermore most of the increase in the foreseeable future will be urban less in rural.

In order to ensure food security at the house hold level for Ethiopia's fast growing population, to transform the rainfed agricultural system which depends on rainfall into the combined rain fed and irrigation agricultural system, more small, medium and large scale irrigation needs to be developed (Makombe et al.,2011). To overcome needs that in Ethiopia different sectoral growth is important including Irrigation development is also necessary for the sustainable and reliable agricultural developments in Ethiopia to meet food security and poverty reduction (Haile & Kassa, 2015).

In the RVLB including the study area, the potential irrigable land was about 37 million hectares, but presently irrigated area ranges between 150,000 and 250,000 hectares which is less than five percent of potentially irrigable land (Seleshi et al., 2007).

According to (RVLBA, 2010) surface runoff was up to 5.6BCM and in the Upper Gidabo watershed the river flows from the northeast and crosses the highway of Addis Ababa to Dilla at Aposto Town where it is gauged, the average flow of the river at the Aposto station was up to 17.35 m^3/s, but in this area the rainfed traditional Agriculture is showing that water resources have yet made little contribution towards the development of irrigated Agriculture; it needs more consideration to achieve rapid and sustainable economic growth of the watershed.

Ethiopia follows Agriculture leading industrial development (AGRLI) to reduce the poverty, in case of study area there is Industries that to process Agricultural products like coffee processing sites are utilize water for washing coffee and prepare for export additionally other Agro processing Industries that is Yirgalem industrial park need water for processing different agricultural products for external and internal export (SCPZ, 2018) So, organize information related to potential, the utilizers and unmet demands are essential due to they need water for the processing.

Increased demand of water causing supply variation that increases the uncertainty of water allocations (Gleick & Heberger, 2013). Moreover, many emerging and developing countries lack adequate supply of water for different uses due to inefficient infrastructural and allocation arrangements (Sampath et al., 2015) In addition, insufficient knowledge of available water resources, lack of coordination in water resources allocation and management, and drought episodes in the river basin often result in water deficits and the over exploitation of limited water resources which have hampered the harmonious development and destroyed the ecological balance in the basin (D. Myronidis, 2012) Therefore, the ability to modeling the availability of freshwater resources has been an issue of importance in most countries for many decades (WMO, 2012)

Effective water resources development, integrated water resources management and sustainable water resources utilization are the best option and recognized as a tool for sustainable economic growth, poverty reduction and water related conflict management in developing countries (McCartney, 2010); (Mayol, 2015). In the context of water management, decision makers in the arid and semi-arid states face a question about how much water should

be allocated among competing users. Around one-fifth of the world's population currently lives in water scarce areas, and more than two-thirds were live in areas with physical or economic water scarcity by 2025 (UN WATER, 2007).

In the context of a river basin, allocation priority becomes important when the full water rights of all water users cannot be supplied. A prioritized system allows the water managers to take control over the water use in a river basin by allocating water in a preferred order. This preferential order could be based on regional or national objectives (Weragala, 2010). In the study area priority or the most utilizer based allocation method was also used to allocate available water resources.

The complexity of the water allocation task and the increasing pressure on water (increasing demand and variability) has stimulated the revision of water allocation goals and means in many countries (Roa-garcía, 2014). Therefore, priority based water allocation requires the understanding of water availability and reliability with considering the equity, efficiency and sustainability as the key principles in water allocation.

Water allocation models are useful because, they are simulating scenarios of situations encompassing complicated hydrological, Environmental and socio-economic factors, they can provide insights into the likely impacts of different development options (McCartney, 2007). Although there are many types of hydrologic and water resources models capability of simulating surface runoff and demands in a given catchments. Among these models, SWAT model selected to simulate surface runoff as well as others hydrological parameters and WEAP used for demand assessment and water allocation through different scenario in the Upper Gidabo watershed.

The upper Gidabo watershed used as an important source of food, for Domestic water supply, Agriculture, Industry, Wildlife, Grazing and Livestock, and as a repository for human and Agriculture. This makes the issue of water resources very crucial for water managers and advances livelihoods in the watershed. Surface water resources modeling portion of this study focused on surface water that can be stored in different rivers as a form of runoff whereas water demands assessment portion for allocation includes sectors like Domestic, Agriculture, Industrial, Livestock, Commercial and Environmental water demands in the watershed.

1.2. Problem Statement of the Study

Rift valley lakes basin is hydrologically different in that contains many lakes than rivers, some of this lakes are connected and all connected system are terminal, terminal lakes are sensitive, fragile, sink to pollutants, and constantly receiving in and never release them, This makes Environmental and management is important to resource and habitats existence to the lakes, so it is better to manage river in the basin and to conserve lakes (Akililu M., 2020) and the Gidabo river as well as Upper Gidabo watershed one of the source for Abaya lake so, allocate this resources are important manage the water resources, for environmental protection and for sustainable source for this lake.

Water demands in basins of Sub-Saharan Africa and in other parts of the world are increasing due to rapid urbanization, poverty and food insecurity, population growth, growing energy demands and climate change (Faurès & Santini, 2008)

Ethiopia has significant surface water resources and groundwater. based on different studies overall water resources are developed annually due to study profusion, According to (MOWIE, 2014) water potential was up to 153 BCM and based on (World Bank, 2014) population number reach up to 99.75 million from this amounts to 1534 m^3 of water per person per year and Right now MOWIE (2021) Water potential is up to 166BCM and population number up to 123 million from this amounts to 1350 m^3 of water per person per year. As we compared the water development per capita water supply increase but population growth increase rapidly, due to this per capita water supply decrease so allocate water resources from small to large scale watershed including Upper Gidabo watershed is urgently needed to achieve needs of this increase population

The population and dependency ratio increase was a reason for allocation, management and conservation of water resources. In the watershed population number and dependency ratio increase, According to RVLB master plan study was almost 90% dependency ratio, which means that for every 100 people there are 90 dependents in the basin including the watershed. So protecting, utilization and creating allocation mechanism is essential to reduce the growing demand in the Upper Gidabo watershed.

Upper Gidabo watershed is suitable land to Agriculture but most parts of the watershed depends on rainfed Agriculture and productivity is less due to season dependent cultivation and there is a desperate need to increase water uses for food, raw materials, for Industries, to

fulfill needs of the environment and other uses, therefore water allocation among competing water users are urgently required.

In the study area less studies was done related to water allocation cause uncertainty in the information related to surface water supply, utilizers and to enlarge other sectors development to fulfill unmet demands, so in order to fill the study gap as well as to utilize available surface water resources and the study like this is very important and different sectors are need to utilize the resource from them Yirgalem agro-industrial parks need water for agro-processing due to the problem of knowing the water potential (supply) and demand (how much water needed by the farmers for Agriculture (including irrigation), coffee processing Industries and other sectors in the area) due to this they can't use this water they depend on Ground water, it needs large economy to use in the sectors (SCPZ, 2018).

Water resources less developed in the upper Gidabo watershed and there is no formal water allocation practice in place for proper and sustainable utilization. Therefore a need to determine available surface water potential and formulate the allocation mechanism for IWRM, conservation and sectoral development to ensure growth the surface water quantification and demand assessment in a given watershed will be of great importance, generally this study will have a profound importance and contribution to achieve District, Regional and National level development and efforts for implement conservation, IWRM the study like this very important.

1.3. Objective of the study

1.3.1. General Objective

The overall aim of this study was to modeling the surface water resources for water allocation in Upper Gidabo watershed, Gidabo sub basin for social, economic, and Environmental benefits.

1.3.2. Specific objectives

- To determine surface water potential of the Upper Gidabo river watershed,
- To assess sectoral water demands at the current year and through future scenario development in the watershed;
- To analyze the impact of different scenarios on water demand in the current and future years for care, protection, sustainable use and IWRM of water resources.

1.4. Research Questions

To reach the objective of the study, these questions need to be answered; the specific research question of the study formulated as follows:

- What is the available surface water potential in the river of the watershed?
- What are the potential water demands currently in the watershed?
- What will be the projected change demands in different management scenario?
- Is there enough surface water in the watershed to satisfy the current account year and future demands?

1.5. Significance of the study

The Upper Gidabo watershed was facing the limitation in utilization of the surface water resources based on the rainfall, river flow received and traditional way of follow to utilize available resources in the area, it would be expected that this water represent a valuable resource for the population. This study expected to contribute a lot endeavor and improving the different problems occurring in the area. As a contribution to the national efforts, this study of the surface water potential and allocation at the watershed will have a paramount importance to understand the better picture of water resources in the study area.

Management of natural resources alike are also enhances benefits to all competing sectors. Conflict can be reduced and benefits maximized if decision makers involve stakeholders in their decision for allocation of water resources between competing needs (Seleshi et al., 2007). Sustainable, well managed and regulated water resource development is equally important to prevent further degradation of water sources.

The use of modeling tools to perform simulation and scenario analysis is an important approach to developing catchment management strategies and achieving integrated management of catchments (DWAF, 2007). Computer-based Decision Support Systems (DSS) are very useful tools for this because they allow the user to forecast and evaluate the impacts of different possible future trends and management strategies before implementing them.

The Upper Gidabo watershed is that need an allocation for IWRM. As a contribution to the regional and national efforts, this study of the surface water potential, demands and scenario development at the watershed will have a paramount importance to understand the better

picture of water resources and water demands for different competing sectors and It can be also used as decision support system for development of different water resource projects, and provide information for the government, planners, decision makers and concerned persons while designing and developing new irrigation schemes and new projects in the watershed.

1.6. Scope and limitation of the study

This research focused on modeling of surface water resources for water allocation in Upper Gidabo watershed, Gidabo sub basin, for utilization of surface water resources in sustainable manner for social, Economic, Environmental benefits, and the watershed located in the Sidaama Region in northern part of Gidabo sub basin include Gorche, Hawella, Shebedino, Wonsho, Dale, Burrisa and Aletawondo Districts.

The allocation of the surface water resources to the most dominant users: Agriculture (including irrigation), Domestic, Commercial and institutional, Livestock, Industrial and for environment use in the watershed. Additionally the study focuses on surface water resources potential and demands through scenario analysis and effective water management in Upper Gidabo watershed. It specifically, focuses on determination of the annual available water resources, current water demands and future scenario development.

This study does not involve ground water resources due to limited set of data availability and needs expensive or vast experimental programs at all.

2. LITERATURE REVIEW

2.1. Overview of Surface Water Potential

Water resources are the central elements for the event of Ethiopia as well as in the whole world. We know that "water-centered development" is important to the growth and transformation of the country. The growth and transforming plan also considers and aims to improve the uses of the country's water resources (MOFED, 2010).

Ethiopia has 12 river basins that provide an estimated annual runoff of approximately 125 BCM (Seleshi., 2010). The estimated amount of annual groundwater recharge of the country is about 28 BMC (MoWIE, 2014). The country has ample surface and ground water potential, but water utilization by all standards is very poor because of economic water scarcity, and due to emerging drivers such as development and climate change induced variability, and this water insecurity is affecting many regions or communities (Tena et al, 2015).

The Rift Valley Lakes Basin (RVLB), which forms the southern part of the Main Ethiopian Rift, covers an area of about 53,000 km² and extends south from the upper catchments of the Awash Basin to the Kenyan border, to the extreme south of ChewBahir. This Basin lies both in the Oromiya and SNNP Regional States right now including Sidaama region. RVLB consist of 4 sub-basins and 14 watersheds. Most of Rift valleys lakes are exist in the Basin; the total surface water resource of the RVLB is estimated at about 5,300 MCM/year, calculated from total annual average river flow into the lake systems under 'natural' conditions without human abstractions.

The Gidabo Sub-basin is one of sub-basin of RVLB. Based on (Mihret et al., 2022) study the surface water potential of the watershed varies spatially from sub-basin to sub-basin, and the mean monthly surface water potential of the Gidabo watershed is 33 million cubic meters and the upper Gidabo watershed considered on this study are one of the watershed exist in the upper part of Gidabo watershed and in the study area two(2) gauging station namely Aposto and kolla, Aposto gauging station on the study area average flow of the river is 17.35m^3/s (RVLBA, 2010). A lot of activities that demands water in the Upper Gidabo watershed such as Domestic, Agriculture including Irrigation, Livestock, Industrial, Commercial, Environmental and others are Utilizers in the watershed, but the total available surface water from the watershed to be used was not quantified as a whole and no scenario was developed for the future use.

2.2. Water Demands and Demanding sectors

Water demand is defined as the volume of water requested by users to satisfy their needs. Water demands predicting are also a process achieved through several techniques and is typically used to predict future water needs for different uses including, Domestic, Agricultural, Industrial, Livestock, Commercial, and Environmental water demands. The type of technique used depends on the availability of the data needed, the general scope of the region for which the forecast is being conducted, and the resources available to the organization for which the forecast is being conducted. For all intents and purposes, future water demand is derived from basic functions. For instance, Industrial demand is often based on the number of employees, Agricultural demand commonly relies on crop type and irrigated land (Water Resources Planning and management) (Dzuirk A., 1996)

The key variables such as population growth, urbanization, increasing irrigation water consumption, changes in cropping patterns, increasing productivity of rain fed Agriculture and the water demand for environment and pollution controls were considered in estimating future water demand.

Over the years, Population growth, Urbanization, Industrialization, and the expansion of Irrigated Agriculture are arresting rapidly increasing demands and pressure on the water resources, besides contributing to the rising of water pollution (GWP, 2010). The quantity of water that the population uses depends on minimum needs, amount of water available for use, level of economic development and extent of urbanizations.

Although Ethiopia's surface water resources are huge, very small volume of it has been developed for Domestic, Irrigation, Livestock uses, Industrial processes, Environmental, and other purposes. In order to satisfy the demands of water of different users, efforts should be intensified on the efficient use of all water resources (surface water, groundwater, and rainfall) and also on water allocation plans that increase the overall economic returns to limited water resources and, equally protect the fragile ecosystem.

Water demand is important technical design parameter. As we know there are three types of water uses such as Withdrawals or abstractions, consumptive and non-consumptive water uses and Water demanding sectors discussed below in detail as per my study area.

- **Withdrawals or abstractions:** - where water is taken from a surface or ground water source and after use returned to a natural water body, e.g. water used for cooling in

Industrial processes that is returned to a river. Such return flows are particularly important for downstream users in the case of water taken from rivers and this type of utilization as per my study area is less.

- **Consumptive water use: -** in this case water consumption starts with a withdrawal or abstraction but, there is no return flow. Water consumption means water abstracted and after that no longer available. Due to, process of evaporation, transpiration, assimilation into crops or products, consumption by humans or Livestock and as a result, removed from freshwater.
- **Non-consumptive water use: -** refers to the insitu use of water body for navigation, flow requirement for fish, recreation, hydroelectric power and effluent disposal.

2.2.1. Agricultural Water Demand (AWD)

Agriculture is the key sector of the Ethiopian economy and contributes approximately 42% to the gross Domestic product (GDP) and in employment over 80% of the population employed by it (MOFED, 2010).

Ethiopia has a significant irrigation potential identified from both available land and water resources, Agriculture would supply irrigators with sustained livelihoods and improve general wellbeing but it covers 4 to 5% of potential area has been developed for irrigation. Irrigation is the process by which water is applied to the soil artificially and which can increase agricultural production can be increased to meet the growing demands in Ethiopia (Seleshi et al., 2007) Struggles are being made to involve farmers gradually in various aspects of management of small, medium and large scale irrigation systems, starting from planning, implementation, and management aspects, particularly, in water distribution, operation and maintenance to increase the irrigated Agriculture productivity.

With regard to Irrigation, there is some scope for irrigation development in some areas of the basin. There are about 153,000 ha which may be developed in the RVLB with relatively small impacts on the lake environments and which may be considered sustainable (RVLBA, 2010) In the Gidabo watershed is one of these areas with more suitable land for irrigation development in Sidaama Regional government and District administration prepare plan for small scale to medium scale irrigation to cultivate land by this river flow and irrigation demand in the upper Gidabo watershed were carried out existing irrigation projects and for irrigable potential areas which will be developed for future periods (planned schemes).

Irrigation potential analysis includes commercial, traditional small-scale, and community schemes.

2.2.2. Domestic water demand (DWD)

Domestic water is used mostly for indoor and outdoor household purposes includes drinking, cooking, washing, bathing, flushing toilets, swimming pools, watering lawns and gardens and somewhere it is used for transporting Domestic wasted own sewers. This Domestic water demands is not uniform in urban and rural parts of the country. The amount water required for supporting life and health in both urban and rural centers varies with climate, the general state of health of the people affected and their level of physical fitness.

In developing countries including Ethiopia daily per capita, water consumption is generally very low throughout the country. DWD is less in almost all towns in the country because of supply shortages. Actual demand is expected to be greater than present consumption if greater supplies were available to the community.

In estimating DWD, general design standards of (MoWR, 2010) were adopted it consider population increase in urban areas for category-1 to category-5 towns : 40 to 100 l/d and constant for rural areas that is 25l/d For both rural and urban areas, Water demand for small towns (with fewer than 10,000 inhabitants) was estimated applying the rural standard and for urban centers DWD Drinking water 5 l/p/c/d, Sanitation services 20 l/p/c/d, Bathing 15 l/p/c/d, Cooking and kitchen 10 l/p/c/d (MoWR, 2010).

Table 2.1: Recommended minimum demand for Domestic requirements

Towns category	Water consumption (l/c/d)	Population
category 1	100	>1,000,000
category 2	80	100,000-1,000,000
category 3	60	50,000-100,000
category 4	50	20,000-50,000
category 5	40	<20,000
Rural	25	<10,000

(Source, MoWR, 2010)

The water demand per site is calculated with the total activity level or the annual water demand per person per capita or as well as the together with the monthly variations.

To determine annual water demand per person getting the actual population number is very important so, direct population count and projection based on pre-counted population are two

possible approaches to collect population data. However, since direct population count at any time requires a great deal of resource and time, it is not usually preferred so, in this study indirect method is applied. Different population forecasting methods are available like Arithmetic increase method, Geometric increase method, Incremental increase method, Ratio method, curvilinear method, and others can be used for population projection. But their result varies from one method to another. For growing town, where relatively high economic activity is observed and rural areas having possibility of growth Geometric method population projection for future period is preferably used. Geometric population forecasting method is applied and expressed as follows;

$$P_n = Po\,(1+K)^n \text{ ---------- } (2.1)$$

Where; Po = initial population, Pn = Population at n decade or years, n=decade or year

K = percentage (geometric) increase

2.2.3. Commercial and institutional water demand (CIWD)

In addition to Domestic household consumers, the water requirements of towns include the needs of such commercial and institutional consumers such as public gardens, schools, clinics, hospitals, offices, shops, bars, restaurants, hotels and other institutions. CIWD is usually linked directly to population size. For small and medium-sized towns, it was estimated at 5 percent of the DWD and. For larger towns, the CIWD estimate was 10 percent of DWD. Those allowances were applied to all towns. No allowances were made for CIWD from rural communities. (MoWR, 2010)

2.2.4. Industrial water demand (IWD)

Water used for Industry expansion is categorized under Domestic use, Industry is made up of several components, especially in estimating water demand. Industrial water demands are linked to both urban and rural areas, because there will be significant small scale Industry developing in rural areas based around agricultural production. Within urban water supply systems, water is used non-Domestically in commercial services, public services and industrial establishments. Commercial services such as hotels, restaurants, private healthcare providers, private schools and colleges are major consumers of non-Domestic water utilizers. Policy decisions are necessary concerning the acceptable decline of lake levels and loss of lake area in the RVLB (RVLBA, 2010).

According to (Mayol, 2015)(Tilahun, 2015) for planning purposes, a reliable industrial water demand indicator was assumed to 10%-30% of Domestic water demand depend on size of towns and number of available industrial zones. In the upper Gidabo watershed stretches from Gelala summit to Aletawondo districts on these areas Industries especially coffee processing sites are many in number above two hundred (200), so, they are need and utilize ample water currently in different Districts on the study area.

2.2.5. Livestock Water Demand (LWD)

Ethiopia's Livestock population, one of the largest in Africa, puts additional pressure on water and land resources. This Livestock sector is important for the economy of the country (CSA, 2013/14). Water resource is pertinent and vital for the existence and development of Livestock sector; there are three sources of water for the animal: (1) Drinking water (2) water contained in the feeds and (3) Metabolic water

One of the first steps required for the Livestock water use study is to gather proper information of the animals like their populations, the conditions in which they are managed, and others. Water requirements vary considerably depending on the species of the animal, breed, age, growth rate, pregnancy, production status, activity, feed type, and weather. Water requirement and intake are also highly affected by climatic factors particularly environmental temperature. Up-to-date steps to calculate water requirements of Livestock species (as influenced by physiological status and Environmental conditions) can be obtained from standard scientific guidelines detailing nutrient requirements of a Livestock species. (NASA, 2016)

In many cases, water consumptions of livestock must be predicted by indirect means, based on production, feed intake, crop production, climate and other data collected during a site assessment. Often, greater than 90% of consumed water by Livestock is associated with the production of feed (Legesse et al., 2017). It is hoped that Livestock numbers will actually reduce in the RVLB over the Master Plan period as they are already far too high as a result, actually retarding economic development.(RVLBA, 2010)

To study Livestock water usage, its productivity, and related impacts, it is necessary to define the population associated with the production of the products of interest (e.g. milk, meat, eggs, etc.) and They are also source income of the area are highly relying essentially on Livestock and their products. According to the (RVLBA, 2010), International Livestock

institute (ILARI) in Ethiopia, Herlocker (1995), Water house (1982), and (FAO, 2012) TLU conversion factors and water requirements in liters for Ethiopian conditions to Animals are discussed in the table below

Table 2.2: Livestock type with TLU conversion factor and daily drinking water requirement

Livestock Type	Conversion Factors	Weight (kg)	Water requirement(l/d)
Cattle	0.7	175-350	25
Sheep and Goat	0.1	30-35	5
Horse	0.8	30	12
Mule	0.7		12
Donkey	0.7		12
Poultry (Chickens)	0.01	2.5kg	0.25-0.5
Beehives			3

2.2.6. Environmental Flow Demand

The Environmental flows are flows that are left in, or released in to, a river system with the specific purpose of managing some aspect of its condition, their purpose could be as general as maintenance of a healthy riverine system for survival of different species like fish or plants and animals in the river or how much of the original flow regime of a river should continue to flow down in order to maintain the riverine ecosystem in a prescribed state. Jain (2012) recommended that, 10 % of the natural flow of the river has to be assigned to the Environmental flow requirement (in stream flow requirement).

The environment is increasingly being considered a legitimate water user in many world countries. As a consequence, the water requirement of the environment needs to be estimated. The IWRM policy of Ethiopia recognizes that Environmental reserve has to be given the highest priority in water allocation besides meeting the basic minimum requirement for human and Livestock drinking needs (MOWR, 2001), (Tena et al., 2015).

The most important interventions in water resources development in the RVLB are conservation, watershed protection and management. As a hydrologically closed basin, the lakes of the RVLB are extremely vulnerable ecologically. The impact of uncontrolled water use is already well illustrated by the decline in Lake Abiyata and the loss of its fish habitat and that of most aquatic birds and the portion of the basin is high erosion potential and degraded. The first concern is water management and rehabilitating, reversing degraded land is the priority of RVLB to increase agricultural productivity for economic growth (RVLBA, 2010). The conservation and watershed management is needed in upper Gidabo watershed for

sustainable use and to develop water resources to fulfill or reduce for different sector utilization as well as ecosystem protection.

2.3. Integrated Water Resources Management (IWRM)

IWRM with the participation of all stakeholders promotes the coordinated management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (GWP, 2009) For the improvement of water infrastructure in the developing world, subsidies are crucial. In most river basins, mechanisms and institutions to manage water resource disputes are either absent or unsatisfactory and integrated management water needs consideration of current and future water resource availability. It involves a simulation of water demand and supply for Domestic, Agriculture, Industrial, Livestock use, Commercial, Environmental and other sectors.

Many studies in this aspect show that a practical challenge to the concept of IWRM is found at two levels. First, water related to development and societies in countless ways. Its priorities and relative importance vary extremely from one place to another. Second, water must see as one factor in a broader context. Therefore, the different concepts and related policies are not integrated. Further, there should be an emphasis on their Latinos between land use and water resources and to the integration of natural limitations, social and economic demands and legal, political and administrative processes (Mostert et al., 1999)

There is a consensus about integrated water management at the basin or watershed level as the approach is to use it for sustainable water resources management. To provide policies, strategies, legal and institutional arrangements, financial and economic instruments and relevant human and institutional capacities at the right time and in the right place and coordinated at the international, regional and river basin level is a task that can only be covered by the aggregated international community (Hofswegen & Jaspers,1999).

2.4. Water Allocation

The simplest definition of water allocation is the sharing of water among users. A useful working definition would be that water allocation is the combination of actions that enable water users and water uses to take or to receive water for beneficial purposes according to a recognized system of rights and priorities.

Water allocation is central to the management of water resources, it refers to the rules, and procedures through which access to water is decide for individual or collective use, and in relation to availability. The overall objective of water allocation is therefore, to maximize benefits of water to society (L. Wang, 2005), general objective implies other more specific objectives that can be classified as social, economic and Environmental in nature or it gives this benefits.

Due to geographically and temporally unevenly distributed precipitation rapidly increasing water demands driven by the world population, degradation of the water environment and other stresses (L. Wang et al., 2003), there are increasing scarcities of water resources in many countries. In order to achieve sustainable water management and a secured society, institutions and approaches for water allocation should reformed, especially for regions having water resources shortages and lack of know how to manage water resources.

2.4.1. Principles of Water Allocation

Basin water allocation planning is typically undertaken to achieve a series of overarching objectives including equity, Environmental protection, and development priorities, balancing water supply and demand and promoting the efficient use of water. The basic principles for the allocation of water resources are efficiency, equity and sustainability, with the aims of pursuing the maximum benefit for society, the environment and the economy, whilst maintaining fair allocation among various areas and people (J. F. Wang et al., 2007).

Equity means the fair sharing of water resources within river basins, at the local, national, and international levels. Equity needs to be applied among current water users, among existing and future users, and between consumers of water and the environment. Since equity is the state, quality, or ideal of being just, impartial, and fair, and different people may have different perceptions for the same allocation (Abdulaahi, 2015)

Efficiency is the economic use of water resources, with particular attention paid to demand management, the financially sustainable use of water resources, and the fair compensation for water transfers at all geographical levels. Efficiency is not so easy to achieve, because the allocation of water to users relates to the physical delivery or transport of water to the demanding points of use. (Abdulaahi, 2015)

Sustainability advocates the environmentally sound use of land and water resources continuously. This implies that today’s utilization of water resources should not expand to

such an extent that water resources may not be usable for all of the time or some of the time in the future (Abdulaahi, 2015)

Table 2.3: Objectives and Principles of water allocation Source: UNESCAP (2000)

Objective	Principle	Outcome
Social objective	Equity	Provide for essential social needs: Clean drinking water for sanitation and Food security
Economic objective	Efficiency	Maximize economic value of production: Agricultural and industrial development Power generation Regional development Local economics
Environmental objective	Sustainability	Maintain Environmental quality: Maintain water quality Support in stream habitat and life Aesthetic and natural values

2.4.2. Criteria for Allocation

Appropriate means of resource allocation are necessary to achieve optimal allocation of resource. Several criteria are used to compare forms of water allocation (Weragala, 2010) such as:

- Flexibility in the allocation of supplies;
- Security of tenure for established users;
- Real opportunity cost of providing the resource is paid by the users;
- Predictability of the outcome of the allocation process;
- Equity of the allocation process;
- Political and public acceptability; an additional set of criteria should include
- Efficiency, so that the form of allocation changes existing undesirable situation such as depletion of ground water, and water pollution, and drives towards achieving desired policy goals.
- Administrative feasibility and sustainability, is to be able to implement the allocation mechanism, and to allow a continuing and growing effect of the policy.

2.4.3. Selection Criteria of Models

So as to select the hydrological model, we consider different criteria. Most of the time these criteria were depends on research problems, research objectives, personal preference, and computer operating system. These are required model outputs for the needed Purpose, different hydrological processes that are required to be modeled for the desired purpose, input data availability and price. The hydrological practice would be improved if models were

objectively chosen on the basis of making the best use of the information available and following some systematic procedure of selection and verification

There are a lot of criteria that can be used for selecting the suitable model

- Required model outputs important for the needed purpose and to be estimated by the model - does the model predict the variables required by the project.
- Hydrologic processes that need to be modeled to estimate the desired outputs adequately.
- Availability of input data: - can all the inputs required by the model be provided within the time and cost constraints of the project
- Price - does the investment appear to be worthwhile for the objectives of the project?
- Based on the type problem considered:- The nature of the physical processes involved, The use to be made of the model, The quality of the data available and The decisions that rest on the outcome of the model's use

2.5. Models specification

2.5.1. Hydrological models

Hydrological models are a simplification of a real-world system (e.g. surface water, soil water, wetland, and groundwater) that aids in understanding, predicting, and managing water resources. Modeling of the rainfall-runoff processes of hydrology is needed for many different reasons the main reasons are being limited range of hydrological measurement techniques and limited range of measurements in space and time.

Hydrologic models can be further divided into continuous-process (has models capable of simulating both short-term and continuous events), event-driven models (are models designed to simulate individual precipitation-runoff events). Their emphasis is placed on infiltration and surface runoff. On the other hand, continuous-process models simulate daily, monthly or seasonal stream flow, usually for long-term runoff-volume forecasting and for estimates of water yield (Cunderlik, 2003)

Many Rainfall runoff models are used simply for research purposes in order to enhance the knowledge and understanding about the hydrological processes that govern a real-world system. Examples of some of the implications of latter type of Rainfall runoff models are: real-time flood forecasting and warning, estimating flood frequencies, flood routing and

inundation prediction, impact assessment of climate and land use change and integrated watershed management. Additionally Hydrological models are mathematical descriptions of components of the hydrologic cycle. Based on process description, the hydrological models can be classified in to three main categories they Lumped, Distributed and semidistributed models

Lumped models treat the catchment area as a single homogenous unit 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 response of individual sub-basins. (Pechlivanidis et al., 2011)

Parameters of **distributed models** are fully allowed to vary in space at a 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 amount of (often-unavailable) data and very specific data at grid scale level. However, the governing physical processes are modeled in detail, and if properly applied, they can provide the highest degree of accuracy (Pechlivanidis et al., 2011).

Parameters of **semi-distributed** (simplified distributed) models are partially allowed to vary in space by dividing the basin in to a number of smaller sub-basins. The main advantage of these models are that their structure is more physically based than the structure of lumped models, and they are less demanding on input data than fully distributed models. The benefits of a semi-distributed model are fast computational time and the ability to use less data and fewer parameters than a distributed model (Pechlivanidis et al., 2011).

SWAT (Arnold et al., 1998), HEC-HMS (USACE, 2001), HBV (Bergström, 1995), TOPMODEL (Beven and Kirkby, 1979), Crawford and Linsley (1966 are considered as semi-distributed models and used for comparison to select the best model for this study.

Generally, for this study, from discussed models semi-distributed models are selected because their structure is more physically based than the structure of lumped model, and they are less demanding on input data than fully distributed models

1. Hydrological Engineering Center Hydrological Modeling System (HEC-HMS) Developed by US Army Corps of Engineers Hydrologic Engineering Center is designed for both continuous and event-based hydrologic modeling. Initially it was developed to simulate

the precipitation-runoff processes of dendritic watershed and later it solves problems including large river basin water supply, flood hydrographs, and watershed runoff (USACE HEC, 2010). Strength of this model is simulate short and longtime runoff events, simple to operate, it needs smaller data than SWAT model and Limitations of this model, is not simulate land phase of the hydrologic cycle like groundwater flow, it needs other Hec-software's to delineate the catchment.

2. Topography Based Hydrological Model (TOP MODEL)

It is a semi distributed conceptual rainfall runoff model that takes the advantage of topographic information related to runoff generation. But according to Beven and Kirby (1979), Beven et al. (1986), the TOPMODEL is considered as a physically based model as its parameters can be theoretically measured or a variable contributing area conceptual model. It can be used in single or multiple sub catchments using gridded elevation data like topography and soil transmisivity for the catchment area. The main aim is to compute storage deficit or water table depth at any location. The limitation of this model is which uses or depends on land surface slope and soil characteristics to sub-divide the catchment and the output will be in the form of area maps or simulated hydrographs.

3. Hydrologiska Byråns Vattenbalansavdelning (HBV)

This model is an example of semi distributed conceptual model (Bergstrom, 1976). The entire catchment is divided into sub catchments, which are further divided into different elevation and vegetation zones. It runs on daily and monthly rainfall data, air temperature and evaporation. It simulates snow accumulation, snow melt. Ground water recharge, runoff and actual evaporation are simulated as functions of actual water storage. The limitation of this model is needs Real time weather information fully with in stations and river monitoring system.

4. Hydrological Simulation Program-Fortran (HSPF)

The US Environmental Protection Agency (US-EPA) HSPF program has its origin in the Stanford Watershed Model developed by Crawford and Linsley (1966). It is a continuous, conceptual, semi-distributed, watershed scale model. It was developed to simulate the hydrological system and associated nutrient states of the pervious and impervious land, stream and reservoir. Limitation of this model needs vast and specific level data compared to other semi distributed models to simulate watershed properties.

5. Soil and Water Assessment Tool (SWAT) model

According to (Arnold et al., 1998) (Arnold & Fohrer, 2005) SWAT is a physically-based continuous-time, conceptual, long-term, semi-distributed watershed scale hydrologic Model developed by USDA's Agricultural Research Service (ARS), designed to predict the impact of land management practices on the hydrology, sediment and contaminant transport in large, Complex catchment. It has Capabilities of simulating surface runoff, percolation, return flow, erosion, nutrient loading, pesticide fate and transport, irrigation, groundwater flow, channel transmission losses, pond and reservoir storage, channel routing, field drainage, plant water use and other supporting processes from small, medium and large watersheds.

The SWAT model divides the watershed into HRUs based on the land use, the soil types and the slope classes. The model estimates relevant hydrologic components such as surface runoff and peak rate of runoff, Evapotranspiration, groundwater flow and sediment yield for each HRU (Demissie et al., 2013) and this hydrological component simulated through land and Water or Routing Phases

There are numerous applications of the SWAT model all over the world (Dhami & Pandey, 2019). Out of the mentioned hydrologic models only SWAT model can simulate all of the components of land phase of hydrologic cycle and so, SWAT model is comparably suited to simulate surface runoff in upper Gidabo watershed.

Table 2.4: Comparisons of Hydrological models for selection.

	HEC-HMS	HBV	HSPF	Top Model	SWAT
Purpose	Base flow, Flow routing, ET, snow accumulation , Infiltration, Surface runoff	Snow melts, Groundwater recharge, runoff , ET, Snow accumulation	Surface Runoff, Infiltration, ET, Interflow, Percolation flow, Base flow, Interception	Surface runoff, ET, flow routing, s-surface Flow	Surface runoff, ET, Infiltration, Base flow, Interflow, Revapflow, Snow accumulation, pumping flow, Interception, Drainage flow, Seepage flow, nutrient loading, pesticide fade and transport, Channel routing
Time scale	Event and continuous	Continuous	Continuous	Event and continuous	Continuous
Computation time	Minute, hourly, daily	Daily, monthly	Daily	Daily	Daily
Discretization	HRU	HRU	Grid	HRU	HRU

Source (Cunderlik, 2003 and Dhami, 2013)

- **SWAT Calibration and Uncertainty Procedure**

It is a program developed to do various calibrations and uncertainties analysis programs for SWAT using the same interface. Currently, the program have different algorithm from them SUFI2 algorithm is the best and widely used. Each SWAT-CUP project contains one calibration method and allows running the procedure many times until convergence is reached. It allows saving calibration iterations in the iteration history for later use. SUFI-2 algorithm particularly suitable for calibration and validation of the SWAT model because it represents uncertainties of all sources (Abbaspour et al., 2007) and this algorithm was used for this study

2.5.2. Water allocation models

There are various models that can be used for appropriate water sharing or Assessing water demand in a given basin based on available water resource and it is essential, Off course there are various models which are capable of assessing water demand in a given catchment or basin. Allocation models are typically divided into two categories, **Simulation** and **Optimization models.**

The optimization models will provide the optimum solution for a particular problem or optimize, select allocations and infrastructure operations based on objectives and constraints and it is useful if improvement of the system performance. Simulation models are widely used by managers for planning and management of complex systems or the assessment of system performance could address better. Simulation based water allocation models use mass balance principles to allocate resources in a river system, as in MODSIM-DSS (Yates et al., 2005) and for this study simulation one was applied.

According to literatures there are a lot of water resource allocation models from the following models WEAP was used after comparison of the following

- **River Basin Simulation Model (RIBASIM)**

It is developed and maintained by Delft Hydraulics in the Netherlands and is a generic model package for simulating the behavior of river basins under various hydrological conditions. The model use as interface of GIS software for different purposes, the result is obtained in water quantity, water quality, used to generate the pattern for water and also sedimentation analysis in reservoirs and rivers. (Deltares, 2020)

- **Modular Simulation Model (MODSIM)**

Is a generic system management DSS originally conceived in the late 1970s at the Colorado University, United State, and continuously maintained, MODSIM simulates water allocation in the system at each or single time step through sequential solution of a network flow optimization problem where nonlinearities (i.e. evaporation, groundwater return flows, channel losses etc.) are assessed within a successive approximations solution procedure (Sechi & Sulis, 2010)

- **Mike Hydro basin (MIKEBASIN)**

Developed by the Danish Hydraulic Institute (DHI) in Denmark, It provides an easy-to-use, map-based modeling framework for water resources management and planning in river basins include water allocation, conjunctive use, reservoir operation, water quality and others. It employs both ArcGIS and hydrologic modeling to give basin scaled solutions, and the emphasis is on simulation and visualization through space and time. (DHI, 2020)

- **Water Resources Graphical Interface – Simulation Tool (WARGI-SIM)**

Developed at University of Cagliari, Italy, is a user-friendly tool specifically developed to help users understanding interrelationships between demands and resources for multi-reservoir water system under water scarcity conditions. The DSS makes it possible to take into account a large number of system components that typically characterize water resources models. The tool is flexible and generalized in the system configuration and data input, in the attribution of planning and operating policies and in processing output (Sechi & Sulis, 2010).

- **Water Evaluation and planning system (WEAP)**

WEAP is an acronym for the Water Evaluation and Planning system. WEAP model was used, and developed by the Stockholm Environment Institute-Boston, Tellus Institute, U.S.A. It is an integrated Decision Support System (DSS) designed to support water planning that balances water supplies and multiple water demands. WEAP incorporates issues such as allocation of limited water, Environmental quality and policies for sustainable water use. It gives a practical integrated approach to water resources development incorporating aspects of demand, water quality and ecosystem preservation (SEI, 2012)

WEAP is a river basin (watershed) simulation model with geo-spatial capabilities that is capable of simulating the allocation on water throughout a river basin based upon a user specified time step (Yates, 2005). WEAP provides a system for conserving or maintaining

water demand and supply information. WEAP21 considers demand priorities and supply preferences, as a forecasting tool, WEAP simulates water demand, supply, flows, storage, and pollution generation, treatment and discharge. As a policy analysis tool, WEAP evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems

The model optimizes water use in the catchment using different algorithm from them an iterative Linear Programming algorithm or solution is the appropriate one, which its objective is to maximize the water delivered to demand sites, according to a set of user defined priorities. All demand sites are assigned a priority between 1 and 99, where 1 is the highest priority and 99 the lowest. Reservoir priorities default 1 to 99, meaning that they will fill only if water remains after satisfying all other demands (SEI, 2015). When water is limited, the algorithms formulated to progressively restrict water allocation to those demand sites given the lowest priority and allocate to most sensitive sectors to utilize water sensitive to water.

One of the strengths of WEAP is that it is adaptable to whatever data is available to describe a water resources system. That is, it can use daily, weekly, monthly, or annual time-steps to characterize the system's water supplies and demands. So for this study WEAP model is selected because of its inclusive, straightforward, easy-to-use, flexible data input, interfacing with Excel (import and export) and Possibility to model the impact of different scenarios on different area. As a database, WEAP provides a system for maintaining water demand and supply information (Hassan, 2015).

Generally WEAP model was suitable to assess demands and allocate available water resources in the study area than other models due to the following reasons

Mike hydro basin is hydrologic model which does not allow for spatial variability, Limitation on physically-based responses to flood propagation, attenuation, and surface-groundwater interaction, used simplified linear groundwater flow model. The limitation of both **RIBASIM** and **WARGSIM** models are performs simulation only and fixed based on a more conventional if-then approach and give lower values of performance system index and Operating policies are fixed. **MODSIM** and **WEAP** are models where optimization methods are developed on the single time period and results are used as an efficient mechanism for performing simulations, operating policies in both are defined as a combination of system states and hydrologic conditions and can be linked to a more detailed higher dimensional

models (e.g. QUAL2E, MODFLOW) to provide comprehensive modeling of water quality conditions and effect of groundwater (Sechi & Sulis, 2010).

Though, MODSIM and WEAP have better advantages over the other models and are equally important to model water demand in the study area but, in MODSIM MODFLOW is not an easy task as it needs an extensive calibration phase, no robustness and no suitable for less data availability, but the reverse is true for WEAP it perform lumped to distributed catchment hydrological simulation, Therefore, WEAP model is easy and best suited to estimate water demand and allocate them in my study area as it can be licensed online annually free of cost.

- ✓ **Demand Management Capability of WEAP**

WEAP is unique in its capability of representing the effects of demand management on water systems. Water requirements may be derived from a detailed set of final uses, or "water services" in different economic sectors. For example, the agricultural sector could be broken down by crop types, irrigation districts and irrigation techniques. An urban sector could be organized by county, city, and water district. Industrial demand can be broken down by industrial subsector and further into process water and cooling water. This approach places development objectives providing end-use goods and services at the foundation of water analysis, and allows an evaluation of effects of improved technologies on these uses, as well as effects of changing (Abraham, 2018)

- ✓ **CROPWAT model specification**

CROPWAT is a DSS developed by the Land and Water Development Division of Food and Agriculture Organization (FAO) for planning and management of irrigation by (Smith, 1992). It is a practical tool to carry out standard calculations for reference evapotranspiration, CWR, IWR, and more specifically the design and management of irrigation schemes. CROPWAT model, which is a practical tool for helping researcher to analysis results with draw conclusion, comparisons results and it let to have extension of the decisions and conclusions from studies to conditions not tested in the field. Therefore, it can offer practical recommendations to farmers and extension staff on deficit irrigation scheduling under various conditions of water supply, soil, and crop management conditions.

CWR and irrigation timing to estimate IWR is important for water project planning, management and maintaining crop evapotranspiration (ETc) when precipitation is insufficient. It can be determined using CROPWAT model and has been applied for calculation of CWR and irrigation schedule for this study.

- ✓ **Previous studies on the study area**

Before the initiation of any project, a review of previous work in the area has been conducted to better understand the area, to increase knowhow to done the research and to reduce the time and expense that could be experienced to collect related information. But in this area projects related to allocation are less. Finally, previous studies and general information related to this project are considered and described as follows:

1) RVLB master plan study it studies on different topics from them related to this study in the whole basin including the study area modeling of water resources and allocation of them to the demanding sectors, According to the master plan study the average flow of the Upper Gidabo river at the Aposto station is 17.35 m3/s and additionally this study projecting number population and growth rate of human and Livestock population and so many findings are included on this master plan in the RVLB and considered for this study.

2) Assessing the Water-Resources Potential and Soil Erosion Hotspot Areas for Sustainable Land Management in the Gidabo Watershed, Rift Valley Lake Basin of Ethiopia.(Mihret et al., 2022)

The goal of this study was to assess the surface water potential and identify erosion hotspot areas of the Gidabo watershed (Gidabo sub basin) in Ethiopia using the Soil and Water Assessment Tool (SWAT) model. Based on their studies they found that the surface water potential of the watershed varies spatially from sub-basin to sub-basin, and the mean monthly surface water potential of the whole watershed at Measso gauging station was up to 33 MCM and this study crosschecking available surface water resources related to the study area and argued with master plan study of Aposto mean flow was up to 17.35m3/s.

3) GIS-Based Surface Irrigation potential assessment of river catchments for Irrigation Development in Dale Woreda, Sidaama Zone, SNNPR (Upper Gidabo watershed) (Kebede, 2010)

This study was focus with the objective of assessing the water and land resources potential of river catchments in Dale Woreda and generating geo-referenced map of these resources by using GIS, Results of the watershed delineation give two main watersheds (Bilate and Gidabo watershed) and four sub-watersheds on Gidabo (Dama, Raro, Wamole and Woyima), identify potential irrigable land, irrigation suitability factors such as soil type, slope, land cover/use, and distance from water supply (sources) were taken into account.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The Upper Gidabo watershed is located in the south-eastern Main Ethiopian Rift(MER) or Rift valley lakes basin at Gidabo sub-basin about 15km south to the regional town Hawassa and above 250 km from Addis Ababa the capital of Ethiopia, The watershed is located between 6°36'00"N and 6°57'30" N latitude, and 38°11'00"E and 38°40'00"E longitude and drainage area of upper Gidabo watershed is 1094 km², it is bordered by the catchment of Lake Hawassa to the North, Bilate River to the West, River Gelana to the South or lower Gidabo and Genale-Dawa River to the East.

The Upper Gidabo River winds through forested and agricultural land of escarpment and rift floor then join to lower Gidabo finally terminating in Lake Abaya, the largest lake in the rift valley lakes basin. It originates on the north-eastern mountains of Gelala or Sokasonicha highland areas in Arbegona near to Goriche district, Sidaama region. The river drains through Goriche, Hawella, Shebedino, Wonsho, Dale, Burrisa, and Aletawondo Districts in Sidaama region and there is two gauging outlet for Upper Gidabo watershed they are Aposto near to Yirgalem town and kolla is occur in Aletawondo district and one ungauged outlet was considered for this study that is Dongora outlet it was found in border between Aletawondo and Aletacukko Woreda.

The altitude of the catchment area ranges from 1560 to 3160 m above mean sea level (m.s.l). The major physiographic units in this area are undulating plains, valleys, steep stream banks, and major escarpment at the eastern part of the watershed. Topographically the river basin has highly been affected by the late tertiary rifting activity and erosion process (Woldegabriel et al., 2000).

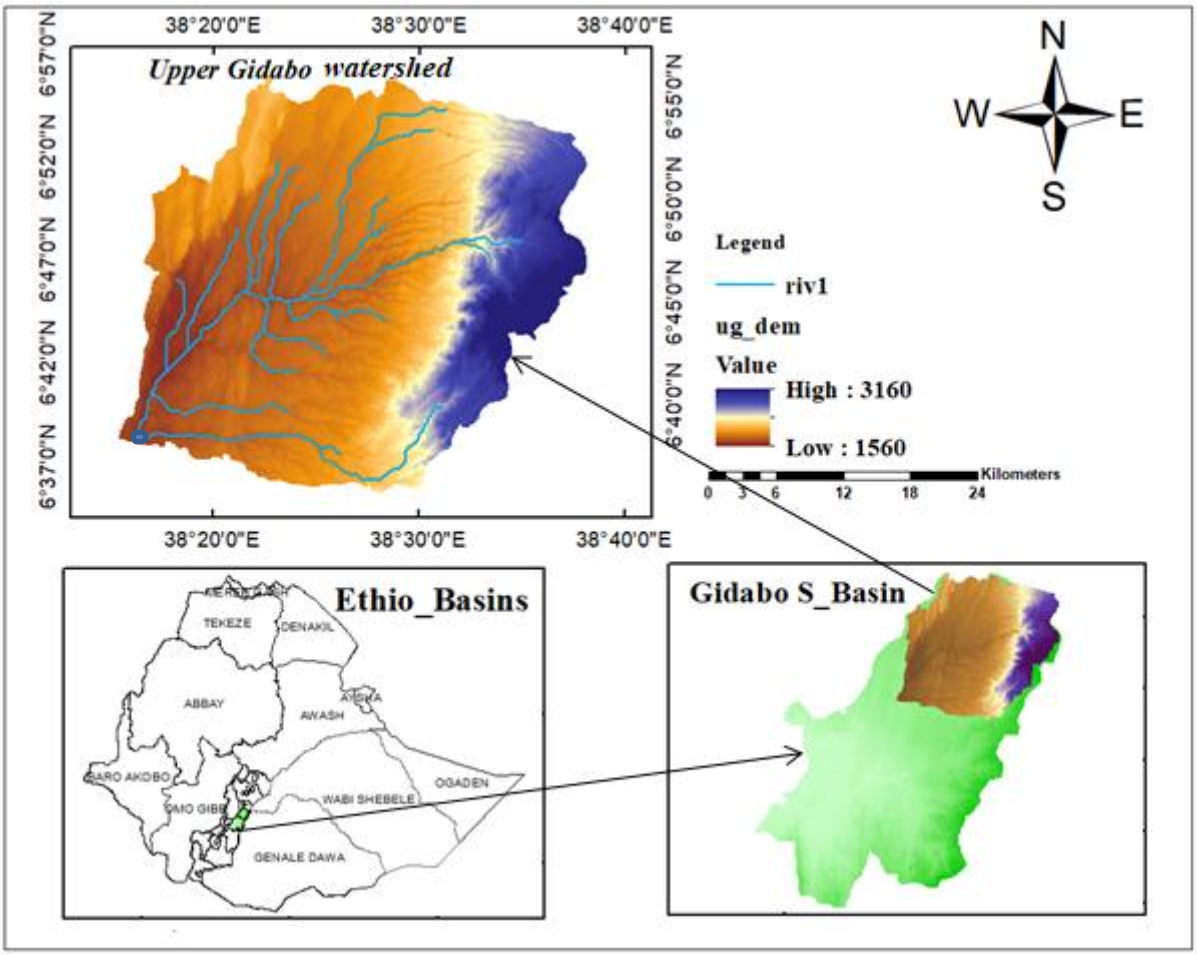


Figure 3.1: Location map of the study area

3.1.2. Major Economic Activities

Agriculture, mainly rain fed cultivation and Livestock rearing are the major Economic/ livelihood activities in the study area. Agriculture is the source of food and cash for those who are engaged in it. The major crops growing in the area include coffee, Enset, Khat, Maize, Sugarcane, Banana, Vegetables; Coffee is the main income source and has a major contribution to the nation's export market. The rainfed agricultural system is the mainstay of the economy (Mamuye et al., 2020). In addition to crop production, Livestock rising is also an integral part of the agricultural system.

The Livestock constitute a major part of the mixed farming system, providing draft power (more than 90% of crop production is dependent on animal draft power), producing milk and conferring a certain degree of security against crop failures. Hides and skins are important Livestock by products for local use as well as for export. It is the second most important foreign exchange earner next to coffee. The annual production of hides and skins cattle (17%) , sheep (46%) and goats (37%), respectively (RVLBA, 2010). Additionally coffee processing

Industries for export and agro processing Industries for food and export purposes are economic activities in the watershed.

3.1.3. Human Settlement

The population density generally decreases as we go from East (i.e. edge of Eastern high plateau) to West in the Sub Basin across the Catchment (Raunet, 1977); and in the watershed has high population density starting from highlands of Gelala is densely populated. This region is densely populated with more than one thousand inhabitants per square kilometers according to the population projection report from 2014 to 2017.

The population lives in the watershed that lives in the same socio-economic system, They are farmers who occupy the eastern rainy regions, with red and black soils, Based on the CSA 2014 to 2017 population projection report the total population living in the study area in urban and rural areas was 1,214,787. From the total population, 13 percent (152,070) were living in urban areas and 87percent (1,062,717) were living in rural areas. Again, from this total population 50% (613,422) were males and the rest 50% (601,365) were females. For this study, the last population projection by CSA was done in 2017 taken from CSA, and then the growth rate has been extended to 2021, which is taken as the current account year in this study (CSA, 2013/14)

3.1.4. Climate

Ethiopia is situated in the north-eastern part of Africa, is characterized by tropical climate moderated by altitude with a marked wet season. The southwestern Ethiopia is characterized by humid tropical climate with rainfall higher than 1,000 mm. In the highlands of Ethiopia, temperature is reasonably warm the year round but rarely hot.

The climate controlled and influenced from the northeast to the Southeast by monsoons bringing moisture from the Indian Ocean. Seasonal migration of the ITCZ, which is conditioned by the convergence of trade winds of the northern and southern hemispheres, the associated atmospheric circulation and it is also highly influenced and depends topography of the country. The convergence of dry north easterly winds, with moist winds from the South-east or South-West from October-March, the North-East winds are responsible for the dry sunny season with low relative humidity from April-May, the weather becomes more irregular with the South-East winds coming from the Indian Ocean, which bring precipitation. The

influence of this moist current is felt especially south of parallel $6^{0}30'$, after which the pattern of North Kenya is gradually reached (Raunet M., 1977)

In Ethiopia (in the study area) mostly there are three seasons occur: the first is the dry season (locally known as Bega) which prevails from October to January; the second is the small rainy season (Belg) that runs from February to May and the third is the main rainy season (Kiremt) which prevails from June to September.

3.3.4.1. Rainfall

There are rainy and dry seasons in the Upper Gidabo watershed, Precipitation is characterized by a bimodal pattern. The main rainy season is from April to October with a peak rainy season from April to May and a second peak rainy season from September to October. The main rainy season (locally known as *Kiremt*) lasts from June to October and the short rainy season (locally known as *Belg*) is from April to May. Rainfall of the study area is generally reliable compared to the main Gidabo watershed and it is decreasing in time with increasing of temperature (Mamuye et al., 2020).

The mean monthly rainfall of the watershed varies between 30.7 mm and 221.5 mm or The least amount of rainfall occurs in December (30.7 mm) and In September, the precipitation reaches its peak, with an average of 221.5 mm, and the mean annual rainfall varies from 492.7 mm to 2198.3 mm (shown in the Figure 3.2 below).

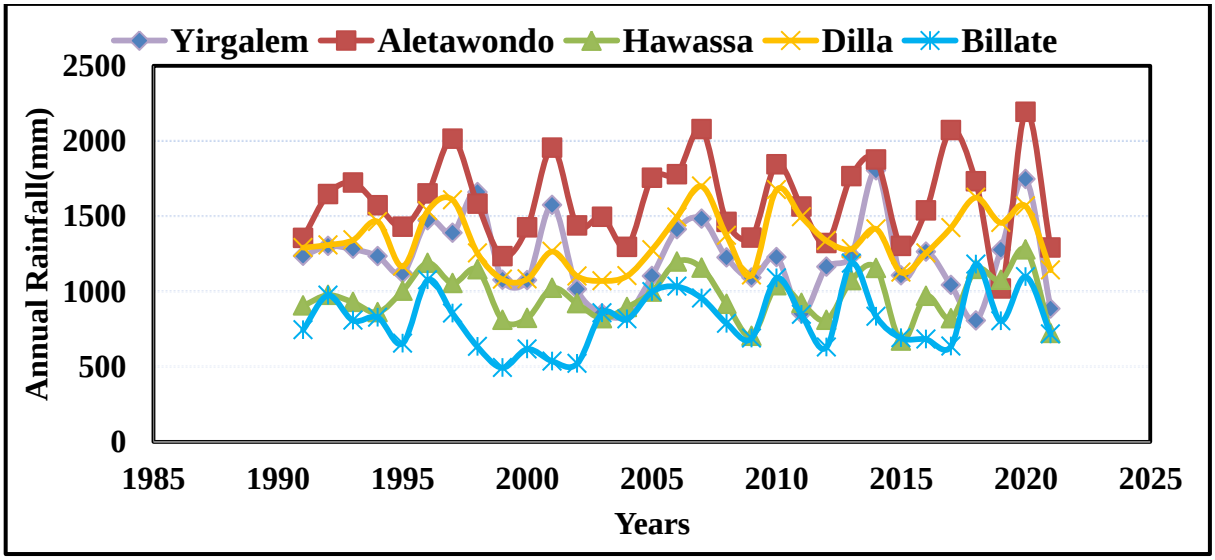


Figure 3.2: Annual Average rainfall of stations in the study area

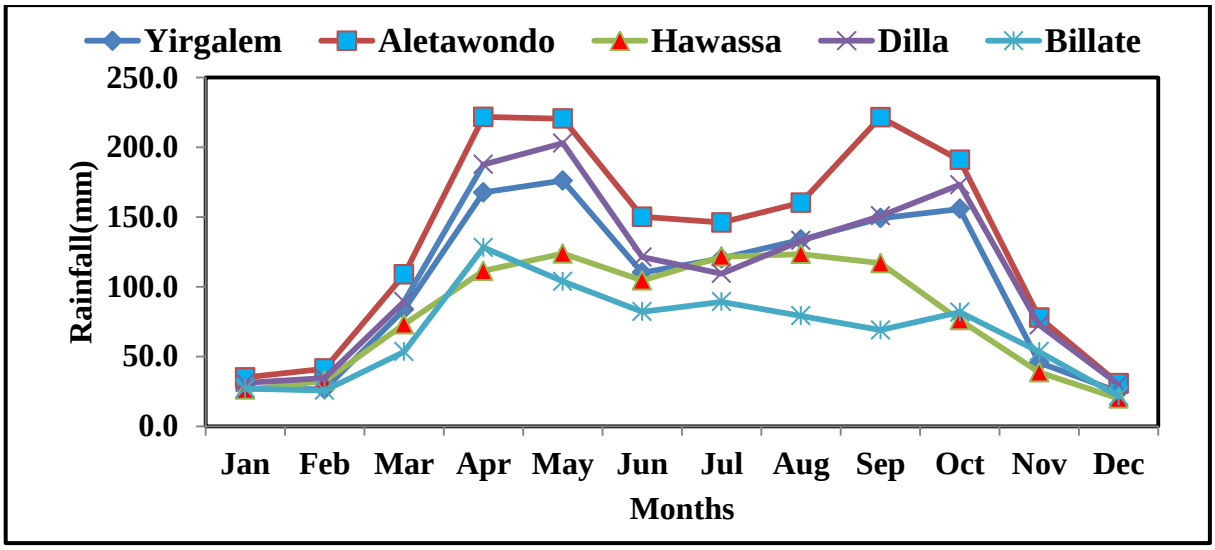
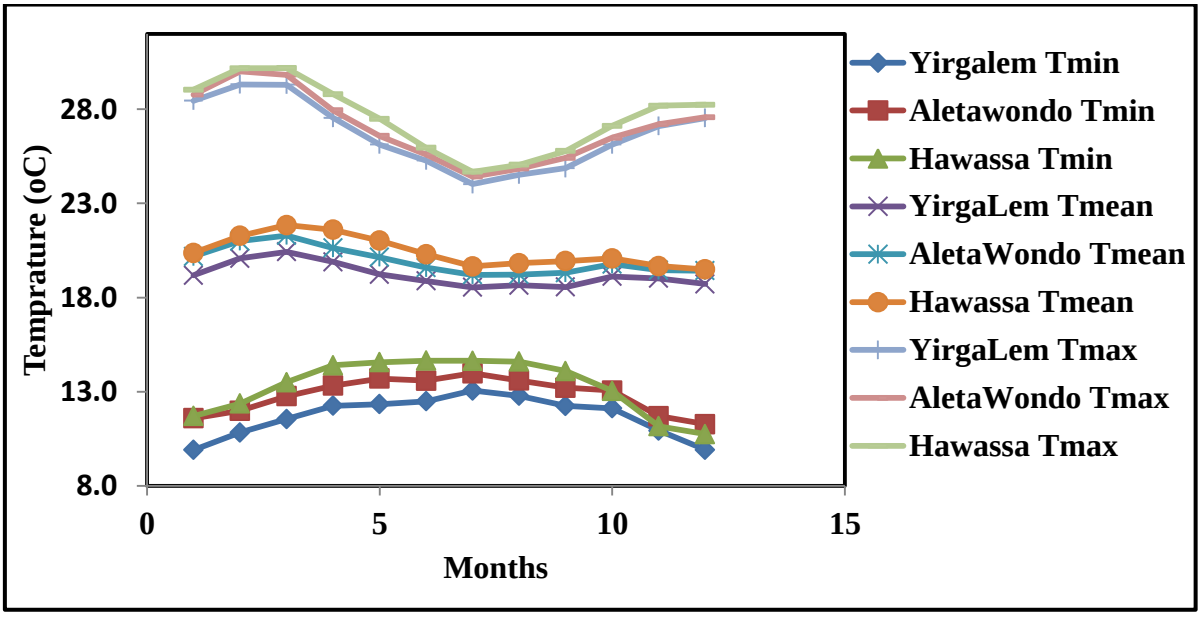


Figure 3.3: Average monthly rainfall of stations in the study area

3.4.1.2. Temperature

According to (Birhanu, 2009), the diurnal variation of temperature in the Gidabo River Catchment is more visible than its seasonal variation.

Temperature ranges from a mean monthly maximum of 24°C and 33.2 °C to mean a monthly minimum of 9.9 °C and 16.7 °C with a mean annual value of 19.4 °C and 25.2 °C in all selected meteorological stations. The temperature value is maximum for November to March and relatively decrease for the other months. Comparatively months from April to October are the coldest months whereas others are the hottest months.



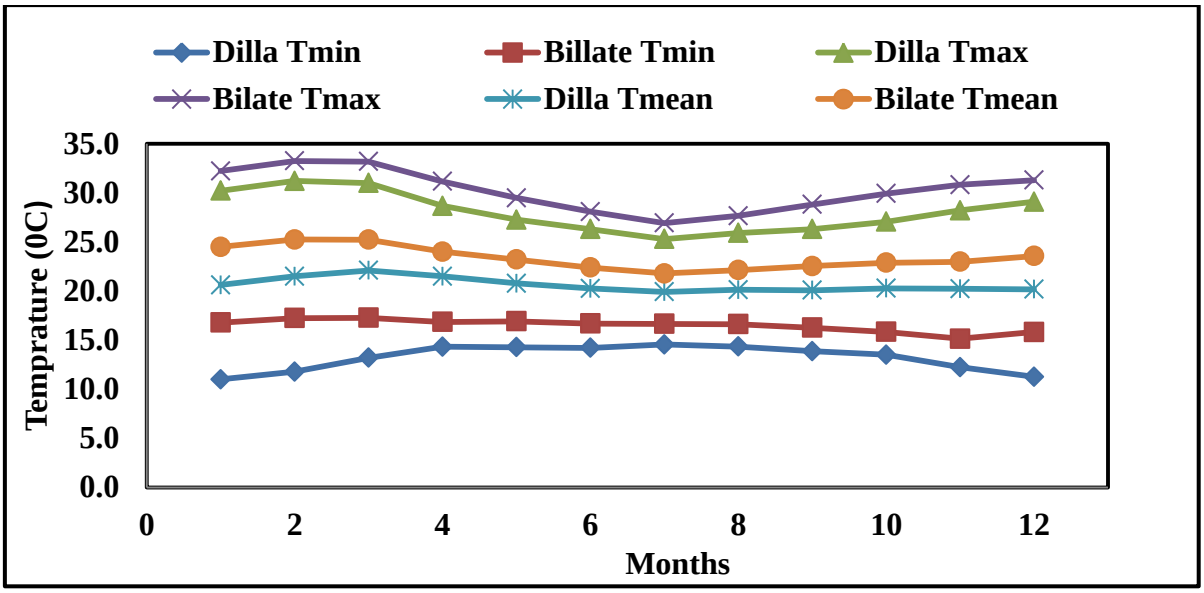


Figure 3.4: Temperature trends at five selected stations.

3.4.1.3. Wind speed

In the watershed, as the wind flow pattern is influenced by the seasonal variations of the ITCZ, the predominant wind direction during June to September. The mean monthly wind speed in the study area ranges from a minimum value of 0.3 m/sec in July to maximum values of 1.3 m/sec in Dec with a mean annual value of 0.7m/s, 0.45m/s and 0.85m/s for Hawassa, Dilla and Bilate stations as is illustrated in the following Figure 3.5.

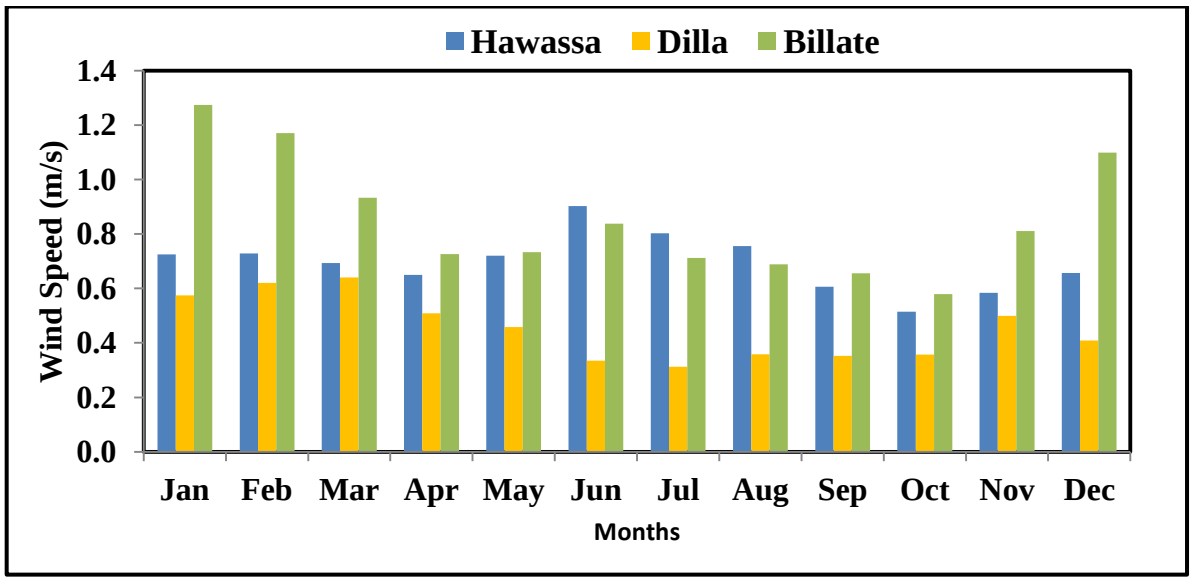


Figure 3.5: Wind speed trends at five selected stations.

3.4.1.4. Relative Humidity

Daily Relative humidity data at the Hawassa, Dilla and Bilate stations obtained from National Meteorological Agency (NMA). Figure 3.6 presents the average humidity from 1991 to 2021 for Hawassa, Billate and Dilla stations, There is relatively little variation over the basin with the mean monthly relative humidity varying from 45.3%-72.4% in Hawassa, Dilla, and Billate stations. The mean annual relative humidity in the stations were estimated about 61.7%, 61.4% and 59.9% and The highest humidity occur in the months ranges from April to October while the lowest humidity occur in the months ranges from November to march.

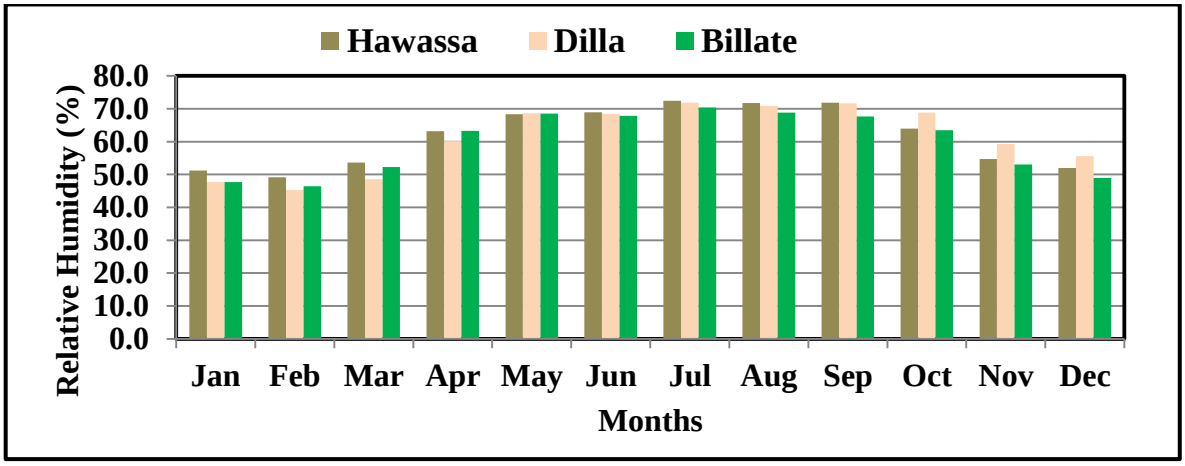


Figure 3.6: Average humidity from 1991 to 2021 at Hawassa, Dilla and Billate stations

3.4.1.5. Solar Radiation

Once water was introduced to the system as precipitation, the available energy solar radiation exerts a major control on the movement of water in the land phase of the hydrologic cycle. Arc SWAT takes the daily solar radiation but the data acquired from the National Meteorological Agency (NMA) was sunshine hour, hence conversions of variable were made using (Angstrom Prescott, 1994) empirical equation.

$$R_S = (a_s + b_s \frac{n}{N})R_a \quad \text{---------- (3.1)}$$

Where: - **Rs** = short wave radiation ($MJm^{-2}day^{-2}$),

n = actual duration of sunshine (hour), **N** = Maximum duration of sunshine (hour)

$\boldsymbol{a_s + b_s}$ = extraterrestrial radiation, $\frac{n}{N}$ = sunshine duration, **Ra** = Extraterrestrial radiation

Solar radiation was needed to the weather generator stations including with other meteorological parameters discussed above. Data for three Class-I stations are available in the catchment. The mean annual solar radiation of Hawassa, Dilla and Billate stations was estimated about 7.3 MJ/m^2day, 5.89 MJ/m^2day, and 7.4 MJ/m^2day, respectively.

3.2. Materials used for the study

Many materials are used to conduct this research the following are some of them that were used for collecting and analyzing data used in the research.

3.2.1. Global positioning system (GPS)

GPS was used to collect the geographic information of the study area and to select the outlet of the watershed. The coordinate which was recorded using GPS are used for the purposes list above and for others.

3.2.2. LAT LONG Converter

This software was used to convert LAT LONG collected by GPS and from others in degree form to UTM and in to decimal, it is useful the software's that need coordinates in different forms used for this study.

3.2.3. Geographical information system software (GIS)

ARCGIS version 10.4.1 was used for locating the study area, for delineating or all other simulation processes in the watershed by SWAT used as a basic interface to use the SWAT model.

3.2.4. Soil water characteristics (SPAW)

This software has many soil water related purposes, for this study it was used to convert different soil texture available in the study area in to one representative soil texture, it makes easy to determine crop water requirements and irrigation water requirements by CROPWAT software.

3.2.5. Models used in this study

In this study basically three hydrological models were used as a material namely SWAT, WEAP and CROPWAT model.

i. Soil and water assessment tool (SWAT) model

SWAT model in this study was used for the watershed delineation of watershed, HRUs analysis and it was used to simulate the quantity of surface water (water balance) in the

watershed. The following are materials which were used to prepare input data for the user weather generator.

1. Pcpstat: it is a software which was used to calculate PCPMM(mon), PCPSTD(mon), PCPSKW(mon), PR_W1(mon), PR_W2(mon) and PCPD(mon).

2. Dew 02.exe: was used to calculate average daily dew point temperature per month using daily air temperature and humidity data. It calculates the dew point temperature using minimum and maximum daily temperature data.

3. Automated base flow separator: it was used to separate the base flow from the surface flow and the software downloaded from this website (www.waterbase/temu/baseflow .com).

ii. SWAT-CUP software

SWAT-CUP is a computer program for selecting sensitive parameters, calibration and validation of SWAT model. It is a public domain program and can be used free. In this case it was used for calibration, validation and sensitivity analysis of the SWAT model and all software's related to SWAT including SWAT CUP downloaded from this website (https://swat.tamu.edu/software/swat-cup/)

iii. Water evaluation and planning (WEAP) model

It was used to calculate the different water requirements or demands, unmet water demands, and scenarios generation or development based on watershed characteristics for priority based water allocation of water resources.

iv. CROPWAT8.0 model

It was used to calculate the CWR and IWR for crops cultivated in the watershed. The software uses monthly averages of climatic parameters, Soil data, and crop data. Penman-Monteith method was employed to calculate the ETo and FAO dependable rainfall formula was used for effective rainfall estimation.

3.3. Methodology

3.3.1. Flow chart for this study

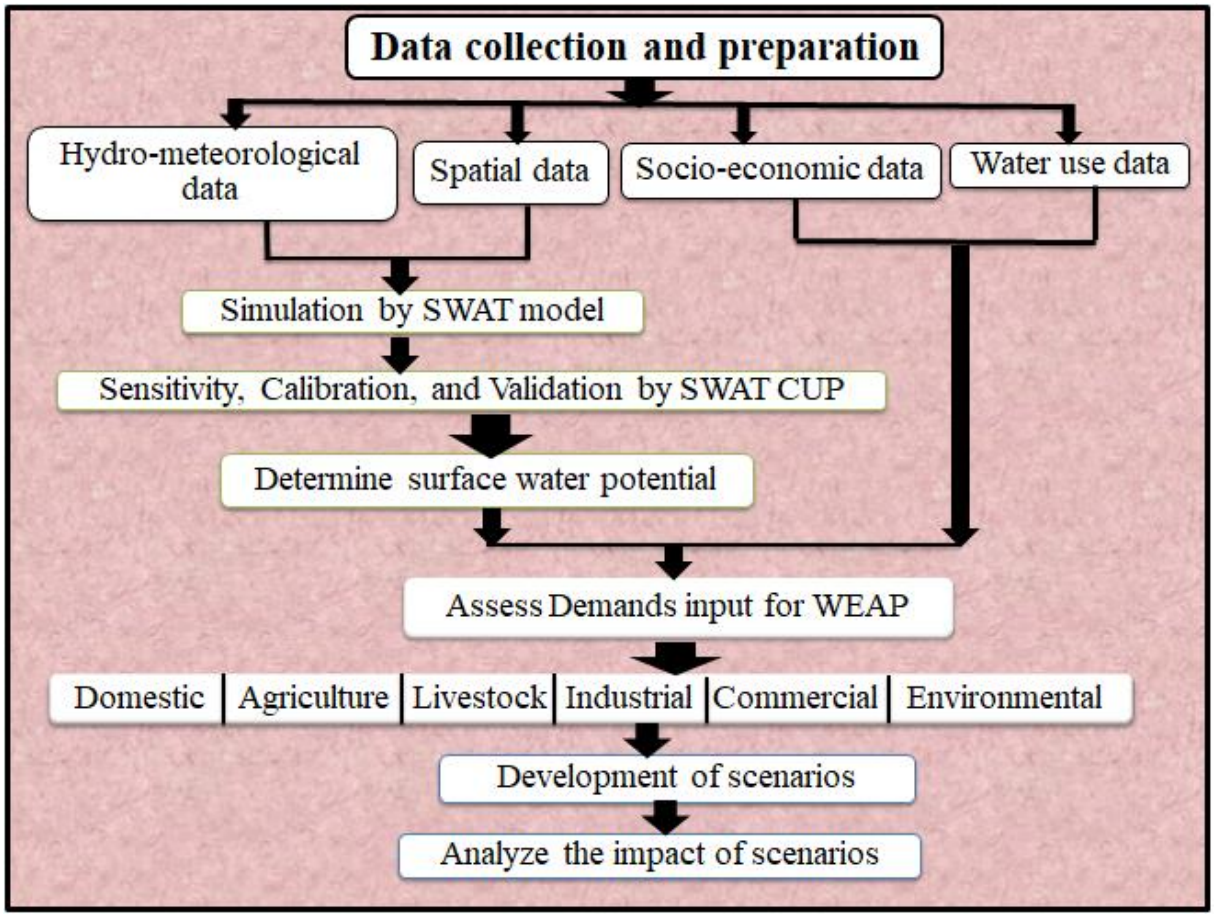


Figure 3.7: Flow chart (Research design)

3.3.2. Data collection

For conducting any research, data is the basic and taken as an input for analyzing the research. General work was carried out by collecting primary and secondary data and validated by comparing the data collected from different data sources and the primary task in data collection was gathering applicable information specific to the model based on the objective of this research and field data was collected. With this regard Spatial, hydro-meteorological, demands data as well as socio-economic data were collected.

Table 3.1: Data used to conduct the research and their sources.

Data type	Source of data	Scale/Period	Purpose
DEM, Shape files	MoWIE and RVLBA	30×30	For further processing in SWAT and WEAP model
Lu/Lc	USGS earth explorer	Landsat 8, 2021	Lu/Lc classification map
Soil map	MoWIE	2015 (2007E.C)	Soil classification map
Meteorological data (RF (mm), T (^{O}C), wind speed (m/s), SH (hr.), RH (%))	National Metrological Agency Hawassa branch	1991-2021	For further processing in SWAT and WEAP model
Stream flow data	MoWIE	Aposto (1996-2015) Kolla (1998-2013)	Daily stream flow (m3/sec) for calibration and validation.
Human and Livestock population	CSA and Sidaama regional state Livestock resource agency	2017 projected population and 2021 Livestock number	For Domestic and Livestock water demand assessment
Agricultural and Industrial like Coffee processing sites	Sidaama regional state Agricultural offices	2021 Collected data from offices	Irrigation water demand assessment

3.3.3. Data analysis

After collecting all data, the filling of missed data and quality checking was done to prepare the necessary input data for the Arc SWAT, and WEAP model in a suitable format. the Arc SWAT model was used to simulate surface runoff and WEAP applied for assess of water demands, and scenario development for the watershed.

3.3.3.1. Areal Rainfall of Gauged Upper Gidabo Catchments

The area rainfall of the Upper Gidabo catchment was calculated by Thiessen polygon method using six rainfall stations namely Aletawondo, Arbegona, Yirgalem, Hawassa, Dilla and Billate which are located inside the catchment and nearby the catchment. The result of the Thiessen polygon method is shown below on figure 3.9.

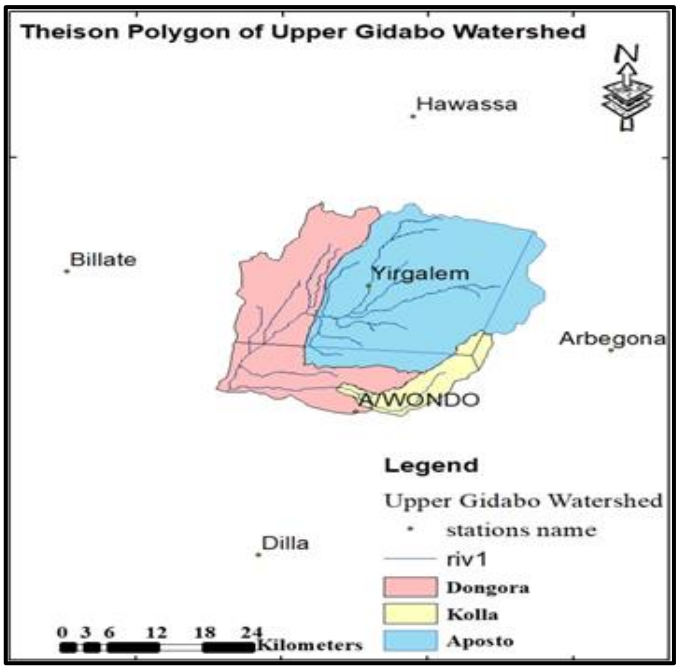


Figure 3.8: Thiessen polygons map of gauged Upper Gidabo catchment

The areal rainfall was then calculated by weighting the individual stations by their respective area and is given by

$$P = \frac{1}{A}\sum_{i=1}^{n} Ai\ Pi \text{ ---------- (3.2)}$$

Where, P is the areal precipitation, n is the number of rain gauge stations, A is the total area of the catchment, Ai and Pi are the area of polygon and precipitations of each stations. With this method the mean monthly and annual areal rainfall of the gauged Upper Gidabo catchment is determined for the period 1991-2021 and it was used to determine stream flow of ungauged sites, filling missing data and for other purposes.

3.3.3.2. Filling Missing Data

Missing data is a common problem in Hydro-meteorological data. Although complete hydro-meteorological data is a pre-requisite for successful water resource planning and management, however, the problem of missing data often occurs due to a variety of reasons include relocation of the stations due to the urbanization of the area, interruption of measurements caused by natural and/or human-induced factors like the malfunction of the instrument in flooding areas, Vandalism of recording and errors in the techniques used in measuring the amount of rainfall Any such causes of instrument failure reduce the length and information content of the flow and rainfall on record (Arnold J. G., 2012).

In this study missing data can be filled using hydro-meteorological stations located in the study area or nearby stations and stations are located in the hydrological homogenous region, Different methods are available for filling missing data from them Arithmetic and Normal-ratio method was used for filling missed hydro-meteorological data based on percentage missing of the stations.

$$p_x = \frac{1}{n}(P_1+P_2+P_3+\ldots..+ Pn) \text{ ---------- (3.3)}$$

The general formula to estimate p_x is:-

$$p_x = \frac{Nx}{N}\left(\frac{P1}{N1}+\frac{P2}{N2}+\ldots\ldots\ldots+\frac{Pn}{Nn}\right) \text{---------- (3.4)}$$

In this study, the Arithmetic Method applied when the normal annual precipitations at the adjacent stations are within 10% of the normal rainfall of the station under consideration and Normal ratio method it takes account of the normal ratio between annual rainfall depths measured in the stations and in this method n-regions gauge stations different from the arithmetic method that is percent of missed of stations greater than 10%, as it can be seen in (Table 3.2 and 3.3).

The data of rainfall recording stations in the study area and nearby stations were first received from National Meteorological Agency Hawassa Branch and from them five (5) stations was selected depending on their percent of missed data; number of years with data and nearness to the study area presented in the following (Table 3.2) and the daily streamflow data at all gauges were obtained from the MoWIE. There are above four stream flow discharge gauging stations are found in the Gidabo sub basin from them two are belongs to study area they are Aposto and kolla stations.

Accordingly, filling of missed rainfall data for the Yirgalem station was done with the help of the Arithmetic Method since the percent of missed data is less than 10% that is 6.15%, whereas for the rest of the four rainfall are discussed below in table 3.3 and Additionally, for streamflow missed data were also filled by the two methods stated above. For instance, missed data of Aposto was filled by Arithmetic Method while missed data of kolla near Aletawondo were filled by the Normal Ratio Method depending on their percentage of missed data (Table 3.3)

Table 3.2: Rainfall station location, year with data, area coverage and percent missed

Station Name	Latitude	Longitude	Elevation	Years	% Missed
Yirgalem	06^0 48' 01.9" N	038^0 25' 56.3" E	1786	1991-2021	6.15
Aletawondo	06^0 36' 13.5" N	038^0 25' 04.8" E	1947	1991-2021	11.7
Hawassa	06^0 48' 01.9" N	038^0 25' 56.3" E	1694	1991-2021	0.08
Dilla(Wenago)	06^0 22' 49.6" N	038^0 18' 24.9" E	1515	1991-2021	23.25
Billate	06^0 49' 20.3" N	038^0 05' 16.1" E	1361	1991-2021	2.05

Table 3.3: Gauges location, area coverage, years with data, and percent of missed data

Station Name	Latitude	Longitude	Area(km^2)	Years	% Missed
Aposto	6°45'N	38°23'E	206.3	1996-2015	7.22
Kolla	6°38'N	38°24'E	646	1996-2013	15.43

3.3.3.3. Consistency test

When rain gauge station has undergone a significant change during the period of record due to observational error, changes in exposure of the gauge, changes in land use, where vandalism frequently occur, replacement old instrument by new, shifting of rain gauge stations, and change in ecosystem, inconsistency would arise in the rainfall and stream flow data of that station. This could result in changing the results the change took place.

In this study, consistency of rainfall stations of a record was done by Double-mass curve. The cumulative sum of both rainfall and streamflow gauging stations to be tested with the base station are plotted against each other and a lines of best fit were drawn in an excel worksheet.

Double mass curve is based on the principle that when each recorded data comes from the same parent population they are consistent (Subramanya, 2008). According to the double mass curve test, all the stations were consistent as indicated in the figure (3.9) below for the meteorological stations and for flow stations Appendix Figure1.

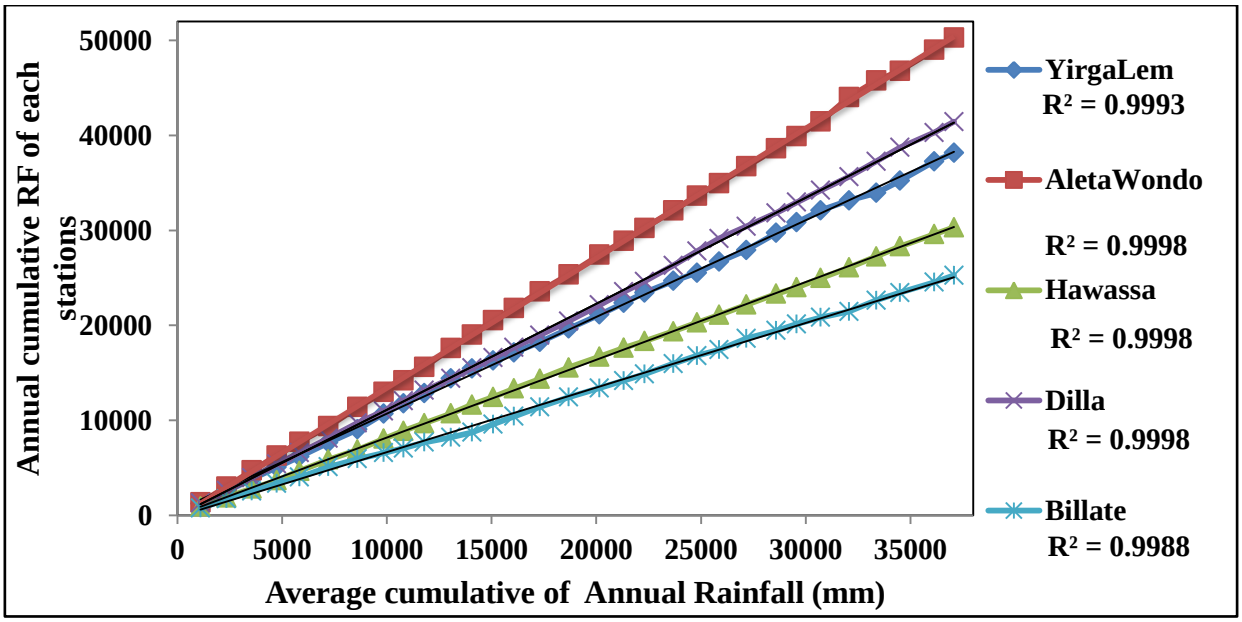


Figure 3.9: DMC of all meteorological stations.

3.3.3.4. Homogeneity test of the stations

Homogeneity tests are used to assess the effects of non-climatic factors such as changes in instruments, observation practices, station relocations, and station environments on climate time series data (Toreti et al., 2011) and it is important to the variation of the statistical properties of the time series, to select the representative meteorological station for the analysis of rainfall estimation, checking homogeneity of group stations are important.

Homogeneous time series of meteorological parameters are vital for studies related to water resources. A time series is homogeneous if measurements have been consistently done by the same method, instrumentation, environment, time and place. This is seldom the case for long time series, and statistical methods should be used to detect possible inhomogeneity in the data. Inhomogeneity‘s may mask or amplify real climatic variation and therefore need to be corrected before being used in water allocation.

The methods for testing the homogeneity of the selected gauging station can be classified into two groups as absolute and relative method. In the relative method, the neighboring (reference) stations are used for testing process. For this study, the graphical relative homogeneity (Non-dimensional plot) analysis was applied. The non-dimensional monthly value *Pi* was obtained using equation 3.5.

$$Pi = \frac{\overline{P}i}{\overline{P}} * 100 \quad \text{---------- (3.5)}$$

Where:
Pi - is non- dimensional value of precipitation for the month in the station I

$\bar{P}$i - is over year's average monthly precipitation for the station I

$\bar{P}$ -is over year average yearly precipitation for station i

The selected stations was plotted for comparison and the stations have the same trend of the hence the group of station selected are homogeneous.

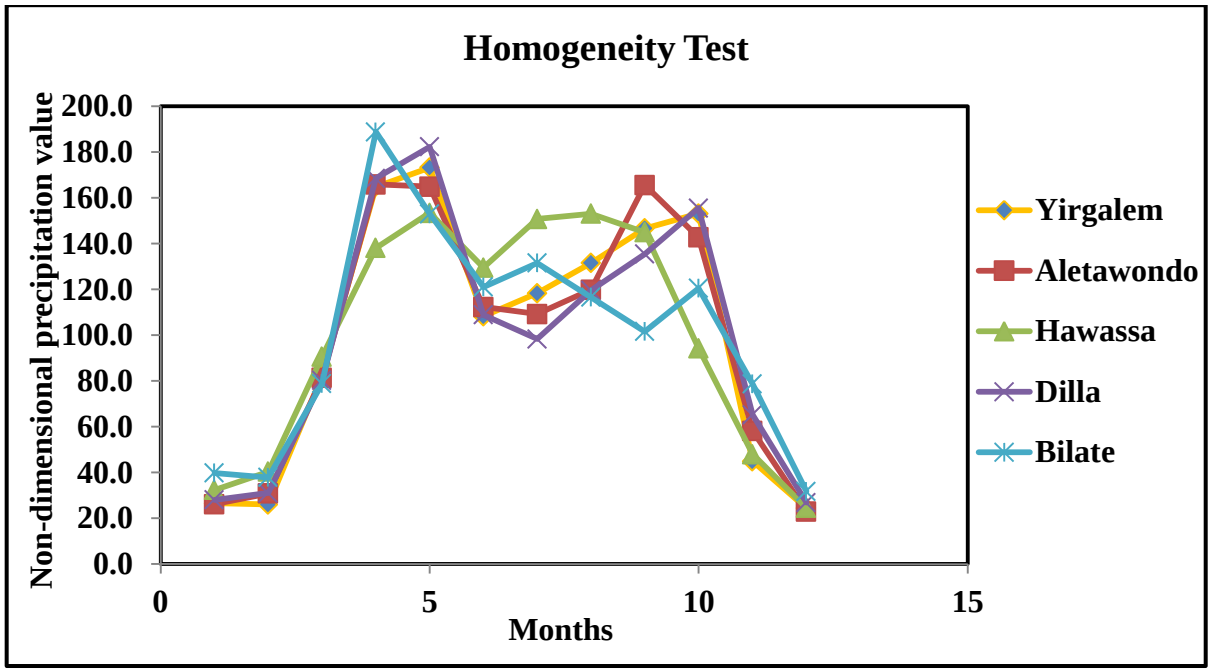


Figure 3.10: Homogeneity test for rainfall recording stations

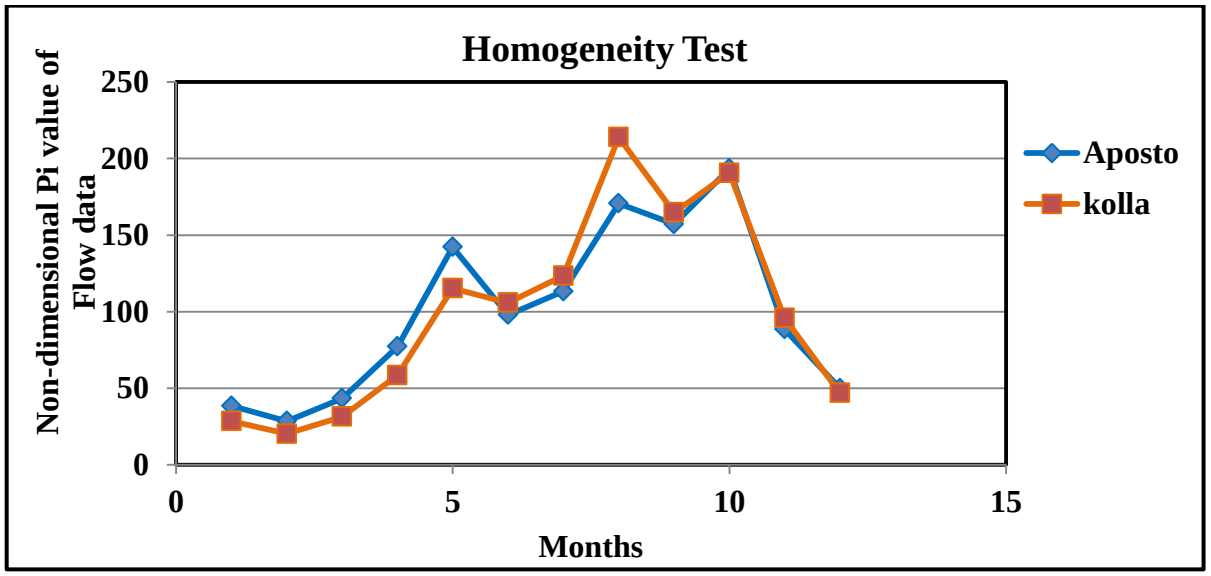


Figure 3.11: Homogeneity test for the streamflow gauging stations

3.3.3.5. Outlier Test for Precipitation and Stream Flow Data

Outliers are data points which depart or very far significantly from the trend of the remaining data. The Water Resources Council method (1981) recommended using that adjustments have to be made for outliers. The retention, modification, deletion of these outliers can significantly affect the statistical parameters computed from the data, especially for small samples due to this problem influence large samples. All procedures for treating outliers ultimately require judgment involving both mathematical and hydrologic considerations.

According to the Water Resources Council (1981), The station skew is greater than (+0.4), tests, for high outliers are considered first; if the station skew is less than (-0.4), test for low outliers are considered first. Where the station skew is between (± 0.4), test for both high and low outliers should be applied before eliminating any outliers from the data set (Chow, 1988). The following frequency equation can be used to detect high outliers:

$X_H = Xav + KnS$---------- (3.7)

Where

X_H: - Logarithmic high – outlier test threshold,

S: - standard deviation

K:-10- percent significance- level critical value for outlier test statistic for samples of size N from the normal distribution.

If the logarithms of values in a sample are greater than X_H in the above equations, then they are considered high outliers.

Hence, the information that shows 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. A similar equation can be used to detect low outliers:

$X_L = Xav – KnS$---------- (3.8)

Where:-

X_L: - logarithmic low- outlier test threshold.

The outlier test result shows that the largest recorded value for all stations does not exceed high outlier test respective threshold value and the smallest recorded value is not below outlier test threshold value, so both high and low outliers were not detected and the rainfall data is safe for outliers and the indicated in the Appendix table 18.

❖ **Outlier test for hydrological data**

The hydrological data the same as meteorological data were required outlier test for performing sensitivity analysis, calibration, validation, and uncertainty analysis of the model

The outlier test result shows in (appendix table 19) that the largest recorded value (Y=2.5) does not exceed high outlier test threshold value which is (X_H=2.6) for Aposto and Aletawondo station largest recorded value (Y=2.1) does not exceed high outlier test threshold value which is (X_H=2.2) and the smallest recorded value (Y = 2.0) is not lower than low outlier test threshold value which is XL=1.8 for Aposto station and for Aletawondo the smallest recorded value (Y=1.6) is not lower than outlier test threshold value which is XL=1.5. So both high and low outliers were not detected within range.

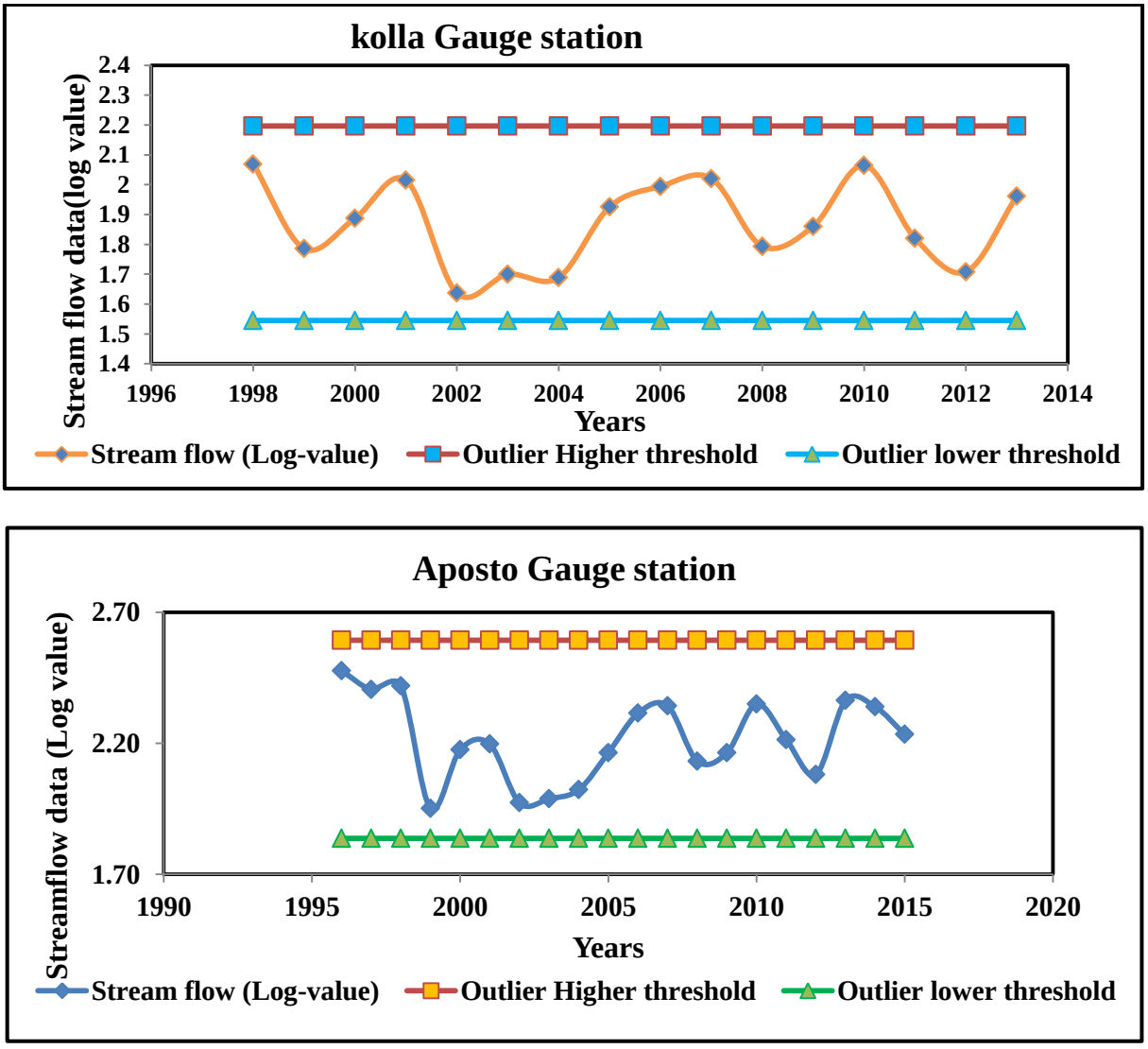


Figure 3.12: Outlier detection test results for stream flow gauging stations (1, 2)

3.3.3.6. Weather generator data preparation

If there are no daily values for weather parameters, SWAT generates from average monthly values. The model generates a set of weather data for each sub watershed. SWAT requires daily precipitation (mm), maximum/minimum air temperature (°C), solar radiation (MJ/m²/day), wind speed (m/s) and relative humidity (percentage)

In order to generate data, weather parameters were developed by using the weather parameter calculator's pcpSTAT.exe, weather generator parameter estimation tool, DEW02.exe, and base flow separator which were downloaded from the SWAT website the statistical parameters for precipitation were calculated using the program pcpSTAT.exe, Pcpstat calculator for weather generator station Dilla are shown in the table (3.4) below. The statistical calculator Dew02 software calculated statistical parameters calculation for dew point temperature data. This software calculates the temperature data to use in weather generator by taking the average of daily maximum and minimum temperature.

In this study weather generator parameters were calculated for Hawassa, Dilla and Billate stations for Upper Gidabo watershed synoptic neighboring stations it is shown below in table 3.4 and for other stations (Appendix table 4 and 5). The reason they are selected as weather generator stations were because they are first class meteorological stations i.e. Full off all the meteorological data (precipitation data, maximum and minimum temperature, relative humidity, wind speed and sunshine hours(converted to solar radiation).

Table: 3.4:- PcpSTAT output of weather generator station (Dilla station)

Month	PCP_MM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD
Jan.	31.26	3.0957	4.5576	0.1269	0.5847	7.61
Feb.	34.58	3.6256	4.9714	0.1538	0.5481	7.71
Mar.	89.42	6.047	3.3524	0.2893	0.5858	13.16
Apr.	187.69	9.1205	2.5511	0.5479	0.7593	21.58
May.	202.99	9.217	2.5115	0.6205	0.7761	23.77
Jun.	121.26	7.195	2.8817	0.4603	0.6467	17.81
Jul.	109.46	7.1473	3.5828	0.3986	0.6709	17.65
Aug.	133.16	7.4381	2.8259	0.4639	0.6922	19.39
Sep.	150.83	6.5707	2.231	0.5284	0.7932	22.61
Oct.	173.18	8.0864	2.6583	0.4192	0.8031	22.61
Nov.	72.6	5.8592	4.6739	0.2509	0.6042	12.39
Dec.	29.96	3.2153	6.9537	0.1262	0.5278	6.97

PCP_MM = average monthly ppt [mm], PR_W1 = probability of a wet day after a dry day

PCPSTD = standard deviation, PR_W2 = probability of a wet day following a wet day

PCPSKW = skew coefficient, PCPD = average number of days of precipitation in month

(Written by Stefan Liersch, August, 2003)

3.3.4. Methodology to determine the surface water potential

For determining the surface water potential of upper Gidabo watershed SWAT model was used for gauged catchments and the procedures followed were shown below.

3.3.4.1. SWAT Model Setup and Application for gauged station

The SWAT model is an ArcGIS extension with its particular user interface including SWAT project setup, watershed delineator, HRU analysis, Write Input Tables, Edit SWAT input and SWAT simulation, they are the main steps. The initial step in initializing a watershed simulation is to partition the watershed into sub-basins.

The user has the option of allowing SWAT to automatically delineate the watershed and sub watersheds using the DEM or the user can provide predefined sub-basins. HRUs are portions of a sub-basin and possess similar land uses, slope ranges, and soil attributes (Neitsch et al., 2005). The data required for the model are DEM, Soil data, Land use data, and Meteorological data for calibrating and validating the model, river discharge (streamflow) data of the outlet are required of the watershed.

The initial stage in using SWAT is a projects Setup so that important folders and databases should have been shaped to save all the data. GIS data such as DEM, Soil, Land Use, and all the data was collected, prepare and set all maps in suitable format to define and process each step.

After the DEM grid was loaded, the grid DEM map was processed to remove the non-draining zones. Stream network and sub-basin out lets were defined based on drainage area threshold approach. The threshold area defines the minimum drainage area required to form the origin of a stream. The interface lists a minimum, maximum and suggested threshold area. In this study, 2355.13 ha threshold area was used based on minimum and maximum area suggested

- **Watershed Delineation**

After project setup and suitable map preparation for the model then delineation of the watershed was done. The leading step prepare spatial input data i.e., DEM, LULC map, and soil map were projected into the same projection called UTM Zone 37N, which is a projection for Ethiopia. The user automatically delineate watershed and sub-watershed by using DEM, The watershed was delineated by using SWAT model 10.4 for this study.

The watershed delineation part includes five main steps, DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition and calculation of sub-basin parameters.

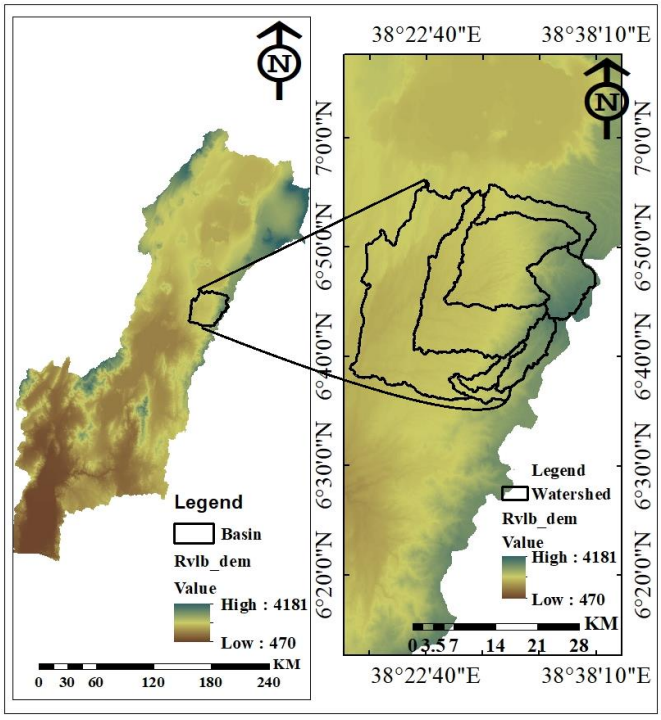


Figure 3.13: Upper Gidabo watershed extracted from RVLB.

To delineate the whole Upper Gidabo watershed from prepared DEM from Ethio_DEM and RVLB map used to demarcation, based on study area an outlet was taken at near Aletawondo (Dongora) were just it starts releasing from. Finally, the stream channels were defined as DEM cells having 1094 km^2 (109385 ha) contributing area. Based on this the Upper Gidabo watershed was divided into eight (8) sub-basins and HRUs from the watershed area of 1094Km2 (109385 ha).

- **Hydrological Response Unit Analysis**

HRU analysis attainable after the watershed delineation is finished where the land use, soil and slope characterization for watershed was done using commands from the HRU analysis menu on the Arc SWAT Toolbar.

The HRU Analysis tool for HRU definition prepared land uses and soils maps were loaded. For slope, the multiple slope option. The LULC, soil and slope map will be reclassified in order to match with the parameters in the SWAT database. After reclassifying the land use, soil, and slope in the SWAT database, all these physical properties were made to be overlaid for HRU definition sub-basins and HRUs were obtained.

i) Land use/land cover

The land uses actual meaning is the technique in which land is used by people in an area to produce what is needed by the people for use through the involvement of labor, capital, and available technology and it reflects human activities such as the use of the land, for example, industrial zones, residential zones, agricultural fields and others and Land cover is observed physical cover on the earth's surface for instance forest, grassland, concrete pavement etc.

LULC was classified based on supervised classification typically by using primary data (field survey) and secondary data (Google Earth). In the process, the image classification of 2021 were analyzed for changes through the maximum likelihood supervised classification algorithm.

Categorization and differentiation of LULC classes based on the training sites which were defined by using Google Earth images and detailed field-cross checking with many some ground control points using GPS considering each land-use type for recent Landsat 8 TM image 2021 with resolution 30x30m was processed by Erdas imagine 2014 version applied in this study comparing with LULC map was done by Different organization and Research works.

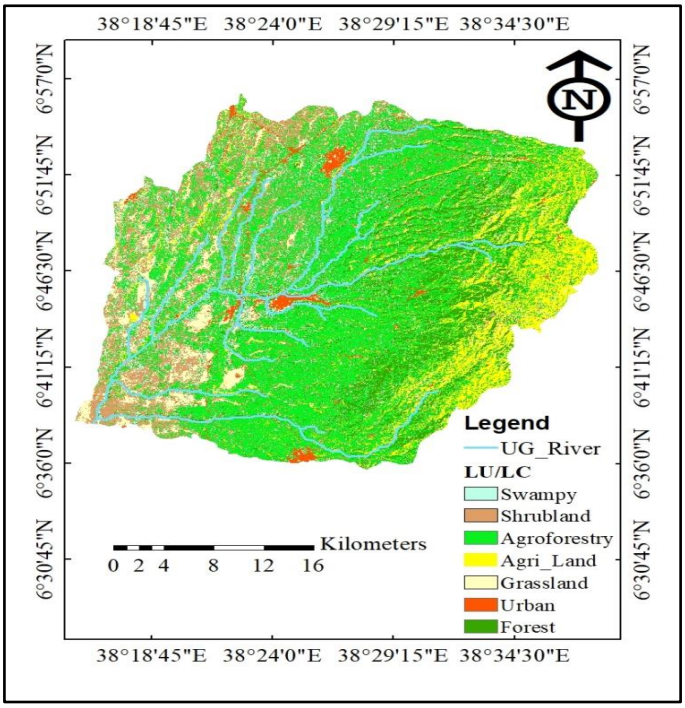


Figure 3. 14: Land use/cover map of the upper Gidabo watershed

Lu/Lc types	SWAT Code	Area (%)	Accuracy (%)
Swampy/Water body	WATR	8.7	100.00%
Range-Brush	RNGB	14.2	92.11%
Forest-Evergreen	FRSE	45.2	100.00%
Agricultural Land-Generic	AGRL	12.5	86.84%
Pasture	PAST	5.04	68.75%
Residential	URBN	2.96	96.77%
Forest-Mixed	FRST	11.41	76.67%
Overall accuracy (%)		89.72%	
Overall Kappa Statistics (%)		0.8786	

Table 3.5: Area (%) and Accuracy result of LULC classes of the study area.

The Upper Gidabo watershed is mainly covered by the Agricultural land, grassland, Shrubland, urban areas, Agroforestry, Water body and Forest. Accuracy assessment of the LULC products was done with the confusion matrix approach, where a cross-tabulation of the class label from the land cover product with the samples collected is computed (Foody, 2015). The overall accuracy of above 70 % and κ value of above 0.60 is considered as an acceptable result (Mou et al., 2021). The two indicators are derived as:

$$\text{Overall Accuracy} = \frac{N0.of\ correctly\ matched\ pixels}{Total\ number\ of\ pixels} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.9)$$

Kappa coefficient = $\frac{Po-Pe}{1-Pe}$---------- (3.10)

Table 3.6: Description of land use and land cover classes in the Upper Gidabo watershed

LULC classes	Description of each Lu/Lc classes
Agriculture	Areas allotted to annual crop, mostly of cereals.
Forest	Areas covered by trees canopies; Natural and Plantation forest, Riverine forest;
Agroforestry (Forest evergreen)	Areas includes Eucalyptus, Podocarpus and others, crops like coffee, Enset, Sugar cane, Godere and Boyna, Fruit (Avocado, Banana, papaya, Mango and others).
Grass Land/pasture	Areas with temporary or permanent grass cover privately and communally owned grazing areas.
Shrub land	Land covered by bushes, shrubs, open stands with of short trees and in some cases mixed with grasses
Swampy land/water body	Land covered with water and marsh areas

Source (Mamuye., et al 2020)

ii) Soil type

Soil is one of the major watershed characteristics and has a great influence on surface runoff generation, the soil data available from the previous study indicated that most of the soils are suitable for irrigation development and do not present any major cropping restrictions, though some areas have heavy clay soils and imperfect drainage and suffer from periodic water logging. The soils apparently affected by salinity are less and are not sodic (SCPZ, 2018).

The soil data in the model allows adding information of the soil texture, available water content, hydraulic conductivity, bulk density, and organic carbon content for each soil type and the physical and chemical characteristics and used in HRU definition in ArcSWAT. The FAO soil classification was used to define the soil type. The soil data for the watershed were collected from MoWR.

According to (MoWR, 2008) the soil types of the watershed are Pellic Verisol, Orthic Luvisol, Chromic Luvisol, and Eutric Cambisol. The major soils in the watershed are Pellic Vertisol, Orthic Luvisol, Chromic Luvisol, Eutric Cambisol, Eutric Nitosol and Eutric Cambisol (MoWR 2007). And According to Kedir Yasin (2002), soils of the Southern part of the corridor namely Upper Gidabo catchment can be divided in to four textural classes: sandy loam (including the Red and Gray varieties), silty loam, clays and thin gravelly sand soils.

These soil data were obtained from major world soils of the Food and Agricultural Organization (FAO, 74 and FAO, 90). To integrate the soil map with the SWAT model, a user soil database of MWSWAT that contains textural and chemical properties of soils was prepared for each soil layer and added to the SWAT user soil databases.

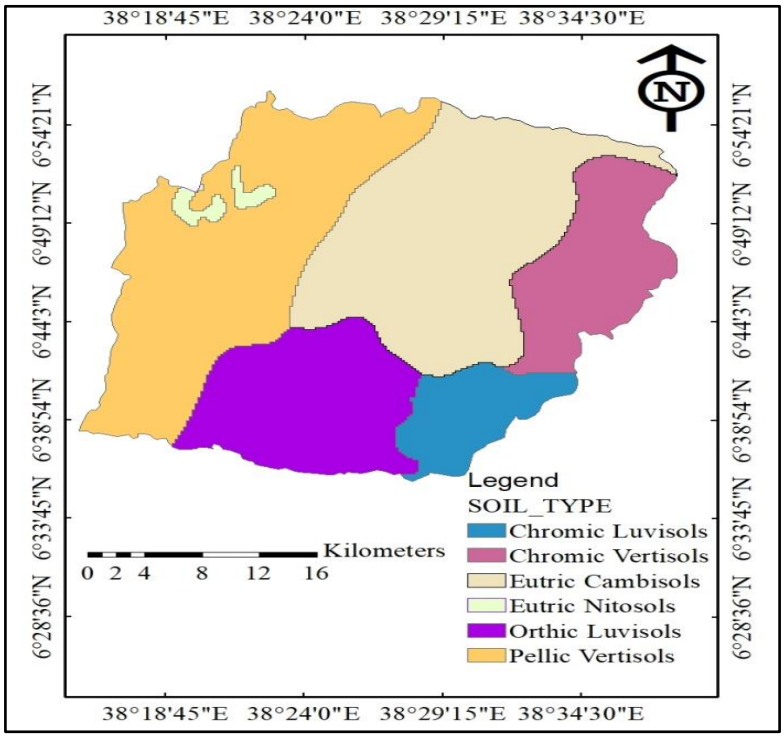


Figure 3.15: The soil map of the study area

iii) Slope

The land slope classes were also combined in defining the hydrologic response units. The DEM map was used for slope classification. The multiple slope discretization operation was chosen over the single slope discretization as the watershed has a wide range of slopes between them. Multiple slope class in Arc SWAT was used to classify the slope in to five (5) slope classes. Based on the widely used minimum, maximum, mean and median slope statistics/ classification of Ethiopia I was classify watershed in to five (5) slope classes (0-3, 3-8, 8-15, 15-30 and >30%) were applied and slope grid was re-classified.

According to (Negash, 2004) study in Abaya-chamo basin including the study area slope classification assumed to be suitable for surface irrigation and water is available, if it is less than 30%. So in this study slope of the area below 30% have high coverage from overall and it is suitable for surface irrigation and to get higher yield practicing pressurized irrigation system is better in the watershed.

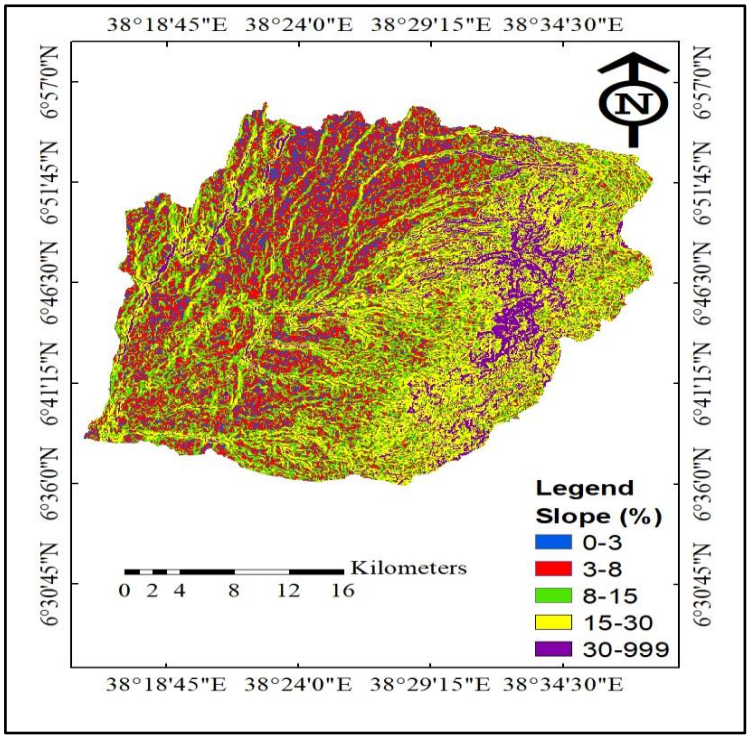


Figure 3.16: slope map of the upper Gidawo watershed

- **The hydrological processes in SWAT**

The hydrology of the areas simulated by SWAT model in two key ways: the Land Phase and the Water or Routing Phase, Land phase method was applied for this study.

Surface runoff occurs after water loses like infiltration, evapotranspiration. SWAT provides two methods for estimating surface runoff: the SCS curve number procedure (SCS, 1972) and the Green & Ampt infiltration method (1911). The SCS-CN method is used to predict runoff, which links rainfall response to soils, land use, and antecedent moisture conditions and widely applicable in predicting event based runoff volume (Teka, 2014). For these research work SCS curve number method has been used, additionally evapotranspiration determined from two methods exist in the SWAT Hargreaves and penman Monteith methods, depend hydro meteorological data that available in daily form, Hargreaves method need sub-daily data and penman Monteith method needs daily, so penman Monteith method for evapotranspiration determination was applied.

The land phase parameters of the hydrologic process or hydrologic cycle in SWAT are simulated depends upon the governing water balance equation (Neitsch et al., 2005) and computed by Equation (3.11) below:

$$SW_t = SW_o + \sum_{i=1}^{t} (R_{day} - Q_{surf} - Ea - W_{seep} - Q_{gw}) \quad \text{---------- (3.11)}$$

SW_t^i is final soil water content (mm H2O), t: is time (days),

SW_o^i is initial soil water content on day i (mmH2O),

Q_{surf} : is amount of surface runoff on day i (mm H_2O),

Ea: is amount of water entering vadose zone from the soil profile on day i (mmH_2O),

$W_{seep:}$ amount of evapotranspiration on a day i (mm H_2O) and

The SCS curve number used to simulate surface runoff as follows

$$Q_{surf} = \frac{(Rd-Ia)}{(Rd-Ia+s)}^2 \text{ ---------- (3.12)}$$

Where; Rday=is the rainfall depth for the day (mmH_2O), Ia =is the initial abstractions which includes surface storage, interception and infiltration prior to runoff (mm H2O), S=is the retention parameter (mm). The retention parameter varies spatially due to changes in soils, land use management and slope and temporally due to changes in soil water content. The retention parameter is defined as:-

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \text{ ---------- (3.13)}$$

Where: CN is the curve number for the day.

The initial abstraction, Ia, is commonly approximated as 0.2S and then the above equation becomes,

$$Q_{surf} = \frac{(Rd-0.2S)^2}{(Rd-0.8S)} \text{ ---------- (3.14)}$$

3.3.4.2. Estimating discharges at un-gauged sites from gauged sites

The rainfall data analysis results, together with discharges from gauged sites, were used to estimate the stream-flow at the ungauged sites in the study area or in the watershed for the areas not included with gauged station simulate runoff to allocation purpose using runoff coefficient method are needed due to no measured runoff data are available and no way to use determined SWAT output without comparison calibration/validation to get accurate result.

According to Goldsmith (2000) and DFID (2004), to estimate mean monthly runoff volume of un-gauged sites from gauged sites, catchment characteristics such as land cover, soil type,

and catchment slope ranges should be similar, and distances between the gauged and un-gauged river catchments should not be more than 50km and a minimum 10 years mean monthly river flow at the gauged sites should be available Otherwise, the simplest method of estimating mean annual runoff in un-gauged site was established in applying a runoff coefficient to the mean annual rainfall.

According to the study area it fulfills the criteria discussed above this means catchment characteristics are nearly similar, the distances between gauged and ungauged catchments are below 30 km and for both Aposto and Kolla river gauging stations flow data above 10 years, so no need of calculating runoff coefficient.

To estimate monthly average runoff of the un-gauged river catchments from gauged river catchments using the following equation (Jamshid, 2003).

$$Qungauged = \left(\frac{Aungauged}{Agauged}\right) * Qgauged * \left(\frac{Pungauged}{Pgauged}\right) \text{ ---------- (3.15)}$$

3.3.4.3. Sensitivity analysis of the SWAT model

Sensitivity analysis was accompanied to identify the sensitive parameters affecting stream flow for consequent application in stream flow calibration Or it is the process of identifying the model parameters that exert the highest influence on model calibration or model predictions or the way of assessing the rate of alteration in model output with respect to rate of change in model input parameter is known as sensitivity analysis.

The SWATCUP software applied for this purpose, In this software there are two ways to identify the most sensitive parameters, The first one is Global sensitivity analysis and the other one is one-at-a time sensitivity analysis, In this study global sensitivity analysis was applied to identify the most sensitive parameters using monthly observed data in the Sequential Uncertainty Fitting (SUFI-2) algorithm that is linked with the SWAT Calibration Uncertainty Program known as SWAT-CUP.

The SWAT model has several parameters that are used to identify the sensitivity of surface runoff. Sensitivity analysis was performed to limit the number of improved parameters to obtain a good fit between the simulated and observed data

3.3.4.4. Calibration and validation of the SWAT model

Calibration means whereby the model parameter is arranged to make the model output match with observed data. There are three calibration approaches widely used by the scientific community. They are manual, automatic, and combination of two. In this study, both the

manual and auto-calibration techniques were applied to get the best model parameters. The main objective of an interface is to provide a link between the input and output of a calibration program and the model. The simplest way of handling the file exchange is through text file formats.

The collection of two methods requires the user to compare measured and simulated values, and then to use expert judgment to determine which variables to adjust, how much to adjust them, and ultimately assess when reasonable results have been obtained (Gassman, 2014). First, the parameters were manually calibrated until the model simulation results were acceptable as per the R^2, NSE, and PBIAS values. Next, the final parameter values that were manually calibrated were used as the initial values for the auto-calibration procedure. Maximum and minimum parameter value limits were used to keep the output values within a reasonable value range. Finally, the automatic tool SWAT CUP was run with optimum values to give the best fit between the stream flow data and simulated data as determined by the R^2, NSE, and PBIAS reasonable values.

After calibration, the model with calibrated parameters was validated by using an independent set of measured flow data that was not used for model calibration.

Generally the SWAT model for Upper Gidabo watershed was calibrated and validated using stream flow recorded data at Aposto and Kolla stream gauging stations in (m^3/s). The first two years are warm-up period for both stations, then from 1998 - 2009 and from 2000-2008, time frame data used for calibration for Aposto and Kolla stations and from 2010-2015 and 2009 - 2013 time frame data used for Validation for Aposto and Kolla stations respectively.

- Model Performance Evaluation

The model performance was evaluated using three well-known statistical criteria, the determination coefficient (R^2), the Nash-Sutcliffe efficiency (NSE) and percent of bias (PBIAS) (Singh, 2014).

The determination coefficient (R^2) is the percentage of variance in the measured data that is explained by the simulated data. It provides a measure of how well observed outcomes are simulated by the model. The range of R^2 lies between 0 and 1 which described how much of the observed desperation is explained by the prediction. A value of zero means no correlation at all; whereas one mean that the desperation of the prediction is equal to that of the

observation and the closer the value of R^2 to 1, the higher is the agreement between the simulated and observed flow. The R^2 value is calculated as:

$$R^2 = \frac{(\sum[QSi - Qsi_{av}][Qob - Qob_{av}])^2}{\sum[Qsi - Qsi_{av}]^2 \sum[Qob - Qob_{av}]^2} \text{---------- (3.17)}$$

The Nash-Sutcliffe coefficient of efficiency (NSE) shows that how well the plot of observed values versus simulated value the 1:1 line fits or measures the efficiency of the model by relating the goodness-of-fit of the model to the variance of the measured data, it ranges from $-\infty$ to 1. An efficiency of 1 corresponds to a perfect match of simulated discharge to the observed data. An efficiency of 0 indicates the model predictions are accurate the mean of the observed data, whereas an efficiency less than zero ($-\infty < NS < 0$) occurs when the observed mean is a better predictor than the model. Besides, due to frequent use of this coefficient, it is known by values between 0.6 and 0.8 tells that model performs reasonably. A 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 (Nash and Sutcliffe., 1970). It can be calculated as follows:

$$NSE = 1 - \frac{\sum(Qob - Qsi)^2}{\sum(Qob - Qob_{av})^2} \text{---------- (3.18)}$$

Where: -

NSE = Nash-Sutcliffe coefficient

Qob_{av} = Average measured discharge value (Cumcs)

Q_{si} = Simulated monthly discharge (Cumcs)

Q_{oi} = Observed monthly discharge (Cumcs)

i = Monthly observed and simulated data

Percent bias is the measure of the mean values of the simulated flow to be greater than or smaller than their stream flow data. Positive values that show model underestimation bias and negative values also show model overestimation bias. A value close to zero percent is best for PBIAS and the recommended range for percent bias is between positive 25 and negative 25. PBIAS is calculated as follows:

$$P_{BIAS}(\%) = \frac{\sum Xi - \sum Yi}{\sum Xi} * 100 \text{---------- (3.19)}$$

Table 3.7: Overall recommended performance ratings (Moriasi et al., 2007)

Performances	R^2	NSE	PBIAS
Very good	$0.70 < R^2 \leq 1.00$	$0.75 < NS \leq 1.00$	$PBIAS < \pm 10$
Good	$0.60 < R^2 \leq 0.70$	$0.65 < NS \leq 0.75$	$\pm 10 \leq PBIAS < 15$
Satisfactory	$0.50 < R^2 \leq 0.60$	$0.50 < NS \leq 0.65$	$\pm 15 \leq PBIAS < \pm 25$
Unsatisfactory	$R^2 < 0.50$	$NS \leq 0.5$	$PBIAS \geq \pm 25$

3.3.5. Methods of Water demands assessment

In general assessment of water demand is the vital input for decision-making in water resources planning and management in the watershed. The water demands in the watershed are different kinds, they are consumptive (Agriculture, Domestic, Livestock, Commercial, and Industrial) and non-consumptive (Environmental requirements) are considered for this study. In this study demand assessment was done at district level due data availability and different studies including (Habitamu, 2018), (Akililu, 2020), (Desalegn, 2018) and others in the RVLB basin or out of this make their study in this way. To achieve this, the WEAP model was selected and here the methods listed below were followed for the current situation and future water demands assessment through scenario analysis:

3.3.5.1. WEAP Model Application for water allocation

The model follows many steps to demand assessment from them the major one is illustrated as follows:-

I. Define of the study area and time frame: The study area was defined and set its boundary by adding the vector layer (shape file) and river network of Upper Gidabo watershed which can be prepared using ArcGIS 10.4.1 to the model, because WEAP reads both vector shape file or raster format of WGS 1984 projection and set the time frame includes the initial year(2021) and last Year of scenario(2050) creation, the time frame set to be based on RVLB master plan that current and future development prediction on different sectors, for instance population growth rate in the whole basin area was up to 2050 due to this and for other sector prediction by the master plan i decided to use this time frame for this study.

II. Create the current account: - The Current Accounts represents the basic definition of the water system in WEAP of current situation or assumed to be the starting/base year for all scenarios. Under the current account, available water resources and various existing demand nodes were specified for the study. This is very important because it is the basis for the whole modeling process of future situation. In this study, as mentioned above the 2021

was the current account year while the last year of the scenario was set to be 2050, therefore all the collected current information on both water supply and demand was the data input to the current accounts.

III. Creation of scenarios: - Scenarios are alternatives or assumptions can be advanced based on future development and expected increases in the numerous indicators. It is the heart for the WEAP model since this supports for possible water resources allocation/ management processes.

The scenarios were used to address a lot of "*what if situations*", like what if population growth and economic development pattern change, and what if the larger area will be irrigated or improvement in irrigation efficiency technology will be applied and others.

In this study, three scenarios were developed namely; reference/baseline scenario, scenario one(population growth scenario) and scenario two (increased water demand scenario) for water demands which consider population increasing, increasing of Livestock population, agricultural area expansion, domestic and commercial water demand increasing and others for proper water allocation and management.

IV. Evaluation or analysis of the scenarios: With regards to the availability of the water resources for the study area in the above applied scenarios were evaluated. Results generated from the creation of scenarios can help the water resources planner in decision-making and core of this study. WEAP uses scenarios as a way to evaluate different water allocation sectors, All the above scenarios were evaluated and possible solutions were put down to avoid water based conflict among water users and strategies for balancing supply and demand.

- **WEAP schematics**

The primary task was preparing vector or raster map with the same projection mostly WGS 1984 projection prepared by GIS software is the suitable one, then schematic diagram of the study area (Figure 3.18) was prepared, and the time frame was set from 2021-2050 as stated above and the model was simulated from 2022 to 2050 as reference scenarios and for other future scenarios.

- ✓ **Demand Sites and entering related data**

Six demand nodes including EFR were shaped and the required data were imported to the model for each demand sites.

✓ **Connecting the Demand with Supply**

In order to notify WEAP how the demand is satisfied, the water supply source (rivers) was connected to each demand sites. These were accomplished in the schematic view by adding the transmission link. The link was first positioned on the river, then pointing or dragging to each five demand nodes.

✓ **Creating the Return Flow Links**

The return flow routing is the percent of total outflow from a demand node, and then the return flow routing for that link must be 100% due to only one return flow link is created for each demand nodes. The return flow links were connected back to the rivers and return flow routing was set to be 100%, so as to use the return flow for other demands efficiently. The key features of the WEAP model in this study are shown in the figure below.

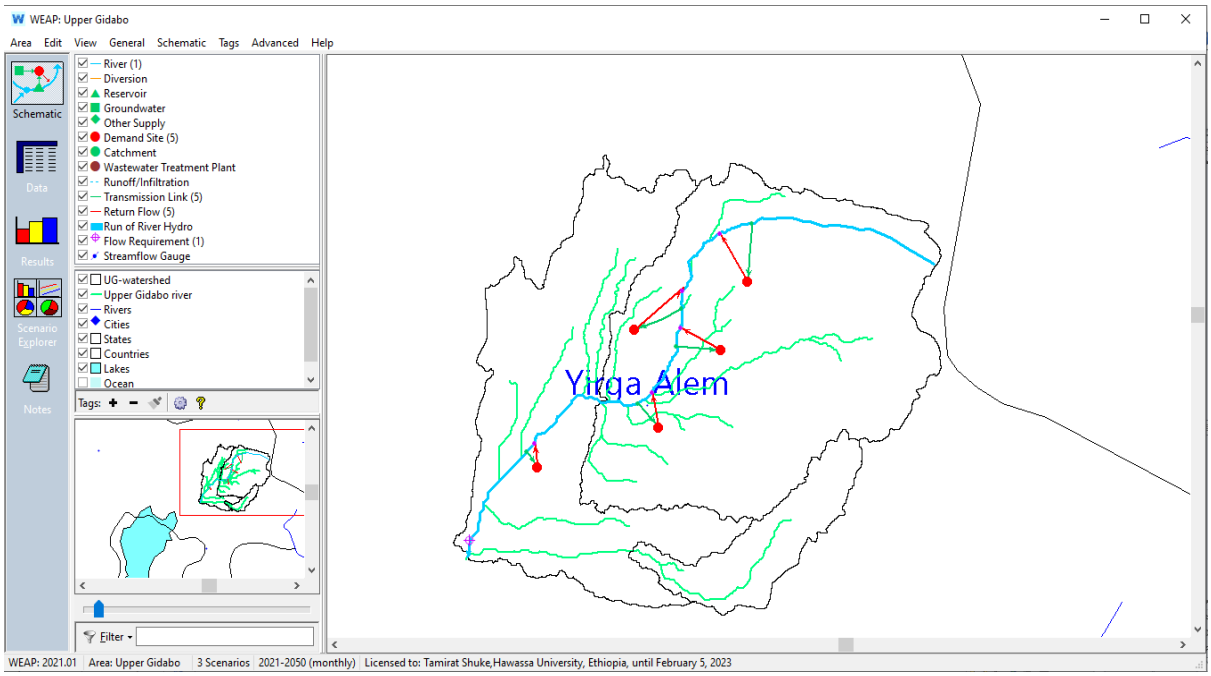


Figure 3.17: WEAP schematic view of the study area

➢ **Priority in water allocation**

A standard linear program or algorithm was used to solve the water allocation problem whose objective is to maximize satisfaction of demand, subject to supply priorities, demand site preferences, mass balances and other constraints. The WEAP model follows prioritization for water allocation; Priorities (1 to 99) were used to classify demands. 1 represents highest priority demand node and 99 represents the lowest priority demand node (SEI, 2020). A

Demand-Priority and supply Preference driven Approach or systems used presents a robust solution algorithm to solve the water allocation problem.

Demand Priority determines the demand site's priority for supply. Demand sites with higher priorities are processed first by the model. Reservoir priorities default 1 to 99, meaning that they will fill only if water remains after satisfying all other demands. Many demand sites can share the same priority. These priorities are useful in representing a system of water rights and are also important during a water shortage (SEI, 2019).

Based on Ethiopian National Water Law and utilization of water resources prepare by (MoWR, 2010) in the study area the priorities below-listed were assigned in the study to each compartment of the demand category.

Table 3.8: Assigned priority levels

Demand type	Priority
Domestic water demand	1
Environmental flow requirement	1
Livestock water demand	2
Agriculture(irrigation) water demand	3
Industrial water demand	4

In the study, the assigned priorities were adopted for the model to understand which demand sector should be given the first, second, third etc. priorities. On the other hand, Environmental flow requirements were considered to keep the needs of the ecological system of the basin. This priority was set to the implementation of the priority was guaranteed the success of a later re-allocation plan so that a computer-based simulation by WEAP models were used to the best allocation priority and schedules under the competing water demands.

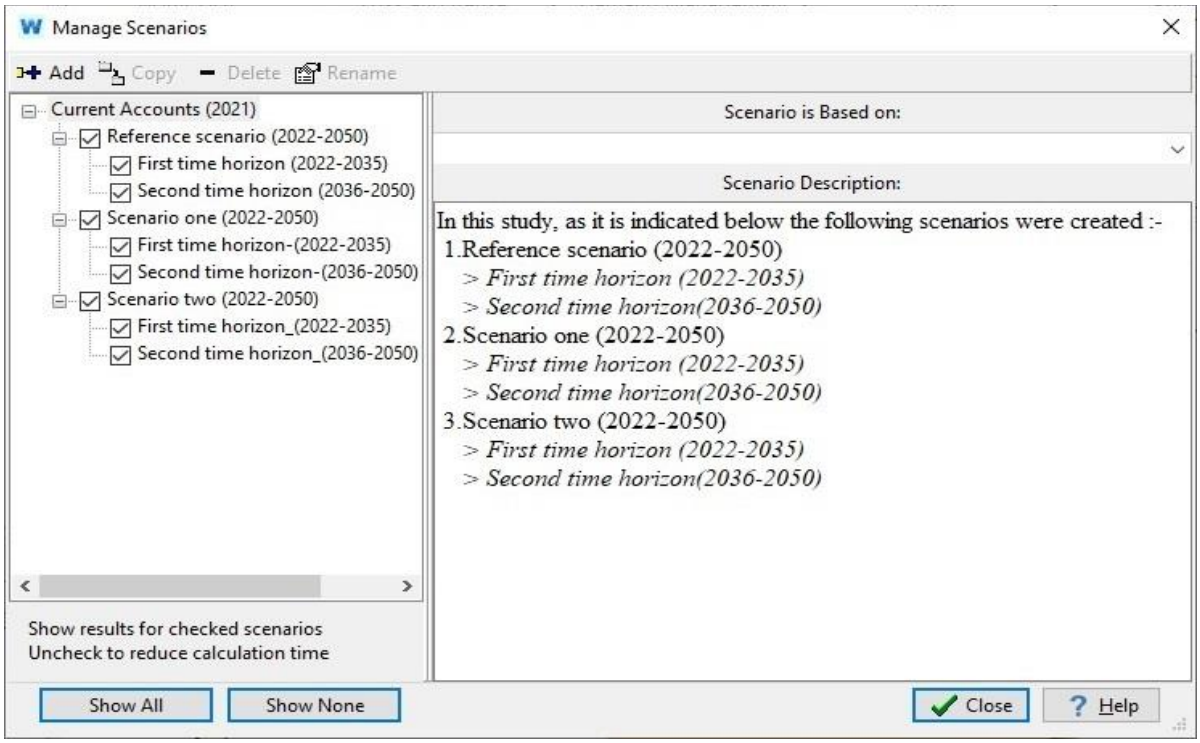
- **Description of Scenarios in WEAP**

Scenarios are the self-consistent storyline of how a future system might evolve or change or develop in a particular socio-economic setting and under a particular set of policy and technology conditions (SEI, 2012) Or Scenarios are alternatives or a set of assumptions (operating policies, pricing, and demand management strategies and alternative supply sources). They can address a broad range of "what if" questions on demand amount, coverage of water for each demand sites and in overall balance of water in the study area.

To support the goal of this study an extensive modeling exercise has been undertaken using the WEAP model to evaluate supply requirement through scenarios. For this study Scenarios were established in WEAP based on population and Livestock growth rate for the reference

scenario from 2022-2050 for two time horizon; from 2022-2035 and 2036 -2050 in the first and second time horizon, respectively. The scenario developed for Upper Gidabo watershed water demand are as discussed below.

Figure 3.18: Scenario description



i) Reference scenario (2022-2050)

Reference scenario it is also called "business as usual", it represents the changes that are likely to arise in the future without intervention new policy measures or no major changes imposed in this scenario; it only considers Human and Livestock population growth rate of the current account. Therefore, the total population within the basin was projected by CSA around 1.36million for the year 2021 based on Census 2007 data (CSA.2014), The current account year (2021) was extended to the future for two time horizon (2022-2035) and (2036-2050).

ii) Scenario one: High population growth scenario

This scenario was modeled to assess the influence of a high population growth rate than the current population growth rate in the watershed for human and Livestock population and population density from the CSA population projection of 2017 and extended to 2021 was up to 1239 peoples/ km^2 so, the growth rate is high in the watershed. The question of what will happen if the rate population growth is set to a higher growth rate than the reference scenario population growths rates was answered and the other sectors like commercial and industrial

are change due population increment and industrial development especially agro-processing Industries in the future, the Agriculture sector considered constant in this scenario.

iii) Scenario two: Increased water demand scenario

According to (Negash, 2004); (Kebede, 2010) on the Gidabo watershed above 80% of slope, land use and soil is suitable for irrigation especially pressurized irrigation is recommended on this area, Irrigation in this watershed is needed to rapidly growing in terms of high population growth rate or other increasing demands. The exploitation of all potential irrigation command areas that identified by the Sidaama irrigation agency, which can be expected to cover up to 80% in the future, from this on this study Agriculture developed by the 3 and 5 times increase for two time horizons 2022-2035 and 2036-2050 respectively, For other sectors also considered by maximizing their demand by half (50%).

3.4. Sectoral water uses rate analysis

The WEAP model requests sectoral water uses rate as basic input. Sectoral information was collected from different bases to evaluate and entirely understand the current and future water demands regarding the available supply of the upper Gidabo watershed. In general water demand calculations was done by assessing the Domestic, Commercial and institutional, Agricultural, Industrial, Livestock and Environmental water demand

3.4.1. Domestic water demands

Domestic water demand involves all Domestic utilization in urban and rural areas. Per capita, water demands show that 25 l/d and 50 l/d for rural and the urban areas (MOWIE, 2015). There are seven(7) districts under Upper Gidabo catchment, this study covers the entire woredas and on those woredas three towns namely Leku, Yirgalem and Aletawondo categorized under category 4 (50 l/d) due to economic growth and population number above 20,000, Water demand for small towns less than 10,000 inhabitants was assessed by applying the rural standard (MoWR, 2010).

The (CSA, 2017) population projection has calculated the total population of Upper Gidabo catchment was up to 1,214,787 of which 1,062,717 (87%) were in rural areas and 152,070 (13%) was in urban areas. Then, these numbers were extended to 2021 by using Geometric method for population projection and the current total population of the districts was around 1,354,779, 1,355,283 and 1,383,061, respectively according to (Halcrow, 2007) Low, Medium and High population growth rate in (appendix table 9), in this study medium

population growth rate was considered because of it is related to overall population growth rate of the country up to 2.3%.

However, these population data was input in the WEAP model to obtain the water demand. Water demand for current and future study was calculated using equation below.

Domestic water demand = activity level * water use rate per activity---------- (3.20)

Where, activity level indicates number of population in the area

According to (RVLBA, 2010), GTP II standard of Ethiopia for towns in basin including Yirgalem town in the study area and rural areas nearly the same of 50-100 l/c/d and 25 l/c/d , respectively (liters per capita per day) depend on number of population.

Based on sample survey RVLB (2010) shows for towns like Yirgalem that about 90% of the communities for DWD are using piped supplies from ground water as the primary source, while springs and rivers are used as secondary sources but springs used for Domestic purpose was less from this for urban water demand 10% from the total and in the rural for Domestic purposes surface water was vastly used so, 50% was assumed from total DWD was considered in this study. On this basis, the total DWD 38,772.6m^3/d was determined, for urban and rural, 8870.2m^3/d and 29902.4m^3/d were calculated, respectively.

3.4.2. Agricultural water demand

Irrigation is the highest water demanding sector which needs attention for the management of the water resources of the watershed. For ensuring food security, reducing poverty and contributing for the national economic development of the country, the importance of irrigated Agriculture in the watershed is very crucial.

According to the MoWIE irrigation command areas can be classified into three groups (Awulachew et al., 2007). The first group is small-scale irrigation areas of (<200 ha), medium-scale (200-3000 ha) and large-scale (>3000 ha). For this study, small and medium-scale for functional and planned projects are considered due to irrigation projects in the study area belongs to them.

The Agriculture demand was assessed based on soil type and water requirement for crops by using Area, Crop coefficients (Kc), and the Reference Crop Evapotranspiration (ETo). CROPWAT, which was developed by FAO, used to determine water requirements for the proposed irrigation schemes. The main crops in the study area include nine crops they are

Banana, Cabbage, Onion, Sugarcane, Tomato, Avocado, coffee, carrot, potato, were chosen to determine the crop water requirement for proposed irrigation. The Penman-Monteith method was used to determine the reference crop evapotranspiration (ETo) and the USDA soil conservation service formula for effective rainfall.

The total water demand for irrigation was determined by multiplying the total area under irrigation with the irrigation water requirement for each cropping pattern. Cropping pattern of the watershed was determined by using secondary data from Woreda and different documents (SNRS agricultural office, Sidaama irrigation agency, District Agriculture and rural development office and consultation with beneficiaries in the kebeles). CWR for different crops was calculated using ETo, Kc and P_{eff}, the following equation was applied.

ETcrop = KcETo ---------- (3.21)

IWR = ETc-Peff ---------- (3.22)

Where:-

ETC- Crop evapotranspiration (mm/period), P_{eff} - is effective rainfall (mm), IWR- is irrigation water requirement in (mm/period), Kc-is crop coefficient, ETo- reference evapotranspiration (mm/ day)

Reference evapotranspiration calculated by using FAO Penman-Monteith method by using climatic data (temperature, humidity, sunshine hour and wind speed from ENMA) form of the equation is given by:

$$ET_O = \frac{0.408\nabla(Rn-G)+\frac{\gamma 900}{\gamma+273}U2(es-ea)}{\nabla+\gamma(1+0.34U2)} \text{ ----------(3.23)}$$

Where: - **Rn** is net radiation at crop surface [MJ m-2 day-1]; $\mathbf{e_a}$ actual vapour pressure [KPa]. **G** is the total soil heat flux [MJ m-2 day-1]; $\mathbf{U_2}$ is the wind speed at 2 m high [m s-1]; **∇** is the slope vapour pressure curve [KPa °C-1]; **γ** psychometric constant [KPa °C-1]; $\mathbf{e_s}$ saturation vapour pressure [KPa]; **T** is average temperature [°C].

Data like Crop coefficient (Kc), crop growth stages, rooting depths, critical depletion fraction, yield responses factor, maximum crop height and length of growth stage were fixed for crops that were planted in the watershed according to local conditions of study area and using literature (Allen et al., 1998), (Pruitt & Doorenbos, 1977), (FAO, 2006) and other related literature) was used. Effective rainfalls used for CWR was calculated procedurally as shown

in the appendix table (IV) using 31 years rainfall data by USDA soil conservation service formula in mm depth. It has different formula for the two ranges of precipitation

$Peff = (\mathrm{p} * (125 - 0.2 * 3 * \mathrm{p}))/125 \quad for\ P \leq 250/3\ mm$---------- (3.24)

$Peff = 125/3 + 0.1 * \mathrm{p} \quad for\ P > 250/3\ mm$---------- (3.25)

Where Peff is effective precipitation (mm); P is precipitation (mm)

In the Districts that included in the watershed currently functional small scale modern and Traditional irrigation schemes are available. Modern irrigation schemes constructed by Sidaama region Irrigation agency, Sidaama region Water, mines and energy office and traditional irrigation cultivated by the farmers with the help of Agriculture offices of the districts. The amount of irrigated lands, types of crops grown and related data which affect the demand for irrigation water in the study area is collected from organizations responsible for the development of the irrigation schemes.

Districts	Modern SSI (ha)	Traditional diversion (ha)	Total irrigated area (ha)	Total IWR (MCM)
Shebedino	151	1814.8	1965.8	2.36
Dale	144	1627.1	1771.1	1.91
Burrisa	100	1652	1752	2.02
Goriche	130	955	1085	1.24
Wonsho		1250.8	1250.8	1.30
Aletawondo		1569.8	1569.8	1.91
Hawella		857.49	857.5	0.98
Total	525	9726.99	10252	11.72

Table 3.9: Water demand of modern and traditional schemes of irrigation in the study area

No	Irrigation project	Districts	Irrigable area (ha)	Annual gross water requirement (MCM/Year)
1	Ereerite, Wonjala and Tarica	Burrisa	213	5.76
2	Wamoole and Garana	Goriche	130	1.07
3	Wamole dam	Shebedino	1250	0.56
4	Tishishe	Hawella	70	0.47
5	Kolla and Kolla dam	Aletawondo	5700	1.5
Total			7363	9.4

Table 3.10: Water demand of planned and under construction irrigation schemes of study area

As per the WEAP model data input requirement, irrigated area, type of crops, and seasons of cultivation are important. Current irrigated areas of the study area are calculated to be 10252 ha. Based on the existing and future plan of the regional government, the crop water requirement of all the crops grown in the study area in a selected climate stations of the area have been used in this study, and the average IWR were observed to be 11.7 MCM/year for the year 2021, and for planed schemes 9.4 MCM/year totally the overall IWR for the study area was up to 21.1MCM/ year and Water use 1198 m3/ha as presented in (table 3.9 and 3.10) for both irrigation schemes.

3.4.3. Livestock water demand

Water is one of constituents for the survival of Livestock, constituting about 75% of body mass. Livestock satisfy their water needs through direct consumption, through the feed they ingest and dairy operation, and other left over (Atela). Succulent types of feed have more water and Livestock eating these may need only a small quantity of additional water.

The water requirements of Livestock are influenced by several factors, including: Type of Livestock, pregnancy and lactation, type of diet, Feed intake and Temperature. Assessing of Livestock Water requirement in the watershed is need to determine the number of each type of Livestock in the basin, in this study, the total Livestock population was calculated by converting different Livestock species into a common reference unit called Tropical Livestock Unit (TLU).

To assess the water demand of Livestock in the Watershed the indirect method was adopted by multiplying Livestock population with TLU and unit water requirement for each Livestock considered in Ethiopian as well as the RVLB condition. One Tropical Livestock Unit (TLU) is equivalent to an animal live weight of 350 kg for Cattles based on (RVLBA, 2010).

LWD = Per capita water consumption (l/d) x Livestock population x TLU------- (3.26)

TLU = Livestock population * TLU fact---------- (3.27)

Live Weight = TLU * 350 (1 TLU is equivalent to the weight 350 kg) ---------- (3.28)

Table 3.11: Estimated Water Demands for Livestocks

No	Livestock	Number	Conversion factor	TLU	Water requirements (L /day)	Water requirements (m3/y)
1	Cattle	1059619	0.7	741733.3	18543333	6768316
2	Goat	36241.3	0.1	2896.31	14481.55	5285.766
3	Sheep	20276.1	0.1	1984.75	9923.75	3622.169
4	Horse		0.8	8922.88	107074.6	39082.21
5	Donkey	23279.9	0.7	16150.4	193804.8	70738.75
6	Mule	671.3	0.7	458.15	5497.8	2006.697
7	Hen		0.01	106.2307	42.49228	15.50968
8	Beehives			48050	144150	52614.75
		1221524		820302	19,018,308	6,941,682

Source: SNRSAFRA (2021)

In the watershed, that the total number of TLU calculated was up to 1,221,524 and Livestock water demand annually in the watershed was up to 6.94 MCM/ year**.**

3.4.4. Public/ Commercial and Institutional water demand

In addition to Domestic water use, water requirements in the urban include the normal needs of the community for public schools, clinics, hospitals, offices, shops, restaurants, hotels and other institutions. The water demand for commercial and institutional needs is usually linked directly to the population. According to (Halcrow 2007) for small and medium sized towns it was assessed at 5% of the DWD and for larger towns it was up to 10%. But in the study area the towns categorized under medium and small sized due to this CIWD assumed 5% DWD.

3.4.5. Industrial water demand

Industrial water demand is water required for factories and Industries. According to (Halcrow, 2007), (Mayol, 2015); (Tilahun, 2015); (Kemal & Adeba, 2021) for planning purposes, a reliable industrial water demand indicator was assumed to 10%-30% of DWD depend on size of towns and number of available industrial zones and they are only considers urban areas but in this study area coffee processing sites are also exist in rural areas. In the watershed and nearby, there are various coffee processing industries, the area are well-known by vast coffee production.

According to Sidaama region natural resources bureau report of 2021 there is around 247 coffee processing sites are available in the study area and the others many in number are under construction and planned. But none of them have been recorded water use/

consumption information there is no metering system available. Therefore, even if it is not usually linked directly to the population, I have decided to link it to Domestic demand, and 20% of the Domestic demand was assumed to be assigned to industrial water demand in urban and rural areas.

3.4.6. Total daily demand

The total daily demand is taken to be the combined total of the Domestic, Livestock, commercial, institutional, and industrial water demands.

Total Daily Demand = DWD + CIWD+ IWD---------- (3.29)

3.4.7. Environmental flow requirement

Environmental flows vary from year to year depending on river flow where it ranges from between 10% to 15% of the annual flow. In dry seasons it is less than 10% of the natural river flow (Petersen & Gadain, 2012). In this study 10 % of total annual flow is left for ecosystem maintenance in the river system and for the satisfaction of the Environmental flow requirements.

4. Results and Discussion

4.1. Sensitivity analysis

Sensitivity analysis was implemented by selecting sixteen (16) parameters based on manual training in Arc SWAT and reviewing different works of literature. The ranges of variation of these parameters are based on absolute SWAT value and the most sensitive parameters were identified using Global sensitivity analysis method in SWAT-CUP SUFI2 algorithm. Sensitivity analysis ranks these parameters from small to high sensitive values. Parameters with small sensitivity values do not significantly affect the model output; hence, they are neglected in calibration process. Only parameters with very high sensitive values which affect the model output significantly are used to calibrate the model. The highest value of t-stat indicates the ratio of the high parameter coefficient to standard error and lower the p-value related to the rejection of the hypothesis that an addition in the value of the parameter provides a significant increase in the variable response (Abbaspour et al., 2017).

According to A *t*-stat that was used to identify the relative significance of each parameter that was a value larger in absolute value was most significant and p-value less than 0.5 the significance of the sensitivity, a value close to zero is more significant. From the model output, as shown in table 4.1 below the most sensitive parameters when calibrating the model were twelve (12) parameters are high sensitive they are threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN), Maximum canopy storage (CANMX), Average slope steepness (HRU_SLP) , Moist bulk density(SOL_BD), SCS runoff curve number f (CN2), Saturated hydraulic conductivity(SOL_K), Groundwater delay 83 (GW_DELAY), Available water capacity of the soil layer (SOL_AWC), Effective hydraulic conductivity in main channel alluvium (CH_K2) ,Biological mixing efficiency (BIOMIX), Soil evaporation compensation factor(ESCO),and Surface Runoff Lag Coefficient (SURLAG).

Parameter Name	t-stat	p-value	Fitted_ Value	Min_value	Max_value	Rank
v__GWQMN.gw	5.43	0.00000017	3157.5	1500	4500	1
r__CANMX.hru	4.58	0.0000083	69.02	30	100	2
r__HRU_SLP.hru	3.78	0.000206	0.41	0.2	0.6	3
r__SOL_BD (...).sol	3.73	0.000252	1.91	0.9	2.4	4
r__CN2.mgt	3.25	0.00137	47.45	40	70	5
r__SOL_K (...).sol	3.25	0.00137	787.26	85	1000	6
v__GW_DELAY.gw	3.15	0.00187	100.02	20	350	7
r__SOL_AWC ().sol	2.90	0.00415	0.65	0.2	0.8	8
r__CH_K2.rte	2.42	0.0165	0.13	0	0.5	9
r__BIOMIX.mgt	2.15	0.0325	0.18	0.1	0.6	10
r__ESCO.hru	2.11	0.0358	0.24	0	0.55	11
r__SURLAG.bsn	2.08	0.0384	19.01	7	25	12
r__GW_REVAP.gw	1.88	0.0606	0.44	0.01	0.5	13
r__REVAPMN.gw	1.63	0.105	223.53	15	350	14
v__ALPHA_BF.gw	1.35	0.177	0.69	0.3	0.98	15
r__EPCO.hru	0.62	0.537	0.51	0.3	0.8	16

Table 4.1: Most Sensitive and fitted parameters in the stream flow for calibration

4.2. Calibration and validation of the model

The calibration and the validation were done using SWAT CUP software SUFI2 algorithm with the objective function of R^2, NSE, and PBIAS for many numbers of iterations, above 500 simulations for 20 and 16 years observed flow data at Aposto and Kolla gauging stations, respectively and their results are presented below in (table 4.2). The calibration and the validation results were performed until a good agreement between the simulated and observed monthly flows at the outlet of both gauging stations in the watershed. The model was calibrated for Flow data for the year 1996-2009 (12 years) it is including two years or 10% warm up of total data at Aposto gauging station and 1998-2008 (11 years) with two years model warm up of kolla gauging station.

In the validation process, data for a period of 2010-2015 (6 years) was used at Aposto gauging station and data for a period of 2009-2013(5years) at kolla gauging station to evaluate model accuracy.

Based on the model performance evaluation parameter numerical values of determination coefficient for Aposto gauging station (R^2=0.81), (NSE=0.60) and (PBIAS=-14.7) at Aposto gauging station and (R^2 = 0.78), (NSE = 0.61) and (PBIAS = -11.5) at Kolla gauging station assures that the model shows good performance during calibration and validation the result is presented in (Figure 4.1 and 4.2) and Table 4.2 according to (Moriasi et al.,2007). So as to

able to simulate the runoff in the study area and estimated numerical values during model calibration and validation are summarized in the table below.

Table 4.2: model performance indicators

Gauging station	Model runs	Model performance evaluation parameters		
		R2	NSE	PBIAS
Aposto	Calibration	0.83	0.65	-19.3
	Validation	0.81	0.60	-14.7
Kolla	Calibration	0.79	0.62	-10.7
	Validation	0.78	0.61	-11.5

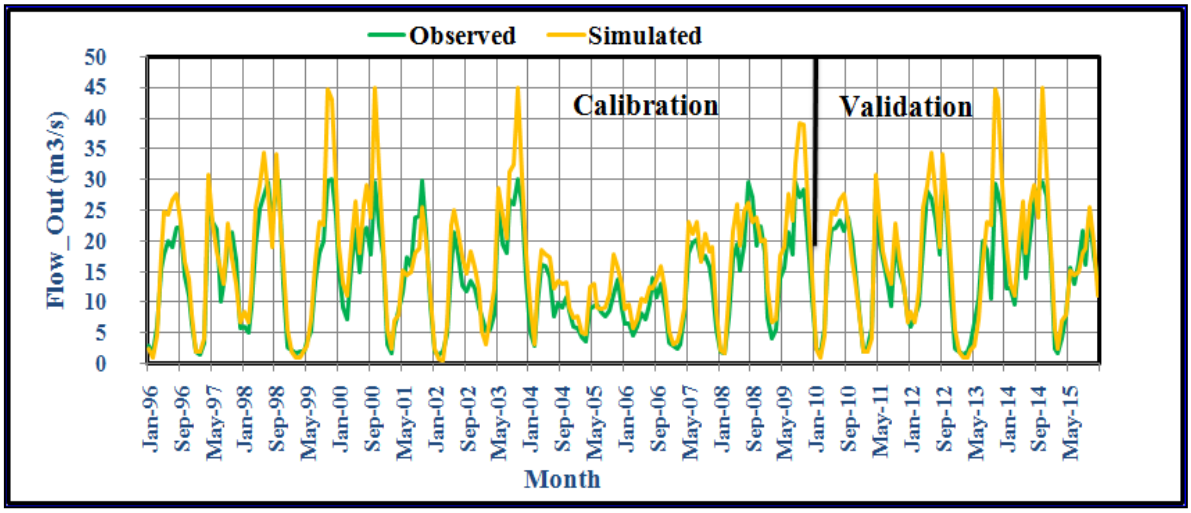


Figure 4.1: Simulated and observed flow hydrograph at the Aposto gauging station

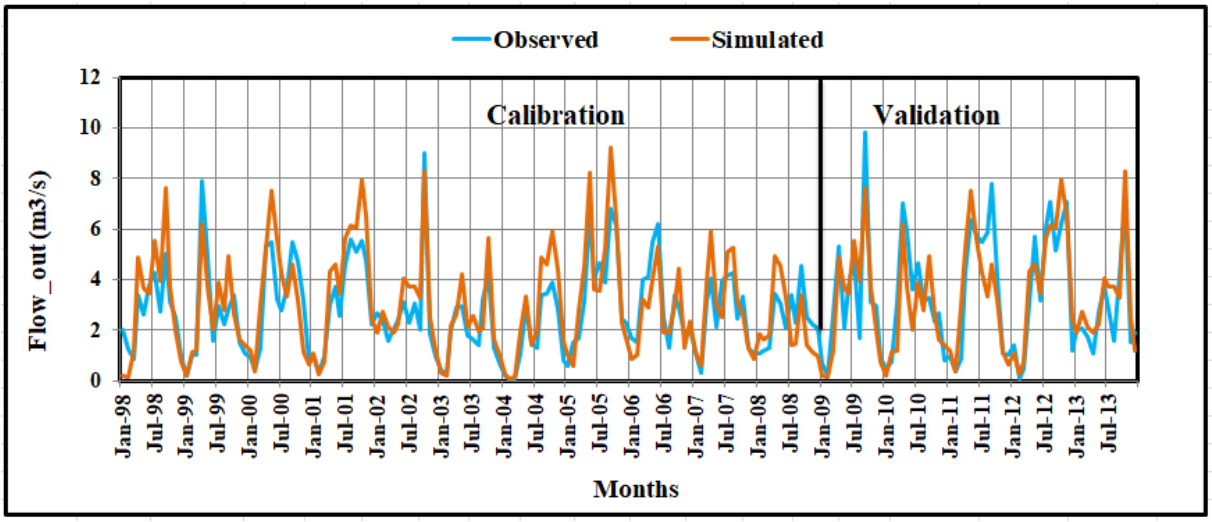


Figure 4.2: Simulated and observed flow hydrograph at the kolla gauging station.

4.3. Water balance and Surface water potential

The water balance showed by inputs and outputs to the area so, based on the model water balance characterized by precipitation, evapotranspiration (ET) and Soil Water Content (SWC) through infiltration and surface run-off. All of the hydrological processes mentioned above are decides the amount of flow in the catchment. The increment of precipitation develops surface water resources by fulfilling different losses like Evapotranspiration; the higher the temperature, the higher is potential evapotranspiration (PET) and therefore enough water in the soil.

After running (simulating) the SWAT model, calibrating and Validating the result with the gauged stream flow data of Upper Gidabo watershed for two gauging station and for one ungauged outlets calculate flow by using runoff coefficient method to determine flow of ungauged station from gauged stations found in the study area.

The mean flow of the river at Aposto gauging station is determined to be 17.35 M^3/sec (SCPZ, 2018), (RVLBA, 2010) and for this study the result obtained on Aposto station was nearly the same, after rerun the model the following result was found. From total 109,385 ha of watershed, totally 773.5 MCM surface runoff was generated by the model from the two gauging stations namely Aposto and Kolla and one ungauged station Dongora mean annually for the year 2021. The watershed has maximum runoff volume of 327.1 MCM and a minimum runoff of 37.6 MCM in April and December, respectively. Exclusively surface runoff was generated annually by runoff coefficient method for ungauged Dongora outlet up to 101.7MCM and for gauged Aposto and kolla outlets 549.9MCM and 121.9 MCM respectively/ the same value I was get from the delineated eight (8) sub basins.

Table 4.3: Average simulated flows at sub basins for gauged and ungauged stations

Stations under	Year	Sub basin	Observed	Simulated
Below Aposto	2021	1	0.841	0.838
Below Aposto	2021	2	1.180	1.178
Below Aposto	2021	3	2.247	2.239
Below Aposto	2021	4	13.114	13.113
Below Kolla	2021	5	0.334	0.32435
Below Kolla	2021	6	0.487	0.55513
Below Kolla	2021	7	3.102	2.97306
Dongora (Ungauged)	2021	8		3.21

According to Aposto gauging station determination the contribution of the water balance during 'Kiremt' season (June, July, August and September) is high, The water balance is low during 'Bega' season (October, November, December, and January) and The water balance during the 'Belg' season (February, March, April and May) the contribution is relatively higher than 'Bega' season as shown in the table (4.4) below.

Table 4.4: Average monthly water balance values of the watershed based on Aposto station

Month	RAIN (MM)	SURF Q (MM)	LAT Q (MM)	WATER YEILD (MM)	ET (MM)	PET (MM)
January	28.33	3.27	1.32	23.58	28.93	175.13
February	26.5	2.69	1.03	14.83	24.75	139
March	93.15	12.39	1.66	28.11	55.47	129.23
April	184.36	31.87	3.09	60.31	65.05	104.31
May	183.92	31.29	4.9	88.49	61.99	95.76
June	118.06	17.43	4.06	83.57	43.57	80.08
July	131.4	21.46	3.86	85.84	40.11	74.65
August	142.87	22.77	4.34	88.82	46.6	87.25
September	166.74	28.15	4.53	94.93	52.41	97.19
October	161.44	31.05	5.47	108.49	52.89	126.42
November	56.93	9.35	3.42	77	36.97	157.63
DECEMBER	26.89	2.62	1.96	46.82	32.58	189.38

Figure 4.3.SWAT model output of UPPER Gidabo watershed

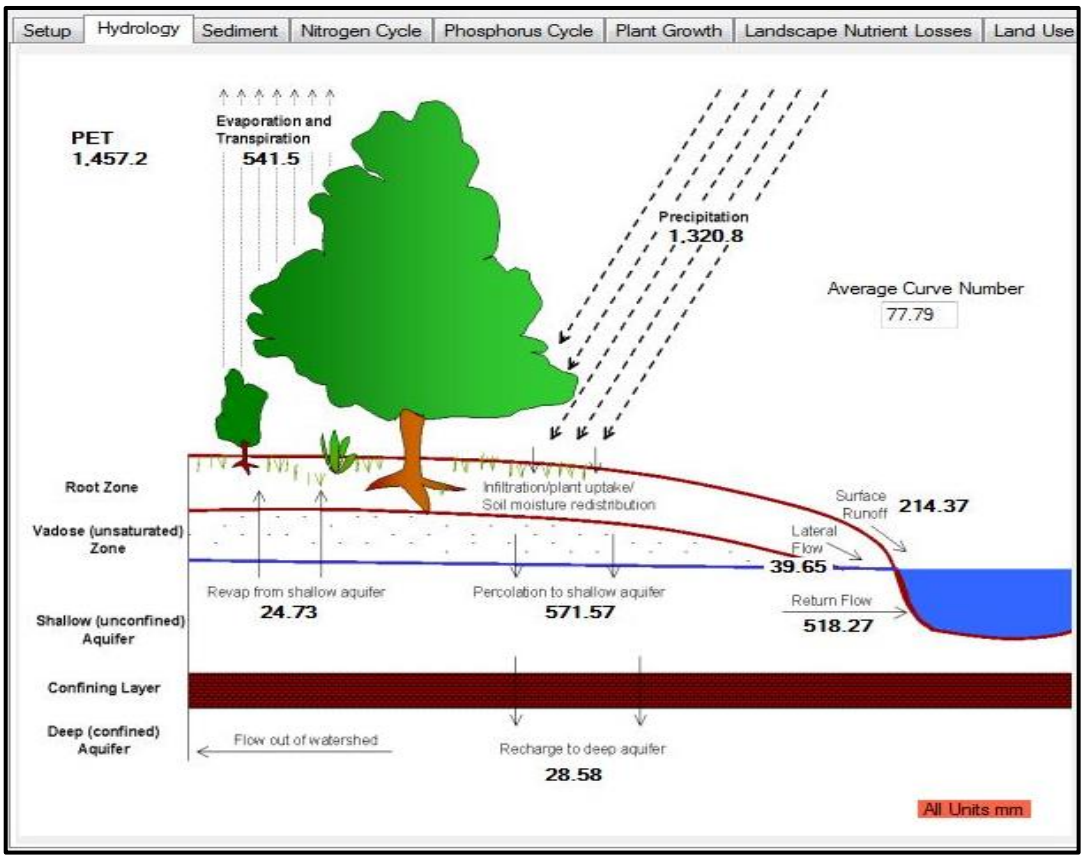
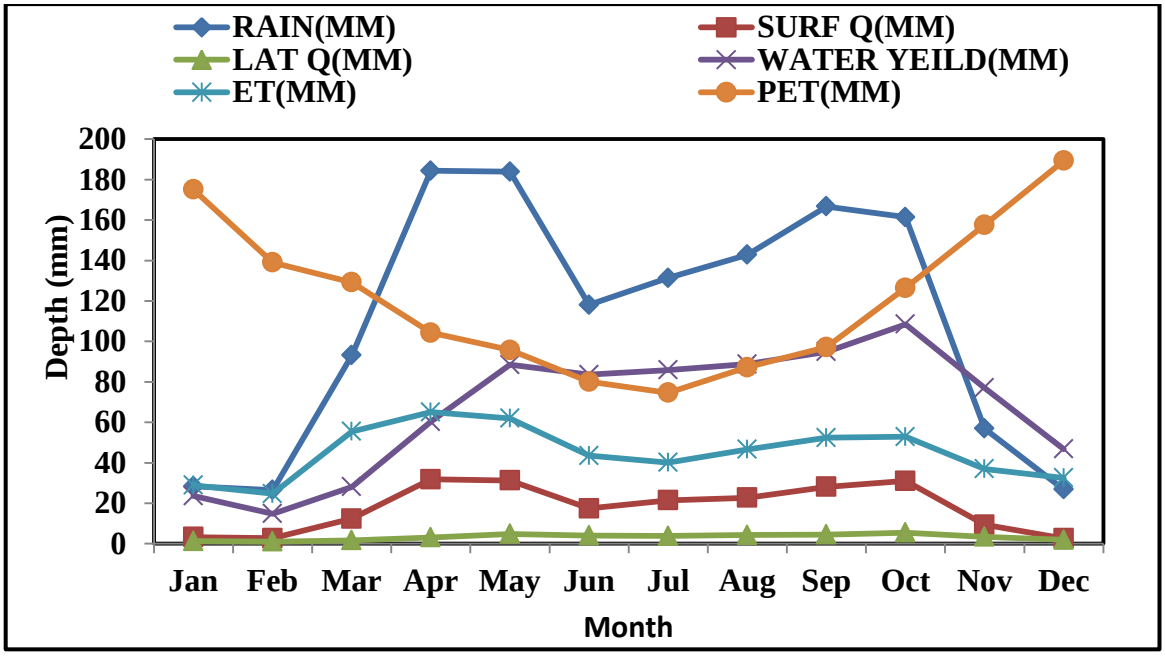


Table 4.5.Average Annual water balance values in the watershed of Aposto station

No	Water balance	Depth (mm)
1	Precipitation	1320.59
2	Surface Runoff(Q)	214.37
3	Lateral soil flow (Q)	39.64
4	Total water yield	800.79
5	Evapotranspiration (ET)	541.32
6	Potential evapotranspiration(PET)	1456.03
7	Ground water recharge (Return flow)	518.27
8	Recharge to deep aquifer	28.58
9	Total aquifer recharge (Percolation to shallow)	571.57
10	Ground water revap (Re-evaporation from shallow aquifer)	24.73

Figure 4.4: Graphical representation of average monthly water balance of the watershed



4.4. Results of water demands in the watershed

4.4.1. Current account sectoral water demand

The current year water consumption in the model was developed by using the demand data of 2021 for Agriculture, Domestic, Livestock, Commercial, Industrial and Environmental sectors and monthly average simulated surface runoff by SWAT model used as source of water supply (1991-2021) in the Upper Gidabo River, and in this research ground water is not considered due to there is no data available on it and it needs vast experimental program.

The watershed has Five consumptive water utilizers namely Agriculture dominant water user over the other sectors (22.1 MCM), Domestic (5.7 MCM), Livestock (3.1 MCM), Industrial

(2.8 MCM), Commercial (0.16 MCM). The current total water consumption for these five users in the watershed was up to be 33 MCM and the Environmental flow requirement for annual water demand was up to 77.35 MCM for the current accounts (10% of available flow). From this, the overall water demand in the Upper Gidabo watershed was around 110.4 MCM/year or 14.3% of the total surface water potential in watershed for consumptive and non-consumptive utilization in the current year (2021).

Current water demands (2021) among Consumptive and non-consumptive use (Environmental requirement) is up to 110.4MCM/year. This indicates that the current water use is low as compared to the current average supply available which has been observed to be 773.5 MCM both high and low flow happening season for consumptive and non-consumptive demands without no need of prioritization.

As shown in Table 4.6, currently all the sectoral water demands have been met and no unmet demands were encountered, although January, February, march, October, November, and December are months with the lowest available water supply, particularly from November to March which is the hottest period in the study area, the highest remaining river flow in April is 212.7 MCM while the lowest remaining flow occurs in February is around 27.6 MCM respectively.

Table 4.6: Comparison of current sectoral water demand with the available flow (2021)

Month	Consumptive (MCM)	Non-consumptive (MCM)	Flow (MCM)	Demand (MCM)	Remaining Flow (MCM)
Jan	6.3	1.86	18.6	8.2	10.4
Feb	4.5	1.55	15.8	6.0	9.8
Mar	2.6	5.57	56	8.2	47.8
Apr	1.2	10.91	109.3	12.1	97.2
May	1.1	10.75	107.2	11.8	95.4
Jun	1.5	7.19	72.1	8.7	63.4
Jul	1.7	8.12	81	9.8	71.2
Aug	1.5	8.66	86.7	10.2	76.5
Sep	1.2	9.44	94	10.6	83.4
Oct	1.4	8.43	84.4	9.9	74.5
Nov	4.3	3.25	32.2	7.5	24.7
Dec	5.7	1.62	16.3	7.3	9.0
Total	**33**	**77.35**	**773.5**	**110.4**	**663.2**

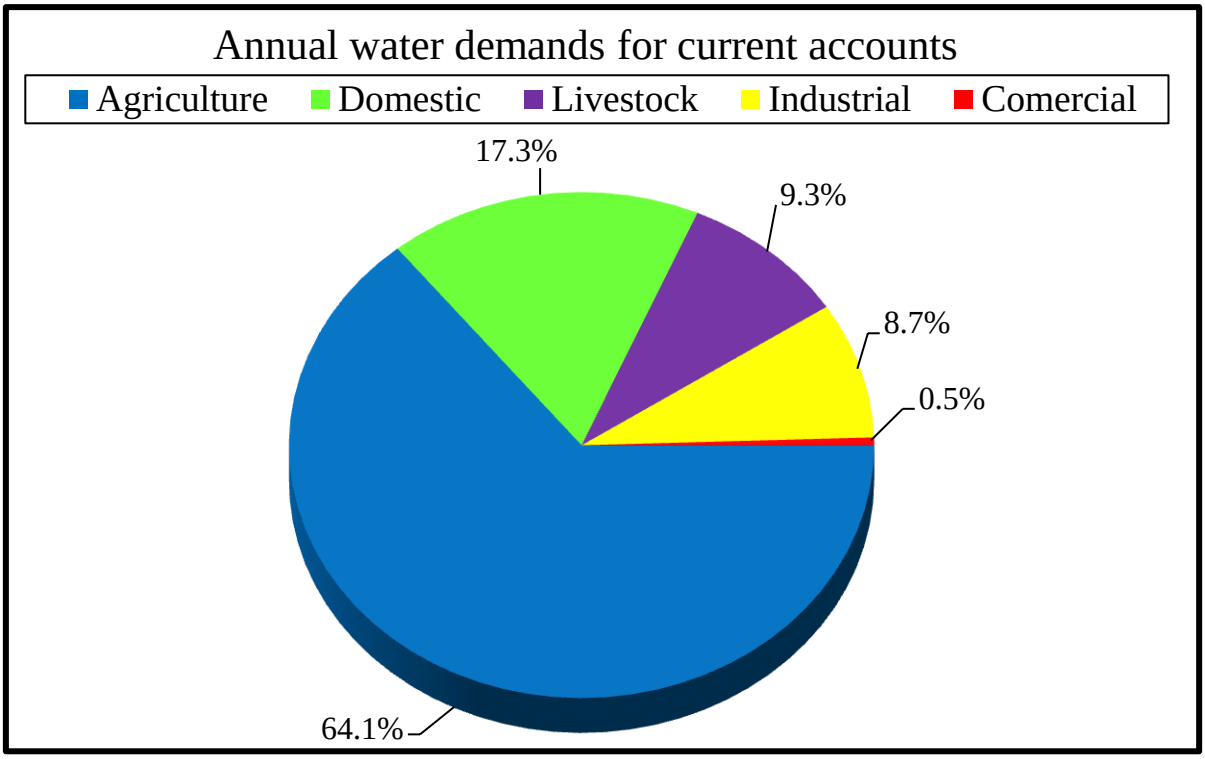


Figure: 4.5:-Percentage of total water consumption by sectors

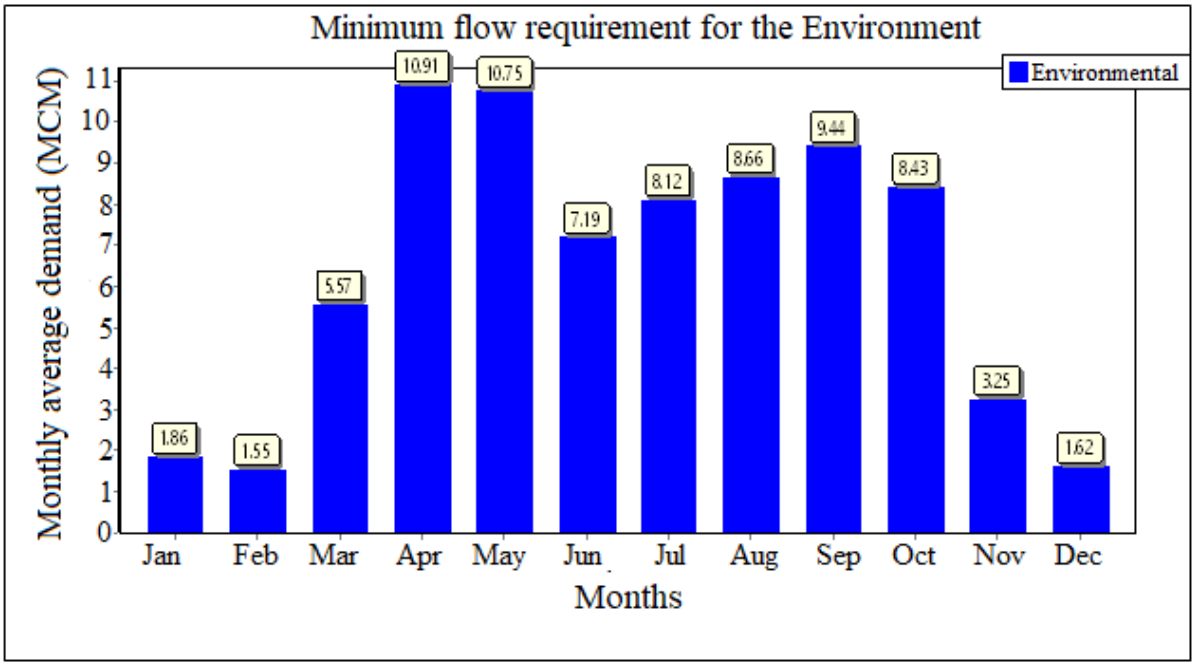


Figure 4.6: Water demand for Environment

4.4.2. Reference or Baseline Scenario

Reference scenario is a scenario in which the current situation, current account year as 2021 is extended to the future for (2022-2050) without any intervention or new policy measures, Often referred to as business as usual scenario. To alter the reference scenario 'what if'

situation is developed and to evaluate the effects of changes of policy and improvement of technology.

In this scenario it rises in population and Livestock growth intensity throughout the year. The annual population growth rate for Domestic and Livestock users was found to be (Halcrow, 2007) medium population growth rate of RVLB and 3.5% for Livestock respectively as shown in Figure 4.7 and 4.8, While except Agriculture other sectors are shows increment in this scenario because of they are depend on the population increment.

The annual total consumptive water demands in current accounts (2021) are calculated to be 48.6MCM while observed that 22.1 MCM is required by the agricultural sector out of 48.6 MCM, it has the highest utilizer, the other demanding sectors like Domestic, Industrial, Livestock and Commercial utilization was up to 11.8, 7.6, 6.2, and 0.9 MCM, respectively as discussed in the table 4.7 below and the annual Environmental flow requirement was up to 77.35 MCM in this scenario (i.e. 10% of available flow), so based on this the overall water consumption in this scenario was up to 126 MCM.

Table 4.7: Annual water demand for consumptive utilizers

Year	2022	2025	2030	2035	2040	2045	2050
Agriculture(MCM)	22.1	22.1	22.1	22.1	22.1	22.1	22.1
Domestic(MCM)	5.9	6.4	7.4	8.5	9.5	10.6	11.8
Industrial(MCM)	3	3.3	4.1	4.9	5.7	6.6	7.6
Livestock(MCM)	3.2	3.5	4	4.6	5.1	5.7	6.2
Commercial and institutional(MCM)	0.2	0.2	0.3	0.5	0.6	0.7	0.9
Total	**34.4**	**35.5**	**37.9**	**40.6**	**43**	**45.7**	**48.6**

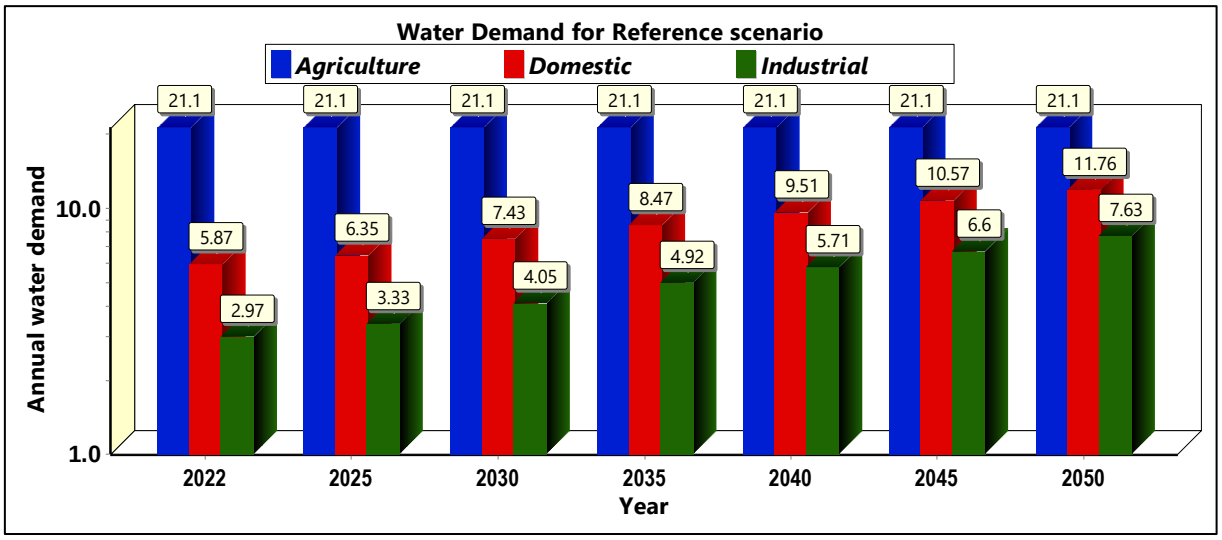


Figure: 4.7: Annual water demand(MCM) for Agriculture, Domestic and industrial sectors

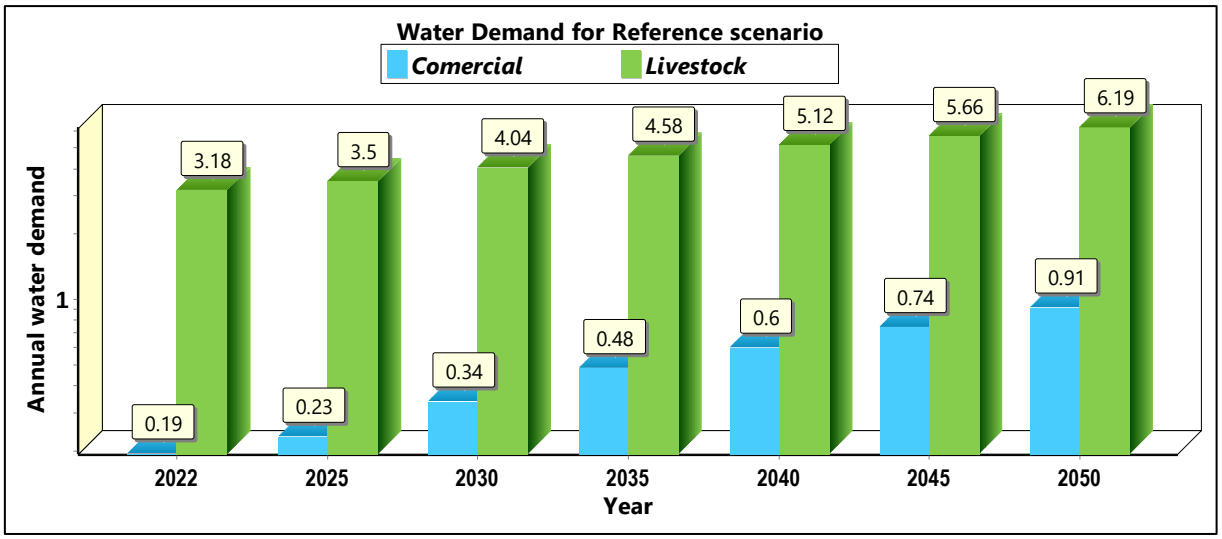


Figure: 4.8: Annual water demand(MCM) for commercial and Livestock sectors

4.4.3. Scenario one: High Population Growth Scenario

If the population growth rate is set to be the higher growth rate than the reference scenario, what will happen in this scenario? In this case, the population growth rate was increase by 3% from reference scenario to simulate the water demand in the future and it is related to maximum growth rate population projection by CSA (2007) for Sidaama region.

The net water demand for each sector was incorporated within the WEAP model and shows the expected water quantity for (2022-2050). From the result, it was projected that the total water demand for consumptive use was up to 117.7MCM**.** As expected in population growth scenario in the consumptive utilizers, the Domestic water demand is high water consumer than others Domestic (around 45.3 MCM (38.5%), Industrial (37.9 MCM (32.2%), Agriculture (22.1 MCM (18.8%), Livestock (6.2 MCM (5.3%) and Commercial and institutional (6.2 MCM (5.3%), and for non-consumptive 10% of available flow is considered it is up to 77.35 MCM. Table 4.8 describes and shows the projected net water demand for the year of 2022 – 2050 and, the total water demand in this scenario was up 195.1MCM.

Year	2022	2025	2030	2035	2040	2045	2050
Agriculture(MCM)	22.1	22.1	22.1	22.1	22.1	22.1	22.1
Domestic(MCM)	6.9	8.2	10.8	14.1	25.6	34.2	45.3
Industrial(MCM)	3.5	4.3	6	8.1	18.3	26.8	37.9
Livestock(MCM)	3.2	3.5	4	4.6	5.1	5.7	6.2
Commercial and institutional(MCM)	0.2	0.3	0.5	0.8	2.5	4.1	6.2
Total(MCM)	**35.9**	**38.4**	**43.4**	**49.7**	**73.6**	**92.9**	**117.7**

Table: 4.8: Net total projected annual water demand for consumptive utilizers

The result shows that the annual water demands when the population growth increases by 3% keeping others as constant in the reference scenario. In this Scenario, the total water demand for all sites is 195.1 MCM per year.

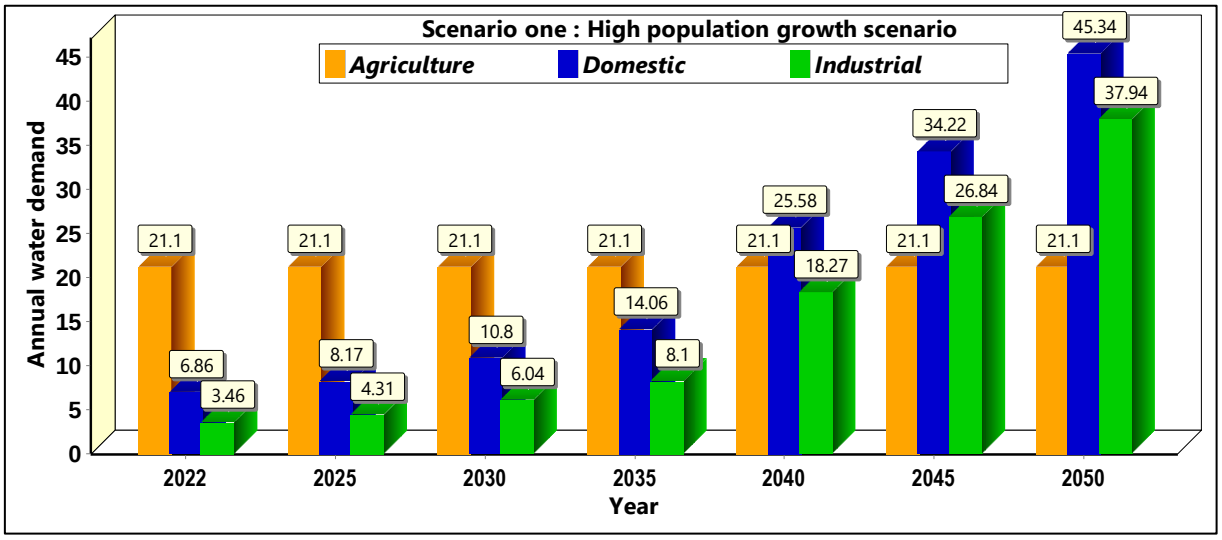


Figure: 4.9: Annual water demand(MCM) for Agriculture, Domestic and Industrial sectors

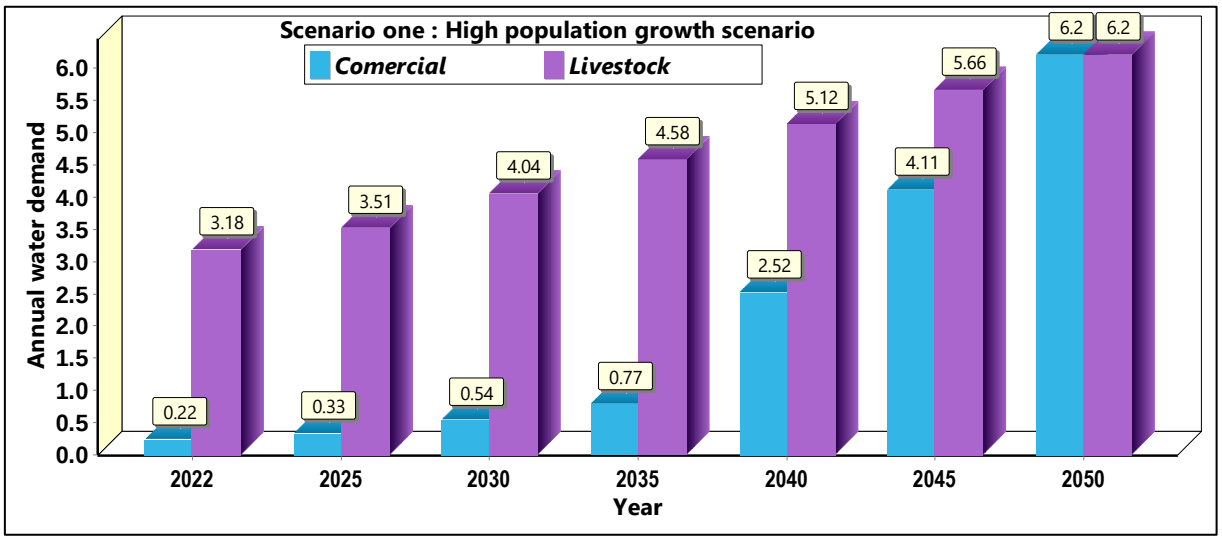


Figure: 4.10: Annual water demand(MCM) for commercial and Livestock sectors

4.4.4. Scenario two: Increased water demand scenario

Irrigation in this watershed is needed to be rapidly growing in terms of areas population growth rate. Additional irrigation projects are identified by different institutions is available but the developed irrigation projects are quite small. Hence this scenario shows the impact of irrigation area expansion by 3.45% annually for (2022-2050) shows up to 3 (2022-2035) and 5 (2036-2050) time increase from the current accounts coverage and it reach up to 80% area expansion 2050 based regional irrigation expansion plan. The watershed is not fully developed in terms of irrigation; there are potential areas suitable for irrigation in Upper

Gidabo watershed. Hence if these potential areas fully developed, what will be the effect in water demand will assess in projection in irrigation area.

The utilization of all potential irrigation areas was identified in the watershed, which brings developed annually the area 3017.6 ha up to the year 2050. Here of, due to population and Livestock growth rate, Industrial, Commercial and other sector development cause water demand increase, demand increment considered except Agriculture as 50%, respectively.

Future overall water demand for consumptive users 264.4 MCM, from them Agriculture was the highest utilizer it was up to 104.8MCM (39.6%), Domestic 88.5MCM (33.5%), Industrial 44.6 (16.9%), Livestock 23.6 (8.9%), and the smallest utilizer commercial 2.9 MCM (1.1%), and in this scenario the same as other scenarios for non-consumptive (Environmental water requirement) considered as 77.35MCM (10%) from available flow. Table 4.9 describes and presents the projected net water demand for the year 2022-2050. From the result, it will be projected that in 2050, the total water demand is increased for both consumptive and non-consumptive to 341.8 MCM.

Year	**2022**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Agriculture	23.99	32.65	45.47	61.52	75.95	90.39	104.83
Domestic	8.6	17.1	31.4	45.7	60	74.2	88.5
Industrial	4.3	7.8	15.8	23	30.2	37.4	44.6
Livestock	3.8	6	9.5	13	14.8	16.5	23.6
Commercial	0.2	0.7	1	1.5	1.9	2.4	2.9
Total	**40.9**	**64.2**	**103.2**	**144.7**	**182.9**	**220.9**	**264.4**

Table: 4.9: Net total projected annual increased water demand for consumptive utilizers

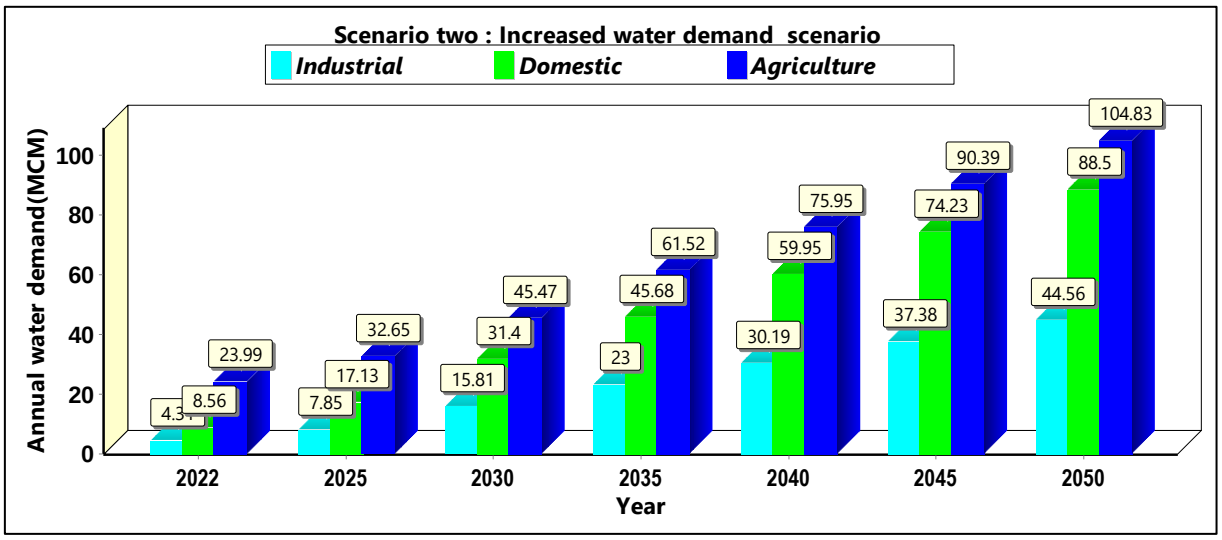


Figure 4.11: Annual water demand(MCM) for Agriculture, Domestic and Livestock sectors

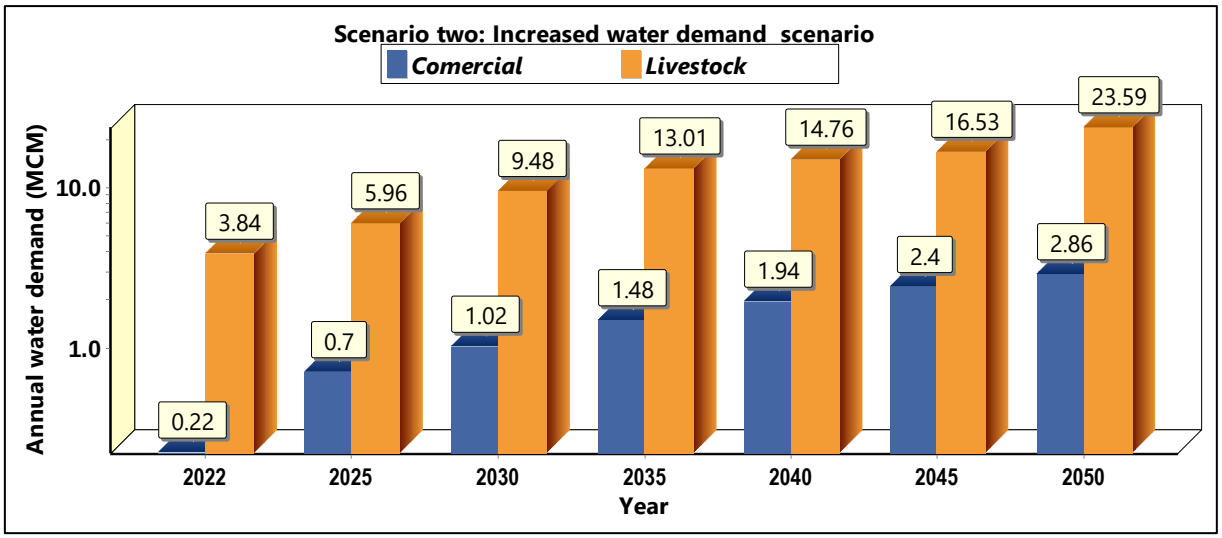


Figure: 4.12: Annual water demand (MCM) for commercial and industrial sectors

4.4.5. Comparison of water potential with current and future water demands

The overall monthly surface water potential and all the demands considered in this research are shown in table 4.10. This research focused on the small and medium projects found in the watershed. Thus, the research output indicated that the surface water potential is meet the current account and future demands in the watershed but it shows on some months variation or deficit were based on these projects. The total surface water potential is about 773.5MCM and the total monthly average water demand for reference, population growth and increased water demand scenario was about 117.24, 140.41, and 224.63 which is about 15.2, 18.2 and 29% of the total surface water potential, respectively.

Figure 4.13 shows the comparison among scenarios based on a monthly average to understand the variation between them. Comparing the three scenarios, for the Upper Gidabo watershed detects an increase in demand of 19.8% in scenario one and 91.6% in scenario two as compared to the reference scenario, the increasing the gap between demand and supply, even though available streamflow were assumed to be constant throughout the modeling period.

Table 4.10: Total monthly surface water potential and demands.

Months	Total monthly flow (MCM)	Reference scenario (MCM)	Population growth scenario(MCM)	Increased water demand scenario(MCM)
Jan	18.61	8.76	10.73	24.83
Feb	15.79	6.58	8.42	18.79
Mar	55.98	8.78	10.75	17.56
Apr	109.32	12.64	14.54	18.40
May	107.17	12.41	14.37	18.10
Jun	72.11	9.24	11.14	15.63
Jul	80.96	10.37	12.33	17.23
Aug	86.69	10.78	12.74	17.39
Sep	94.04	11.21	13.11	17.06
Oct	84.37	10.44	12.41	16.85
Nov	32.24	8.10	10.00	20.03
Dec	16.28	7.92	9.88	22.78
Total	**773.55**	**117.24**	**140.41**	**224.63**

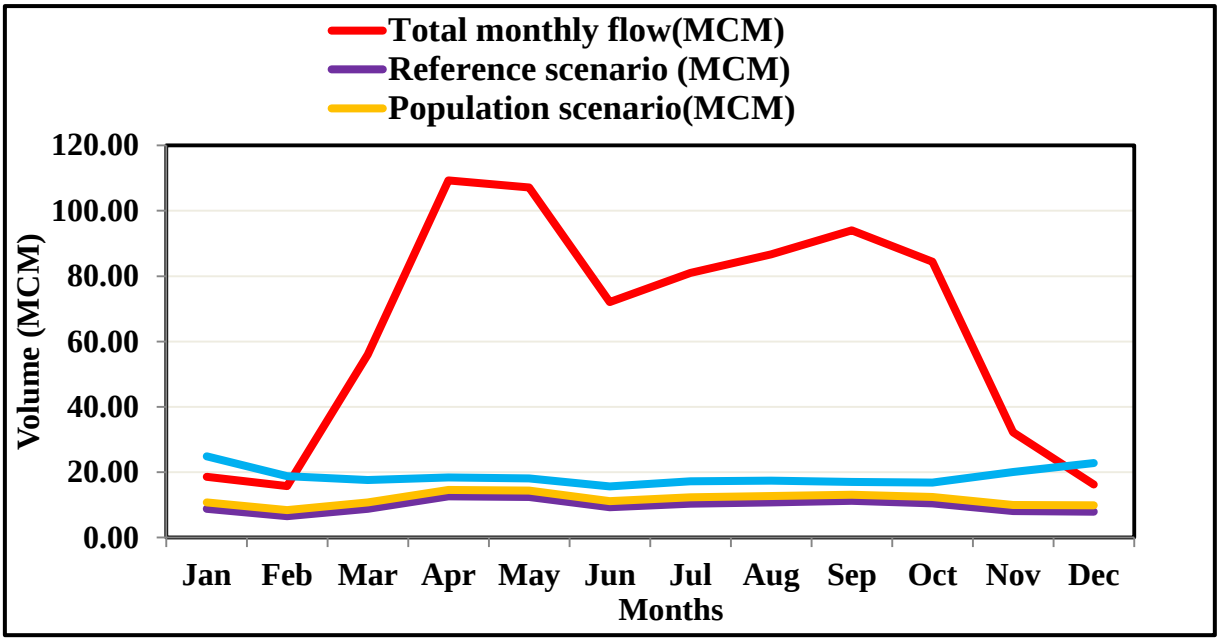


Figure 4.13: Comparison of the monthly water demand with potential (2020-2050)

4.4.7. Unmet Demands under Different Scenarios

Unmet demand is the amount of each demand site's requirement that is not met. The annual total unmet demand for all of the demand sites was assessed as shown below on figure 4.14. The unmet demand is increasing mainly in monthly time frame due to the current and expected future expansion of irrigation which uses huge amount of water. Based on Woreda irrigation experts and beneficiaries as most of the traditional irrigation sites depend on the rivers flows the water demands of these sites reach climax at the time where the flow

of the rivers decreases to the minimum. Therefore, the analysis shows that the main water demand sites which get met but in some months water scarcity problem happen in increased water demand scenario so, prioritization for water allocation was needed and the water allocated based on priority that assigned before and use available resources in managed way is important to reduce water demanding conflict.

Table 4.11 : Unmet monthly water demand for all Scenarios (2021-2050)

Months	Reference Scenario (MCM)	Population increase Scenario (MCM)	Increase water demand Scenario (MCM)
Jan	0	0	2.52
Feb	0	0	0.20
Mar	0	0	0
Apr	0	0	0
May	0	0	0
Jun	0	0	0
Jul	0	0	0
Aug	0	0	0
Sep	0	0	0
Oct	0	0	0
Nov	0	0	0
Dec	0	0	2.02
Total	**0**	**0**	**4.74**

The annual unmet demand of the three scenarios respected to six demands sites calculated in the WEAP model are Reference, population increases and increased water demand scenario at (2021-2050) was up to 0, 0 and 4.74MCM annual unmet demands, respectively and they are shown on the table 4.14 below.

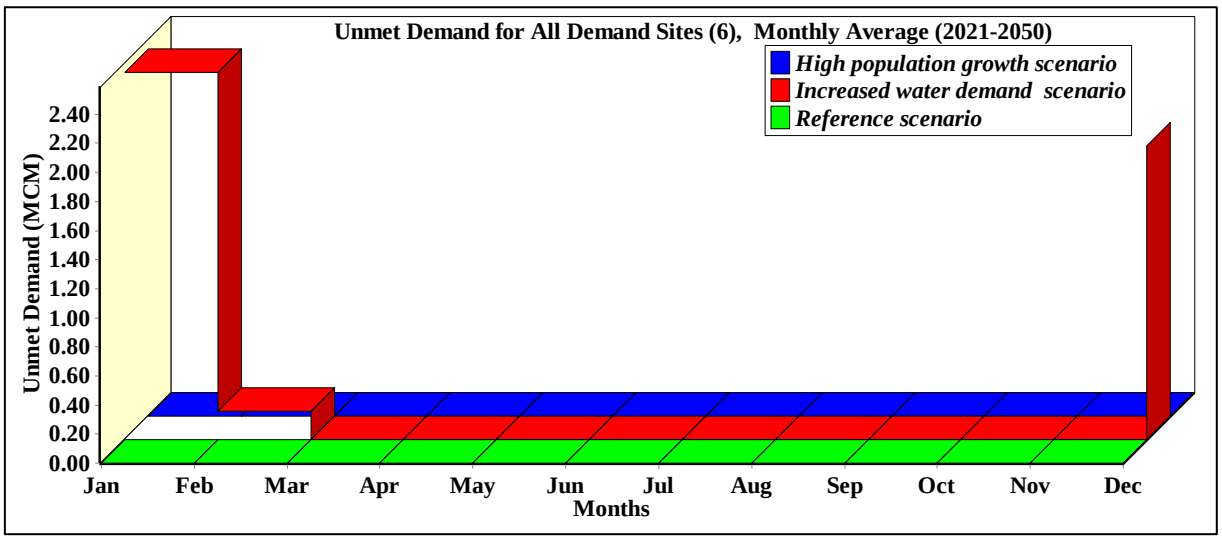


Figure 4.14: Monthly average all year unmet water demand

4.4.8. Demand coverage

Coverage is the percent of each demand site's requirement (adjusting for demand site losses, reuse and demand-side management savings) that is met, from 0% (no water delivered) to 100% (delivery of full requirement). In this study from different water allocation methods in WEAP Linear programing algorithm is used to know the coverage, reliability, unmet demand based on available supply. Figure 4.16 indicates all the sectoral demands were met fully in the reference scenario and scenario one.

In scenario two (increased water demand scenario) the monthly sectoral demand coverage is mostly satisfied The percent of coverage that less than 100% or occur in January, February and December months was up to 89, 99 and 90% of overall monthly average demand of Agriculture sector respectively. Generally the result of the scenarios is shown in the (figure 4.15, 4.16 and 4.17).

Figure 4.15: Monthly Demand coverage in Reference scenario (2021-2050)

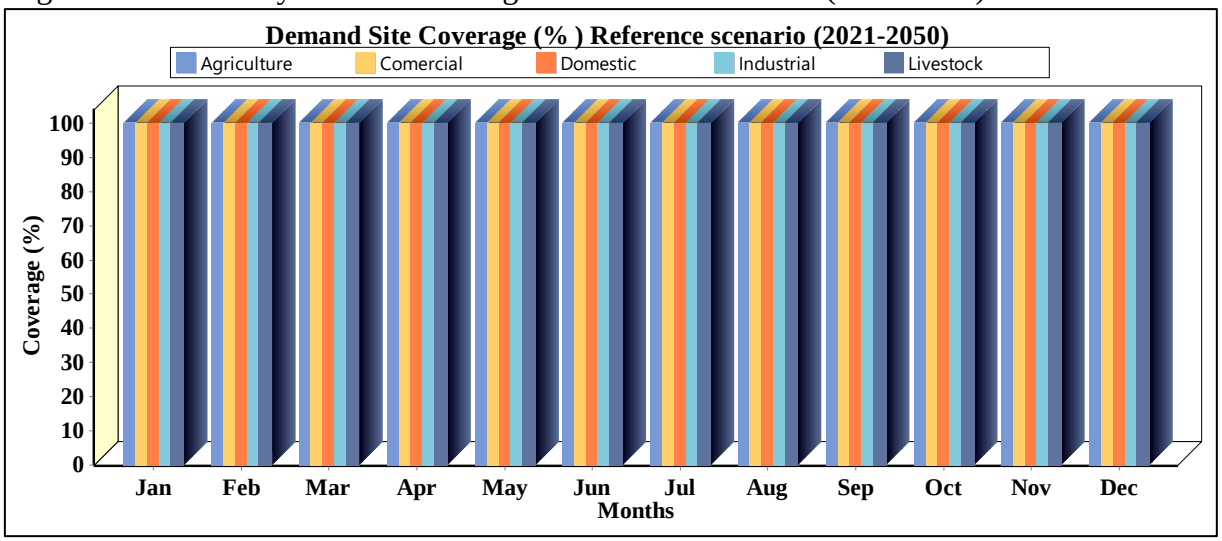


Figure 4.16: Monthly Demand coverage in Population (2021-2050)

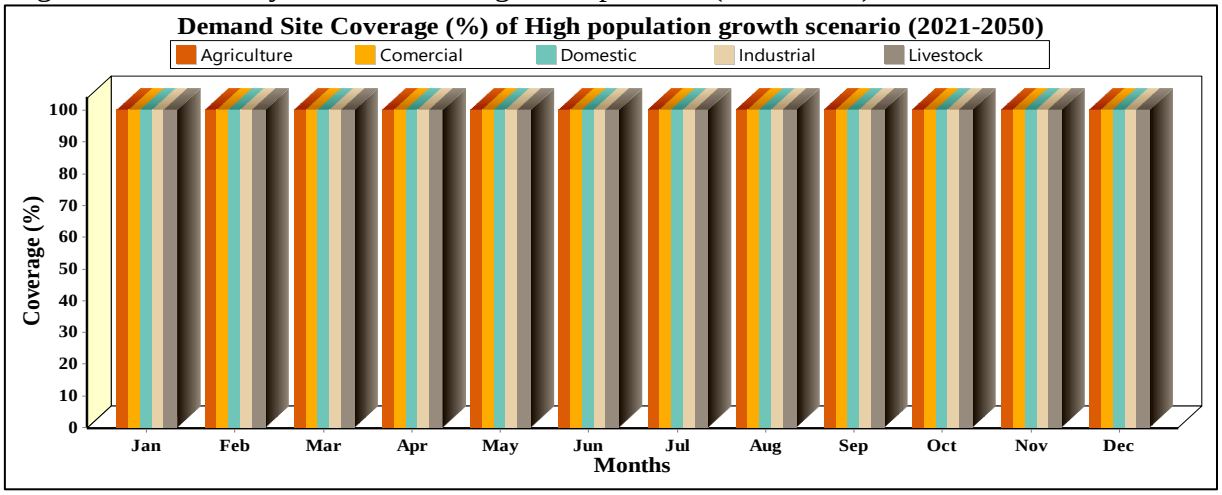
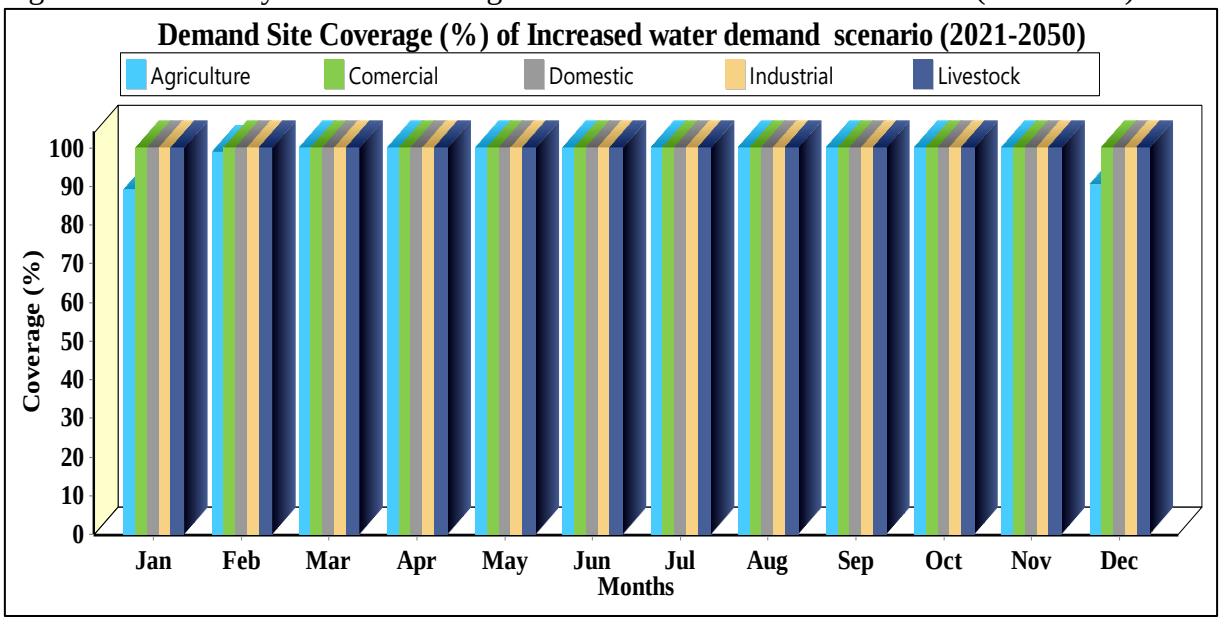


Figure 4.17: Monthly Demand coverage in Increase water demand scenario (2021-2050)



4.4.9. Demand Reliability

Reliability is a measure of frequency or probability that a system is in an acceptable state meeting a given criterion or which is the percent of the time steps in which a demand site's demand was fully satisfied. The reliability of each demand site has been analyzed under three future demand scenarios in WEAP model and the result are shown on figure 4.18.

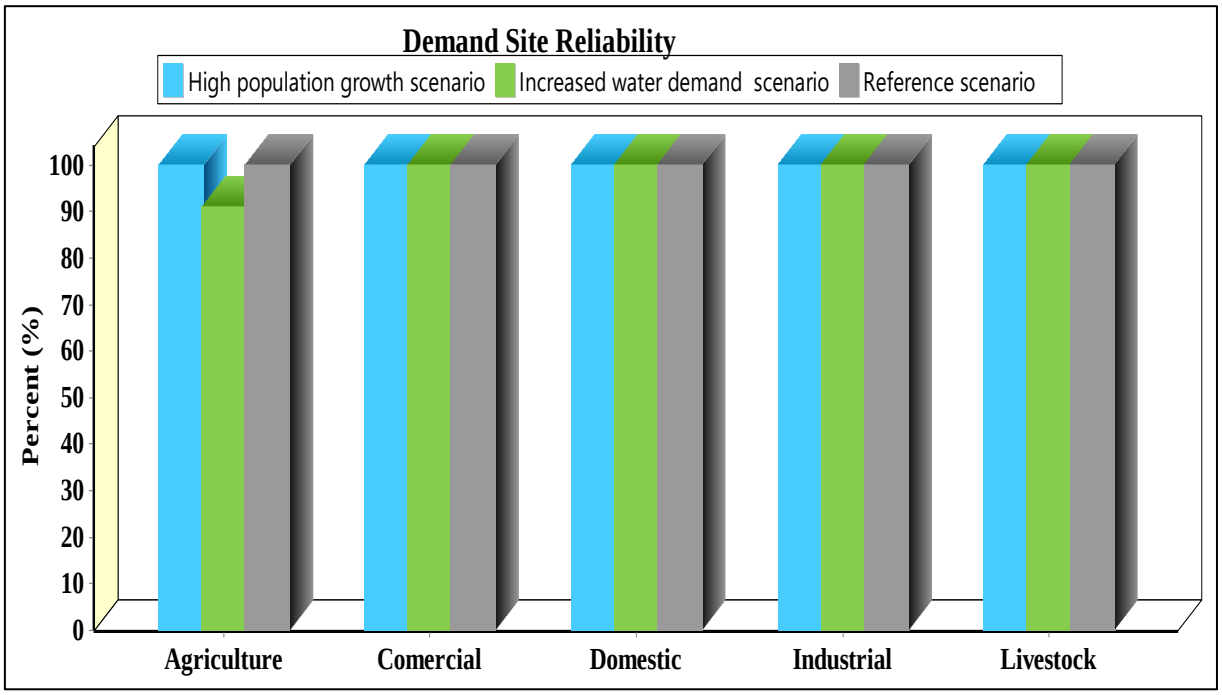


Figure 4.18: Sectoral Demand Site's Reliability in all scenarios

The demand sites which do have less reliability sites of traditional irrigation sites and small scale modern irrigation sites in scenario two. The reason behind is that the water demand of

these sites is very high during the low river flow months where there is scarcity of water and these sites are mainly dependent on the natural flows of the rivers. The inter-annual water demand and resource availability for the study area is somehow variable. Therefore, from this result, it can be observed that all sectors were fully satisfied in all months and years in all scenarios, except Agriculture in scenario two which has 91% i.e. there is deficit occur in scenario two is up 9% Agriculture sector utilization in monthly time frame.

4.4.10. Sustainable use of available resources and demand management

From the very beginning for the sustainable use of the water resources available in the watershed Environmental protection, utilize based on priority by comparing level of importance, development water resources and wisely use of the available resources are important to fulfill the existing and future demands.

According to the increasing water demands in the study area, it is expected that the total water requirement of currently existing and water uses is not exceed annually but in some months' time frame variation of supply is occur due to sectorial development.

The upper Gidabo watershed experiences poor water management due to lack knowhow to manage the available resources, less infrastructures that used to distribute, less Environmental protection with planting trees and others to develop water resources. So in order to utilize sustainably and to manage the water resources the actions associated with control, forecasting, and protection should be a fundamental part of strategic planning on the watershed. Once again, stakeholder participation, non-governmental agencies, and public consultation are needed in water management and water conservation.

5. SUMMARY, CONCLUSION AND RECOMMENDATION

5.1. SUMMARY

Water is a precious, essential natural resource required for the survival of all living beings and it is necessary for all forms of human, animal and plant life, and it plays an important role in supporting productive human activities such as Agricultural expansion, Energy and Industrial production, Livestock development, Domestic utilization and others. However, water demand has been rapidly increasing because of population growth, Agricultural expansion and numerous developmental activities.

To make the study more valid and well-meaning, first, the meteorological and streamflow filling missed data were filled by the Arithmetic and Normal Ratio method. The consistency, homogeneity, and outlier test of the filled data were then checked at hydro meteorological stations. After this examination, all of the data were checked consistent, homogeneous, and some outliers were found and corrected.

In this study the first step was determining surface water potential by applying semi distributed hydrological model (SWAT), it requires soil, land use/cover, topographic slope and metrological data as basic inputs And SWAT-CUP (Sufi-2 algorithm). Was used to reduce the difference measured data and simulated result.

The simulated result has exposed that about 773.5 MCM available surface water resources through Aposto and kola gauging stations and Dongora ungauged station each year. The inflows to the area maximum over April and minimum over December months was up to 327.1 MCM and 37.6 MCM, respectively.

After that the second step allocation of the surface water resources to demanding sectors in the watershed. In this hierarchy assessing current and future water demand of the area under three different scenarios, namely reference scenario, scenario one, scenario two. All of scenarios assessed based on population growth rate (Human as well as Livestock Population increase) and water demand increment due to irrigation expansion.

The watershed is rich with quantities of surface water resources compared to currently available demands. The current utilization of these resources is very limited at the moment and it is around 110.1 MCM (14.3% of available flow) within catchment for current account year 2021, for reference scenario (2022-2050) it is around 126 MCM (16.3% of available

flow) and population growth scenario water demand was up to 195.1(25.2%) for all utilizers discussed above attain their water requirement completely.

Though, the result of future water demand assessment indicates that supply is scarce in monthly timeframe on the last scenario two. The total water demand reveals that the water demands in the Upper Gidabo watershed area under this scenario reach up to 341.8 MCM including all water demands in 2050 which would make up 44.2% of the total river flows. Agriculture is considered as the highest water consumer in this scenario due to irrigation expansion by 3.45% or 5times increased from the current year, the demand is around 104.83MCM in this scenario unmet water demand occur in January, February and December up to 2.52, 0.2 and 2.02 MCM, respectively.

From this, we can conclude that future water demands based on the developed and planned activities in the sub-basin both upstream, and downstream mostly will met demands but on some scenarios in monthly time frame water deficit happen due to irrigation expansion, population growth, economic development through industrial, commercial and other activities, and therefore the all-inclusive approach or stakeholders participated approach has to be applied, due to seasonal as well as monthly gaps with low river flows while sustainable use of limited water resources could be maintained.

5.2. CONCLUSION

This study deals about modeling of surface water resources for water allocation in the Upper Gidabo watershed, Gidabo sub basin, Ethiopia, in the first step determining available surface water resources and then assessing increasing water demand from Livestock and population growth, expansion of irrigated areas, increasing industrial activities and commercial activities and others.

The water allocation to meet current and future water demands are important in this watershed especially in scenario two prioritization is needed so, the water is allocated in that manner and in both scenarios to fulfill the demands are finding another source and effectively utilize available surface water resources to cultivate the crops in this way easily overcome the demanding problem.

The study also concludes that since there is hydrologically availability of surface water resources with existing demands are met but seasonal gaps or monthly variation with low river flows, Future water demands based on the developed and planned activities in the area

of the watershed will have an seasonal impact on meeting all demands due to expansion of irrigated areas, high human and Livestock population growth with urbanization, economic development due to industrial and commercial activities, and therefore, all-inclusive or stakeholder approach for integrated water resources planning and management has to be applied.

5.3. RECOMENDATION

- The study determines surface water resources only, so groundwater potential of the watershed should be studied for more supply enhancement to demanding sectors.
- Since the watershed has high potential available surface water compared to existing demands, it is a good opportunity to use for various water resources projects mainly irrigation projects hence it is recommended to use the resource sustainability for different purposes.
- During the demand and supply analysis there was a deficit in January, February and December, it is recommended to harvest water during wet season by building engineering works such as construction of reservoirs, canals and others.
- The irrigation requirement for 9 crops was addressed simply using CROPWAT 8.0 model by considering the vegetative characteristics. Therefore it is highly recommended to do a further experimental research to determine the irrigation water requirement.
- The hydrology of the Catchment using improved climatic and hydrologic data monitoring are needed due to data availability are insufficient in the study area to determine of current and future water resources potential.
- Integrated and coordinated water resources development and management strategy is required; to maximize the benefits in demanding sectors.

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7. APPENDICES

Appendix I: Meteorological and hydrological data

Appendix Table 1: annual Rainfall (mm) data for selected meteorological station

Year	Yirgalem	Aletawondo	Dilla	Hawassa	Billate
1991	1236.6	1354.6	1291.9	905	744.4
1992	1300.6	1645.6	1308.9	975.3	973.6
1993	1281.8	1722.7	1341.3	928.4	807.1
1994	1234	1571.7	1464.1	861.2	827.3
1995	1120.7	1428.9	1166.72	1004.4	654.8
1996	1472.2	1649.9	1535.58	1189.2	1075.8
1997	1389.1	2014.7	1609.07	1054.7	853.7
1998	1658.8	1582.6	1254.4	1145.8	632.4
1999	1075.7	1233.4	1080.1	810.2	492.7
2000	1073.1	1425.3	1081.9	822.3	616.7
2001	1573.9	1956	1265.4	1022	536.2
2002	1014.1	1438.3	1101.5	919.5	519.7
2003	852.5	1496	1070.2	821.4	857
2004	849.3	1294.8	1102.8	895.6	815.6
2005	1100.8	1755.5	1276.2	997.6	997.6
2006	1412.9	1778.5	1493.4	1197.9	1032.4
2007	1482.2	2079.1	1698.9	1156.5	955
2008	1224.1	1460.8	1371	915.4	787
2009	1090.5	1356.6	1108.2	704.3	687.7
2010	1227.4	1844.1	1676.1	1038.8	1088.3
2011	853.5	1564.4	1496	922.8	845.7
2012	1162.7	1319.7	1337.6	809.3	628
2013	1236.6	1766.6	1282.3	1074.4	1186.1
2014	1804.7	1876.4	1415.4	1154.6	833.8
2015	1106	1301.7	1127	670.9	690.7
2016	1263.1	1538.5	1255.7	969.2	682.6
2017	1041.9	2072.5	1423.7	819.5	635.1
2018	806.6	1730.7	1624.4	1147.3	1180.2
2019	1275	1018.5	1456.8	1075.1	804.2
2020	1747.26	2193.8	1567.1	1277.5	1097.6
2021	885.28	1291.2	1141.7	721.7	716.6

Source ENMA Hawassa branch

Appendix Table 2: Monthly Observed flow data for calibration & validation in Aposto station

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996	2.86	1.87	5.98	15.29	17.83	19.96	18.9	22.02	22	14.17	11.13	6.6
1997	2.12	1.53	3.55	25.38	23.08	21.8	10.12	12.95	19.16	21.41	16.76	5.83
1998	6.06	5.05	9.19	19.34	25.1	27.48	29.58	23.14	28.93	29.75	13.11	2.73
1999	2.17	1.74	1.91	1.91	3.67	5.47	13.47	18.07	19.95	29.83	29.99	23.89
2000	15.41	9.3	7.27	15.96	21.91	15.02	21.51	22.2	17.83	29.48	22.27	17.45
2001	3.24	1.81	5.9	8.77	11.63	17.36	15.93	23.81	23.92	29.83	21.14	9.48
2002	2.01	1.56	2.04	4.93	15.94	21.29	17.71	12.66	11.89	13.53	12.19	9.24
2003	7.84	5.47	5.71	8.02	25.99	19.4	18.01	26.55	25.84	29.91	25.99	13.49
2004	5.18	2.86	9.33	16.15	16	14.24	7.79	10.02	9.21	10.94	8.62	6.17
2005	5.77	4.37	3.72	8.84	9.53	9.76	8.56	7.81	8.78	11.27	13.67	9.02
2006	6.65	6.67	4.75	5.96	8.25	7.27	9.96	13.93	10.87	12.99	9.37	3.54
2007	3.04	2.53	3.29	7.96	17.96	19.62	20.16	16.72	17.62	15.91	13.08	5.51
2008	2.01	1.73	7.53	17	19.43	15.06	19.34	29.47	27.2	19.25	22.38	17.93
2009	7.62	4.22	5.61	13.99	15.66	21.41	17.71	29.6	27.03	28.23	19.99	10.51
2010	2.41	1.79	5.74	15.93	21.77	22.2	23.29	21.55	23.84	19.86	15.51	8.41
2011	2.07	2.74	5.79	27.94	19.32	17.07	13.8	9.38	19.9	15.24	12.82	7.24
2012	6.18	7.84	9.74	19.33	28	26.88	23.44	17.83	28.39	24.75	11.44	2.46
2013	1.95	1.57	2.12	3.22	6.84	10.74	19.96	18.44	10.58	29.31	27.55	23.98
2014	12.3	12.38	9.61	17.18	22.86	13.94	20.76	26.44	28.41	29.49	27.25	17.03
2015	2.54	1.67	4.13	7.99	15.66	12.91	16.46	21.69	16.06	24.61	17.59	13.6

Appendix Table 3: Monthly Observed flow data for calibration and validation in Kolla station

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	2.03	1.26	0.88	3.41	2.65	3.76	4.3	2.76	5.07	3.11	2.51	0.98
1999	0.2	1.04	1.02	7.9	4.96	1.56	2.96	2.23	2.87	3.4	1.5	1.1
2000	0.91	0.43	1.29	5.33	5.51	3.26	2.81	3.6	5.5	4.71	3.19	0.68
2001	1.04	0.31	0.98	3.04	3.74	2.56	4.62	5.6	5.1	5.54	4.75	2.25
2002	2.7	2.42	1.58	2.07	2.38	3.14	2.32	3.05	2.04	9	1.86	0.97
2003	0.4	0.26	2.04	2.89	2.97	1.81	1.62	1.44	3.22	4.23	1.33	0.69
2004	0.19	0.11	0.11	1.08	2.98	1.45	1.3	3.4	3.45	3.9	2.87	0.81
2005	0.59	1.54	1.67	3.17	6.71	4.04	4.69	3.91	6.84	6.17	2.44	2.28
2006	1.71	1.52	4.02	4.1	5.5	6.2	2.54	1.31	3.38	2.92	1.84	2.05
2007	1.13	0.3	3.1	4.08	2.13	3.93	4.18	4.27	2.47	3.34	1.29	1.1
2008	1.09	1.17	1.29	3.43	3.07	2.09	3.4	2.28	4.58	2.51	2.22	2.08
2009	0.71	0.19	2.6	5.32	2.09	3.72	4.9	1.67	9.87	3.1	2.96	0.94
2010	0.5	0.73	3.1	7.04	5.92	3.61	4.64	3.2	3.29	2.36	2.66	0.79
2011	0.96	0.36	0.86	4.28	6.39	5.77	5.48	5.89	7.81	4.1	1.07	1.05
2012	1.42	0.11	0.5	3.09	5.74	3.17	6.09	7.1	5.17	6.2	7.1	1.19
2013	2.04	2.1	1.74	1.1	2.71	3.73	2.87	1.6	4.23	7.08	1.52	1.93

Appendix II: Input data for SWAT model

Appendix Table 4: Average Daily Dew Point Temperature Dilla station (1991-2021)

Month	Tmp_max	Tmp_min	Hmd	Dewpt
Jan	30.27	11.14	45.9	10.21
Feb	31.14	11.97	43.6	10.23
Mar	30.52	13.32	46.26	10.7
Apr	28.43	14.25	56.4	12.84
May	27.27	14.09	64.08	14.16
Jun	26.54	14.19	63.92	13.72
Jul	25.94	14.16	67.31	14.13
Aug	26.21	14.34	66.15	13.99
Sep	26.31	13.9	66.62	13.99
Oct	26.84	13.48	63.91	13.54
Nov	28.05	12.1	55.81	11.93
Dec	29.1	11.02	52.51	11.49

Appendix Table 5: Average Daily Dew Point Temperature for Hawassa station, (1991 - 2021)

Month	Tmp_max	Tmp_min	Hmd	Dewpt
Jan	29.04	11.71	51.16	11.45
Feb	30.18	12.37	49.16	11.68
Mar	30.19	13.50	53.64	13.25
Apr	28.80	14.41	62.72	15.20
May	27.49	14.56	68.31	15.90
Jun	25.96	14.65	68.93	15.14
Jul	24.67	14.64	72.41	15.11
Aug	25.05	14.60	71.76	15.16
Sep	25.78	14.10	71.81	15.49
Oct	27.12	13.04	63.96	14.10
Nov	28.19	11.16	54.68	11.85
Dec	28.26	10.75	51.93	11.03

Appendix III: Input data and Output results of WEAP model

Appendix Table 6: Number of Livestock population in the Watershed

No	**District Name**	**Cattle**	**Goat & sheep**	**Horse & Mule**	**Donkey**	**hen**	**Beehives**	**Total**
1	Wonsho	86349	83,596	2,179	3,616	85,331	6676	267,747
2	Dale	164,677	56,025	486	4404	132424	9820	367,836
3	Shebedino	226,321	59,260	18	6867	246319	7845	546,630
4	Aletawondo	119,762	67,864	4,086	8822	417283	6394	624,211
5	Goriche	269,994	100,795	2,875	6,392	91,361	6795	478,212
6	Arbegona	192,635	77,068	3,745	297	87,965	7753	369,463
7	Hawella	90,147	55,654	340	2,446	35,912	4231	188,730
8	Burrisa	102,369	64,912	4,893	413	53,677	6289	232,553
	Total	**1252254**	**565,174**	**18,622**	**33257**	**1150272**	**55803**	**3075382**

Source: Sidaama national regional state Animals and Fish resource Agency (2021)

Appendix Table 7: Livestock population after converted to TLU in the watershed.

No	District Name	Cattle	Goat & Sheep	Horse& Mule	Donkey	Hen	Beehives	Total
1	Wonsho	60444.3	8359	1716.3	2,531	853	6676	80581
2	Dale	115273.9	5603	388.4	3,083	1,324	9820	135492
3	Shebedino	158424.7	5926	14.1	4,807	2,463	7845	179480
4	Aletawondo	83833.4	6787	3251.6	6,175	4,173	6394	110614
5	Goriche	188995.8	10079	2268.7	4,474	914	6795	213,527
6	Arbegona	134844.5	7707	2993.8	208	880	7753	154385
7	Hawella	63102.9	5565	272	1,712	359	4231	75243
8	Burrisa	71658.3	6492	3896.4	289	537	6289	89161
	Total	**876577.8**	**56517**	**14801**	**23280**	**11503**	**55803**	**1,038,483**

Source: Sidaama national regional state Animals and Fish resource Agency (2021)

Appendix Table 8: population growth rate for RVLB by (Halcrow, 2007)

Growth rate	High growth rate		Medium growth rate		Low growth rate	
	Rural	Urban	Rural	Urban	Rural	Urban
2015	3.4	5.7	3.2	5.45	3	5.2
2020	3	5.3	2.75	5	2.5	4.7
2025	2.8	5.1	2.45	4.75	2.1	4.4
2030	2.8	5.1	2.3	4.65	1.8	4.2
2035	2.7	5.1	2.15	4.55	1.6	4
2040	2.5	5	2	4.4	1.4	3.8
2045	2.5	5	1.85	4.4	1.2	3.8
2050	2.5	4.7	1.8	4.05	1.1	3.4

Appendix Table 9: Total population number of the study area Source: CSA (2017)

Year	District Name	Gorche	Shebedino (Hawella)	Wonsho	Dale	Aletawondo	Burrisa
2017	Urban	6333	25107	4334	64507	46905	4884
	Rural	122002	264383	104309	252739	198663	120621
2021	Urban	7698	30518	5268	78409	57013	5936
	Rural	135986	294687	116265	281708	221434	120361
2030	Urban	11589	45942	7930	118037	85828	8936
	Rural	166869	361607	142669	345684	271722	147695
2035	Urban	14478	57389	9906	147448	107213	11163
	Rural	185595	402188	158680	384477	302215	162270
2040	Urban	17956	71176	12286	182869	132969	13845
	Rural	204912	444048	175195	424494	333669	179159
2045	Urban	22269	88275	15237	226800	164912	222198
	Rural	224581	486671	192011	465239	365697	196356
2050	Urban	27159	107658	18583	276601	201123	270988
	Rural	245534	532076	209925	508645	399816	214676

Appendix Table 10: Reference Scenario (MCM)

Years	Agriculture	Commercial	Domestic	Environmental	Industrial	Livestock	Total
2021	21.1	0.16	5.71	77.35	2.88	3.08	110.27
2022	21.1	0.19	5.87	77.35	2.97	3.18	110.67
2023	21.1	0.21	6.03	77.35	3.09	3.29	111.07
2024	21.1	0.22	6.19	77.35	3.21	3.40	111.47
2025	21.1	0.23	6.35	77.35	3.33	3.50	111.87
2026	21.1	0.25	6.57	77.35	3.47	3.61	112.35
2027	21.1	0.27	6.78	77.35	3.61	3.72	112.84
2028	21.1	0.29	7.00	77.35	3.76	3.83	113.32
2029	21.1	0.31	7.21	77.35	3.90	3.93	113.82
2030	21.1	0.34	7.43	77.35	4.05	4.04	114.31
2031	21.1	0.36	7.64	77.35	4.22	4.15	114.82
2032	21.1	0.39	7.84	77.35	4.39	4.26	115.33
2033	21.1	0.42	8.05	77.35	4.57	4.37	115.85
2034	21.1	0.45	8.26	77.35	4.74	4.47	116.38
2035	21.1	0.48	8.47	77.35	4.92	4.58	116.90
2036	21.1	0.49	8.66	77.35	5.04	4.69	117.34
2037	21.1	0.52	8.87	77.35	5.21	4.80	117.85
2038	21.1	0.54	9.08	77.35	5.37	4.90	118.36
2039	21.1	0.57	9.30	77.35	5.54	5.01	118.87
2040	21.1	0.60	9.51	77.35	5.71	5.12	119.39
2041	21.1	0.63	9.72	77.35	5.89	5.23	119.91
2042	21.1	0.65	9.94	77.35	6.06	5.33	120.44
2043	21.1	0.68	10.15	77.35	6.24	5.44	120.97
2044	21.1	0.71	10.36	77.35	6.42	5.55	121.50
2045	21.1	0.74	10.57	77.35	6.60	5.66	122.02
2046	21.1	0.79	10.81	77.35	6.81	5.76	122.63
2047	21.1	0.84	11.05	77.35	7.01	5.87	123.22
2048	21.1	0.87	11.29	77.35	7.21	5.98	123.80
2049	21.1	0.90	11.53	77.35	7.42	6.09	124.38
2050	21.1	0.91	11.76	77.35	7.63	6.19	124.94

Appendix Table 11: Scenario one: Population Growth Scenario (MCM)

Years	Agriculture	Commercial	Domestic	Environmental	Industrial	Livestock	Total
2021	21.1	0.16	5.71	77.35	2.88	3.08	110.27
2022	21.1	0.22	6.86	77.35	3.46	3.18	112.18
2023	21.1	0.26	7.32	77.35	3.74	3.29	113.06
2024	21.1	0.29	7.75	77.35	4.03	3.40	113.92
2025	21.1	0.33	8.17	77.35	4.31	3.51	114.76
2026	21.1	0.37	8.73	77.35	4.66	3.61	115.81
2027	21.1	0.41	9.27	77.35	5.00	3.72	116.85
2028	21.1	0.45	9.79	77.35	5.35	3.83	117.87
2029	21.1	0.49	10.31	77.35	5.69	3.94	118.88
2030	21.1	0.54	10.80	77.35	6.04	4.04	119.87
2031	21.1	0.58	11.47	77.35	6.45	4.15	121.11
2032	21.1	0.63	12.13	77.35	6.86	4.26	122.34
2033	21.1	0.68	12.79	77.35	7.28	4.37	123.56
2034	21.1	0.73	13.43	77.35	7.69	4.47	124.77
2035	21.1	0.77	14.06	77.35	8.10	4.58	125.97
2036	21.1	1.17	18.42	77.35	11.13	4.69	133.87
2037	21.1	1.51	20.56	77.35	12.92	4.80	138.23
2038	21.1	1.84	22.46	77.35	14.70	4.91	142.36
2039	21.1	2.18	24.13	77.35	16.49	5.01	146.26
2040	21.1	2.52	25.58	77.35	18.27	5.12	149.94
2041	21.1	2.83	27.48	77.35	19.99	5.23	153.98
2042	21.1	3.15	29.29	77.35	21.70	5.33	157.93
2043	21.1	3.47	31.02	77.35	23.41	5.44	161.80
2044	21.1	3.79	32.66	77.35	25.13	5.55	165.58
2045	21.1	4.11	34.22	77.35	26.84	5.66	169.27
2046	21.1	4.53	36.58	77.35	29.06	5.77	174.38
2047	21.1	4.94	38.88	77.35	31.28	5.87	179.42
2048	21.1	5.36	41.10	77.35	33.50	5.98	184.39
2049	21.1	5.78	43.26	77.35	35.72	6.09	189.29
2050	21.1	6.20	45.34	77.35	37.94	6.20	194.12

Appendix Table 12: Scenario Two: - Increased Water Demand Scenario (MCM)

Years	Agriculture	Commercial	Domestic	Industrial	Livestock	Environmental	Total
2021	21.10	0.16	5.71	2.88	3.08	77.35	110.3
2022	23.99	0.22	8.56	4.31	3.84	77.35	118.3
2023	27.00	0.37	11.25	5.42	4.51	77.35	125.9
2024	29.89	0.53	14.10	6.60	5.21	77.35	133.7
2025	32.65	0.70	17.13	7.85	5.96	77.35	141.6
2026	35.42	0.76	19.75	9.30	6.61	77.35	149.2
2027	38.08	0.82	22.49	10.83	7.28	77.35	156.9
2028	40.65	0.88	25.34	12.42	7.99	77.35	164.6
2029	43.11	0.95	28.31	14.08	8.72	77.35	172.5
2030	45.47	1.02	31.40	15.81	9.48	77.35	180.5
2031	48.65	1.10	34.07	17.15	10.14	77.35	188.5
2032	51.85	1.19	36.83	18.54	10.83	77.35	196.6
2033	55.06	1.28	39.68	19.98	11.53	77.35	204.9
2034	58.28	1.38	42.63	21.47	12.26	77.35	213.4
2035	61.52	1.48	45.68	23.00	13.01	77.35	222.0
2036	64.44	1.57	48.38	24.44	13.71	77.35	229.9
2037	67.34	1.66	51.16	25.82	13.98	77.35	237.3
2038	70.23	1.75	54.01	27.24	14.24	77.35	244.8
2039	73.10	1.84	56.94	28.69	14.50	77.35	252.4
2040	75.95	1.94	59.95	30.19	14.76	77.35	260.1
2041	78.86	2.03	62.69	31.57	15.11	77.35	267.6
2042	81.76	2.12	65.48	32.97	15.47	77.35	275.2
2043	84.65	2.22	68.33	34.41	15.82	77.35	282.8
2044	87.52	2.31	71.25	35.88	16.18	77.35	290.5
2045	90.39	2.40	74.23	37.38	16.53	77.35	298.3
2046	93.29	2.56	76.99	38.77	17.87	77.35	306.8
2047	96.19	2.68	79.81	40.19	19.24	77.35	315.5
2048	99.08	2.77	82.66	41.62	20.65	77.35	324.1
2049	101.96	2.83	85.56	43.08	22.10	77.35	332.9
2050	104.83	2.86	88.50	44.56	23.59	77.35	341.7

Appendix IV: Input data for CROPWAT 8.0 model and its results

Procedures to determine the effective rainfall

Appendix Table 13: Precipitation data of Dilla metrological station (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	72.3	51.9	123.6	194.7	172.4	143.6	107.4	132.5	187.5	57.9	8	40
1992	20.4	76.0	68.8	154.7	140.8	130.5	120.4	147.6	141.6	209.3	73.3	25.8
1993	89.3	114.6	36.7	153.7	340.8	158.1	34.5	72.7	114.8	157.4	50.5	18.2
1994	1.3	10.2	136.1	378.2	147.4	106.0	257.4	154.0	142.6	92.1	38.4	0.4
1995	0.5	53.4	73.9	249.7	117.3	83.3	142.0	102.1	186.3	60.9	27.5	69.8
1996	108.9	14.1	157.2	200.6	190.2	269.6	151.7	131.2	197.0	80.1	19.9	15.3
1997	29.0	1.9	24.5	257.3	272.3	161.3	111.5	93.1	149.0	220.3	203.3	85.5
1998	58.4	55.5	108.4	139.1	210.6	67.9	112.7	147.2	107.5	155.2	84.7	7.2
1999	20.7	15.1	116.9	148.4	123.2	79.6	134.8	130.5	104.8	168.9	21.9	14.9
2000	2.2	0.0	18.6	141.8	195.2	80.5	112.4	151.5	130.8	148.0	72.7	27.6
2001	13.4	35.0	119.2	109.4	194.3	144.4	72.4	145.3	153.6	197.1	52.4	28.8
2002	35.6	18.7	208.0	85.6	138.1	104.8	69.6	109.0	88.2	57.4	70.8	115.7
2003	56.7	6.6	77.1	146.9	109.6	100.8	123.6	135.7	67.3	128.0	95.4	22.2
2004	87.3	32.1	63.3	275.5	113.0	40.9	73.7	63.4	126.0	70.0	112.2	45.4
2005	44.3	9.3	77.0	265.2	246.2	63.7	76.9	95.9	151.7	183.4	58.6	4.0
2006	15.5	51.4	151.1	206.5	158.4	151.4	53.7	159.5	130.3	292.1	90.1	33.4
2007	81.3	10.5	94.9	149.8	340.2	201.3	83.2	274.8	212.5	193.3	57.1	0.0
2008	2.2	4.5	59.2	198.5	213.9	85.1	143.8	89.4	161.7	337.5	74.6	0.6
2009	52.6	40.8	39.5	207.2	115.9	72.0	25.9	46.0	177.3	156.5	15.9	158.5
2010	45.4	141.1	203.9	217.0	314.2	139.8	80.5	147.5	132.5	238.7	7.3	8.2
2011	11.0	23.3	39.5	135.6	276.4	110.5	95.6	180.3	190.0	223.6	198.7	11.5
2012	14.8	12.6	29.2	136.4	198.9	198.6	198.8	127.1	175.9	181.2	42.6	21.6
2013	16.9	12.4	98.4	175.5	155.5	93.8	151.5	183.2	119.2	218.2	57.8	0.0
2014	8.8	23.6	122.6	134.5	368.5	74.9	96.7	104.9	140.4	218.3	109.6	12.6
2015	6.3	0.3	72.1	145.3	162.9	159.0	81.2	60.7	140.0	151.7	95.5	52.0
2016	31.5	31.9	56.0	201.2	233.3	126.6	79.2	155.6	66.9	175.6	75.1	22.8
2017	1.5	36.4	45.7	140.3	237.3	89.4	77.3	206.0	269.2	255.0	65.6	0.0
2018	1.6	97.7	132.3	225.8	179.8	210.0	8.6	149.4	169.8	230.4	179.8	39.2
2019	6.1	19.4	59.0	132.8	324.9	172.7	270.4	155.7	115.4	120.6	59.9	19.9
2020	20.6	45.5	106.7	253.1	178.8	111.8	115.0	209.8	182.1	250.2	76.8	16.7
2021	12.3	26.4	52.3	257.7	121.9	26.2	130.7	66.2	243.3	139.3	54.8	10.6

Appendix Table 14: Rank of precipitation from the highest to the lowest

Rank	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	108.9	141.1	208.0	378.2	368.5	269.6	270.4	274.8	269.2	337.5	203.3	158.5
2	89.3	114.6	203.9	275.5	340.8	210.0	257.4	209.8	243.3	292.1	198.7	115.7
3	87.3	97.7	157.2	265.2	340.2	201.3	198.8	206.0	212.5	255.0	179.8	85.5
4	81.3	76.0	151.1	257.7	324.9	198.6	151.7	183.2	197.0	250.2	112.2	69.8
5	72.3	55.5	136.1	257.3	314.2	172.7	151.5	180.3	190.0	238.7	109.6	52.0
6	58.4	53.4	132.3	253.1	276.4	161.3	143.8	159.5	187.5	230.4	95.5	45.4
7	56.7	51.9	123.6	249.7	272.3	159.0	142.0	155.7	186.3	223.6	95.4	40.0
8	52.6	51.4	122.6	225.8	246.2	158.1	134.8	155.6	182.1	220.3	90.1	39.2
9	45.4	45.5	119.2	217.0	237.3	151.4	130.7	154.0	177.3	218.3	84.7	33.4
10	44.3	40.8	116.9	207.2	233.3	144.4	123.6	151.5	175.9	218.2	76.8	28.8
11	35.6	36.4	108.4	206.5	213.9	143.6	120.4	149.4	169.8	209.3	75.1	27.6
12	31.5	35.0	106.7	201.2	210.6	139.8	115.0	147.6	161.7	197.1	74.6	25.8
13	29.0	32.1	98.4	200.6	198.9	130.5	112.7	147.5	153.6	193.3	73.3	22.8
14	20.7	31.9	94.9	198.5	195.2	126.6	112.4	147.2	151.7	183.4	72.7	22.2
15	20.6	26.4	77.1	194.7	194.3	111.8	111.5	145.3	149.0	181.2	70.8	21.6
16	20.4	23.6	77.0	175.5	190.2	110.5	107.4	135.7	142.6	175.6	65.6	19.9
17	16.9	23.3	73.9	154.7	179.8	106.0	96.7	132.5	141.6	168.9	59.9	18.2
18	15.5	19.4	72.1	153.7	178.8	104.8	95.6	131.2	140.4	157.4	58.6	16.7
19	14.8	18.7	68.8	149.8	172.4	100.8	83.2	130.5	140.0	156.5	57.8	15.3
20	13.4	15.1	63.3	148.4	162.9	93.8	81.2	127.1	132.5	155.2	57.1	14.9
21	12.3	14.1	59.2	146.9	158.4	89.4	80.5	109.0	130.8	151.7	54.8	12.6
22	11.0	12.6	59.0	145.3	155.5	85.1	79.2	104.9	130.3	148.0	52.4	11.5
23	8.8	12.4	56.0	141.8	147.4	83.3	77.3	102.1	126.0	139.3	50.5	10.6
24	6.3	10.5	52.3	140.3	140.8	80.5	76.9	95.9	119.2	128.0	42.6	8.2
25	6.1	10.2	45.7	139.1	138.1	79.6	73.7	93.1	115.4	120.6	38.4	7.2
26	2.2	9.3	39.5	136.4	123.2	74.9	72.4	89.4	114.8	92.1	27.5	4.0
27	2.2	6.6	39.5	135.6	121.9	72.0	69.6	72.7	107.5	80.1	21.9	0.6
28	1.6	4.5	36.7	134.5	117.3	67.9	53.7	66.2	104.8	70.0	19.9	0.4
29	1.5	1.9	29.2	132.8	115.9	63.7	34.5	63.4	88.2	60.9	15.9	0.0
30	1.3	0.3	24.5	109.4	113.0	40.9	25.9	60.7	67.3	57.9	8.0	0.0
31	0.5	0.0	18.6	85.6	109.6	26.2	8.6	46.0	66.9	57.4	7.3	0.0

(Source: ENMA; 1991-2021)

Appendix Table 15: Effective rainfall (mm)

Month	Rain(mm)	Effective rain(mm)	July	73.7	65
January	6.1	6	August	93.1	79.2
February	10.2	10	September	115.4	94.1
March	45.7	42.4	October	120.6	97.3
April	139.1	108.1	November	38.4	36
May	138.1	107.6	December	7.2	7.1
June	79.6	69.5	Total	867.2	722.4

Appendix Table 16: Irrigation Water Requirement at Dilla Stations (MCM)

Irrigation requirement = (irrigation demand /season) ×total area

No	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total (MCM)
1	**Tomato**	0.29	0	0	0	0	0	0	0	0	0.05	0.37	0.53	1.24
2	**Banana**	0.48	0.55	0.48	0.03	0.01	0.14	0.15	0.02	0	0	0.07	0.30	2.23
3	**Potato**	0	0	0	0	0	0	0	0	0	0.03	0.13	0.01	0.17
4	**Cabbage**	0.42	0	0	0	0	0	0	0	0	0.09	1.22	1.85	3.58
5	**Onion**	0.55	0.33	0	0	0	0	0	0	0	0.03	0.33	0.50	1.74
6	**Avocado**	0	0	0	0	0	0	0.01	0.04	0	0	0	0	0.05
7	**Coffee**	0	0	0	0	0	0	0.02	0.05	0	0	0	0	0.07
8	**Carrot**	0	0	0	0	0	0	0	0	0	0.003	0.06	0	0.06
9	**Sugarcane**	0.58	0.55	0.48	0.06	0	0	0	0	0	0.06	0.35	0.50	2.58
TOTAL														**11.72**

Appendix v: Different tests to use Meteorological and Hydrological data

Appendix Table17: Outlier test for hydrological data

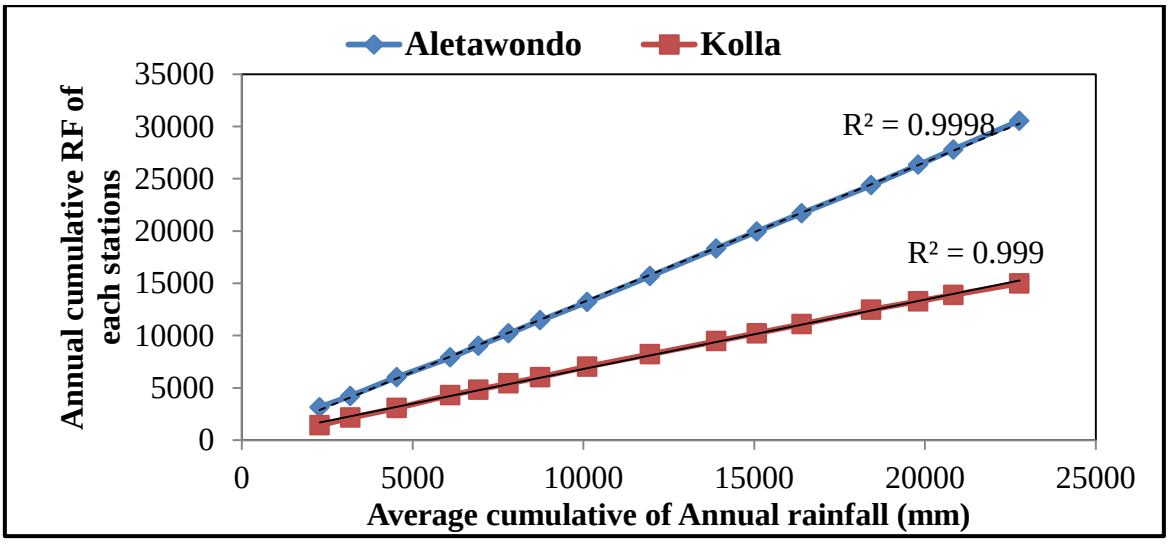
Year	Aposto(Qav)	Log-value (Y= LogQ)	kolla(Qav)	Log-value (Y=LogQ)
1996	299.5	2.5	-	-
1997	254.2	2.4	-	-
1998	262.3	2.4	117.3	2.1
1999	89.2	2.0	61.1	1.8
2000	149.7	2.2	77.2	1.9
2001	157.2	2.2	103.5	2.0
2002	93.9	2.0	43.3	1.6
2003	97.2	2.0	50.1	1.7
2004	105.3	2.0	48.8	1.7
2005	145.9	2.2	84.3	1.9
2006	206.2	2.3	98.7	2.0
2007	220.0	2.3	104.9	2.0
2008	135.3	2.1	62.2	1.8
2009	145.8	2.2	72.5	1.9
2010	223.6	2.3	116.2	2.1
2011	163.5	2.2	66.2	1.8
2012	120.4	2.1	51.1	1.7
2013	230.5	2.4	91.5	2.0
2014	218.3	2.3	-	-
2015	171.2	2.2	-	-
Xav	174.5	2.2	78.0	1.9
STDEV	61.5	0.2	24.9	0.1
N	20		16	
K_N	2.385		2.279	
X_H		2.6		2.2
$Q_H(m^3/s)$	321.2		134.8	
X_L		1.8		1.5
$Q_L(m^3/s)$	27.7		21.3	

Appendix Table18: Outlier Test on rainfall stations in the study area

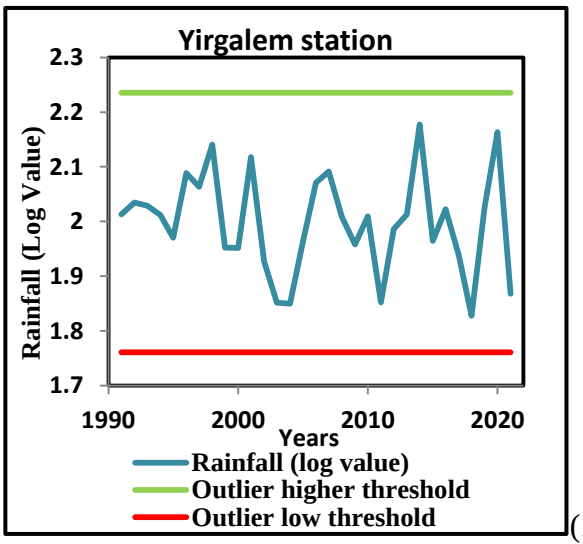
Year	Yirgalem	Log-Value	Aletawondo	Log-value	Hawassa	Log-value	Dilla	Log-value	Billate	Log-Value
1991	103.1	2.0	112.9	2.1	75.4	1.9	107.7	2.0	62.0	1.8
1992	108.4	2.0	137.1	2.1	81.3	1.9	109.1	2.0	81.1	1.9
1993	106.8	2.0	143.6	2.2	77.4	1.9	111.8	2.0	67.3	1.8
1994	102.8	2.0	131.0	2.1	71.8	1.9	122.0	2.1	68.9	1.8
1995	93.4	2.0	119.1	2.1	83.7	1.9	97.2	2.0	54.6	1.7
1996	122.7	2.1	137.5	2.1	99.1	2.0	128.0	2.1	89.7	2.0
1997	115.8	2.1	167.9	2.2	87.9	1.9	134.1	2.1	71.1	1.9
1998	138.2	2.1	131.9	2.1	95.5	2.0	104.5	2.0	52.7	1.7
1999	89.6	2.0	102.8	2.0	67.5	1.8	90.0	2.0	41.1	1.6
2000	89.4	2.0	118.8	2.1	68.5	1.8	90.2	2.0	51.4	1.7
2001	131.2	2.1	163.0	2.2	85.2	1.9	105.5	2.0	44.7	1.7
2002	84.5	1.9	119.9	2.1	76.6	1.9	91.8	2.0	43.3	1.6
2003	71.0	1.9	124.7	2.1	68.5	1.8	89.2	2.0	71.4	1.9
2004	70.8	1.8	107.9	2.0	74.6	1.9	91.9	2.0	68.0	1.8
2005	91.7	2.0	146.3	2.2	83.1	1.9	106.4	2.0	83.1	1.9
2006	117.7	2.1	148.2	2.2	99.8	2.0	124.5	2.1	86.0	1.9
2007	123.5	2.1	173.3	2.2	96.4	2.0	141.6	2.2	79.6	1.9
2008	102.0	2.0	121.7	2.1	76.3	1.9	114.3	2.1	65.6	1.8
2009	90.9	2.0	113.1	2.1	58.7	1.8	92.4	2.0	57.3	1.8
2010	102.3	2.0	153.7	2.2	86.6	1.9	139.7	2.1	90.7	2.0
2011	71.1	1.9	130.4	2.1	76.9	1.9	124.7	2.1	70.5	1.8
2012	96.9	2.0	110.0	2.0	67.4	1.8	111.5	2.0	52.3	1.7
2013	103.1	2.0	147.2	2.2	89.5	2.0	106.9	2.0	98.8	2.0
2014	150.4	2.2	156.4	2.2	96.2	2.0	118.0	2.1	69.5	1.8
2015	92.2	2.0	108.5	2.0	55.9	1.7	93.9	2.0	57.6	1.8
2016	105.3	2.0	128.2	2.1	80.8	1.9	104.6	2.0	56.9	1.8
2017	86.8	1.9	172.7	2.2	68.3	1.8	118.6	2.1	52.9	1.7
2018	67.2	1.8	144.2	2.2	95.6	2.0	135.4	2.1	98.4	2.0
2019	106.3	2.0	84.9	1.9	89.6	2.0	121.4	2.1	67.0	1.8
2020	145.6	2.2	182.8	2.3	106.5	2.0	130.6	2.1	91.5	2.0
2021	73.8	1.9	107.6	2.0	60.1	1.8	95.1	2.0	59.7	1.8
Xav	101.8	2.0	133.8	2.1	80.7	1.9	111.4	2.0	67.9	1.8
STDEV	21.6	0.1	23.7	0.1	13.0	0.1	15.9	0.1	16.1	0.1
N	31.0									
KN	2.577									
XH		**2.2**		**2.3**		**2.1**		**2.2**		**2.1**
PCP(mm)	157.4		194.9		114.3		152.4		109.4	
XL		**1.8**		**1.9**		**1.7**		**1.9**		**1.6**
PCP(mm)	46.1		72.7		47.1		70.3		26.3	

List of figures in the Appendix

Appendix Figure 1: Consistency test by double mass curve for flow stations.



Appendix figure 2: Outlier detection test results for rainfall recording stations (1-5)



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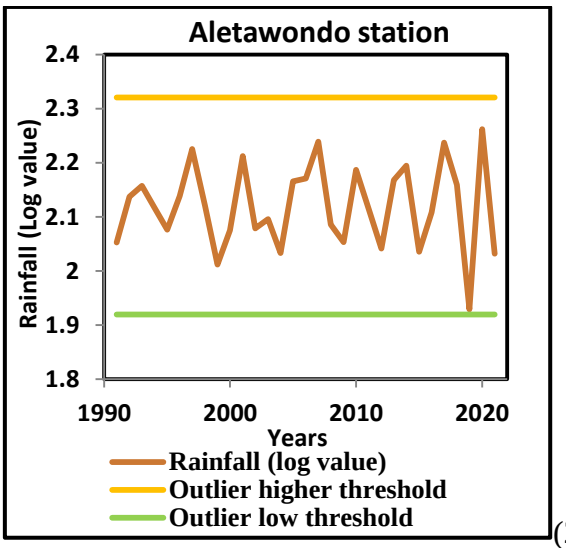

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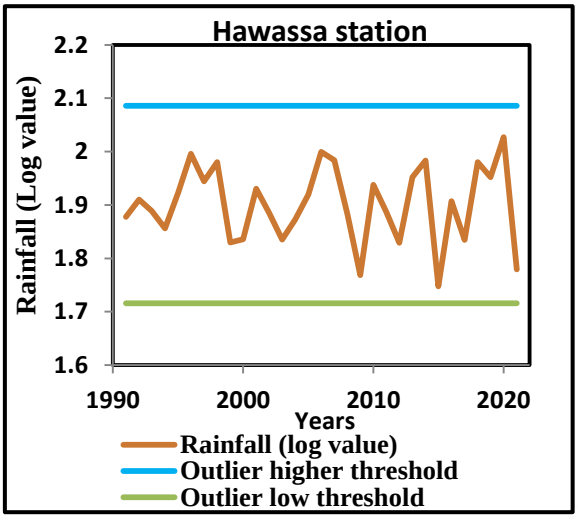

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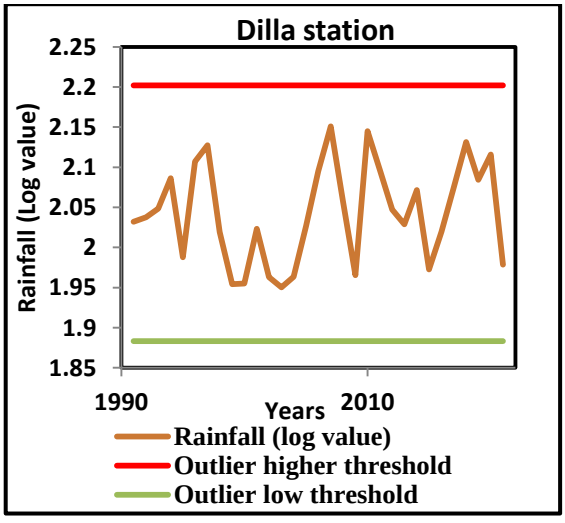

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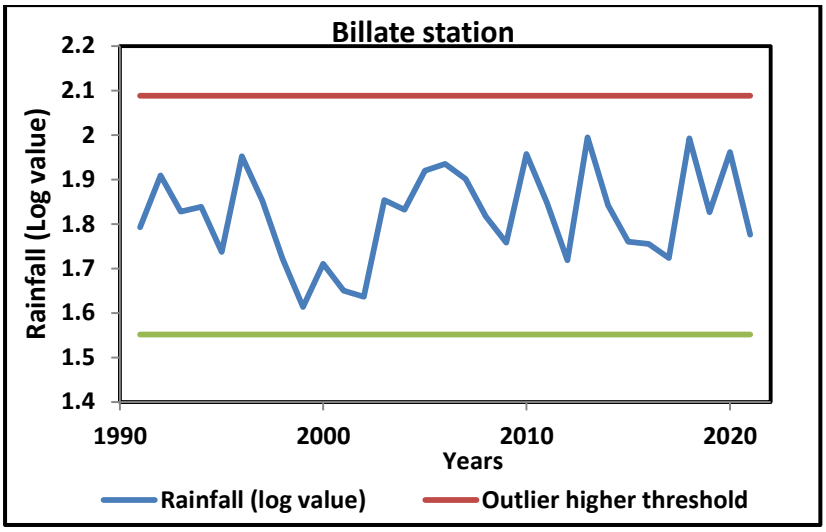
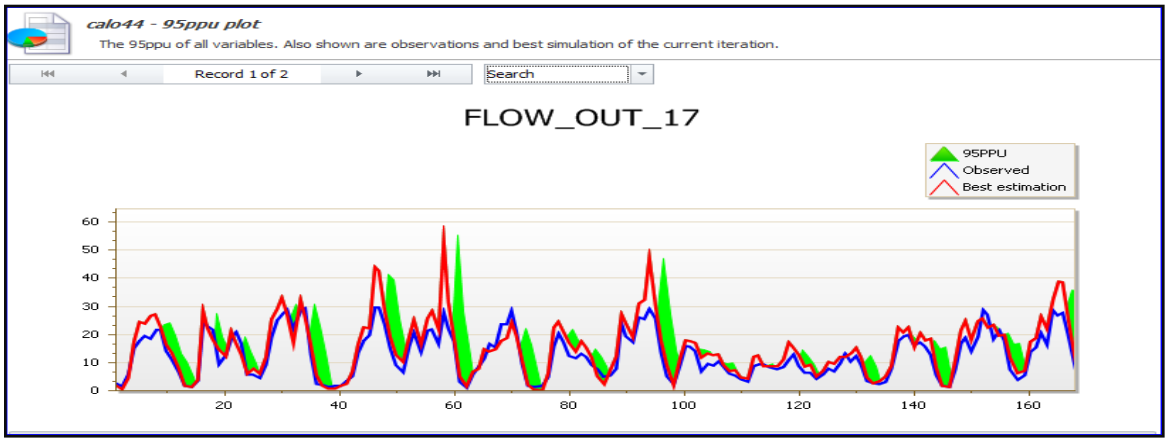
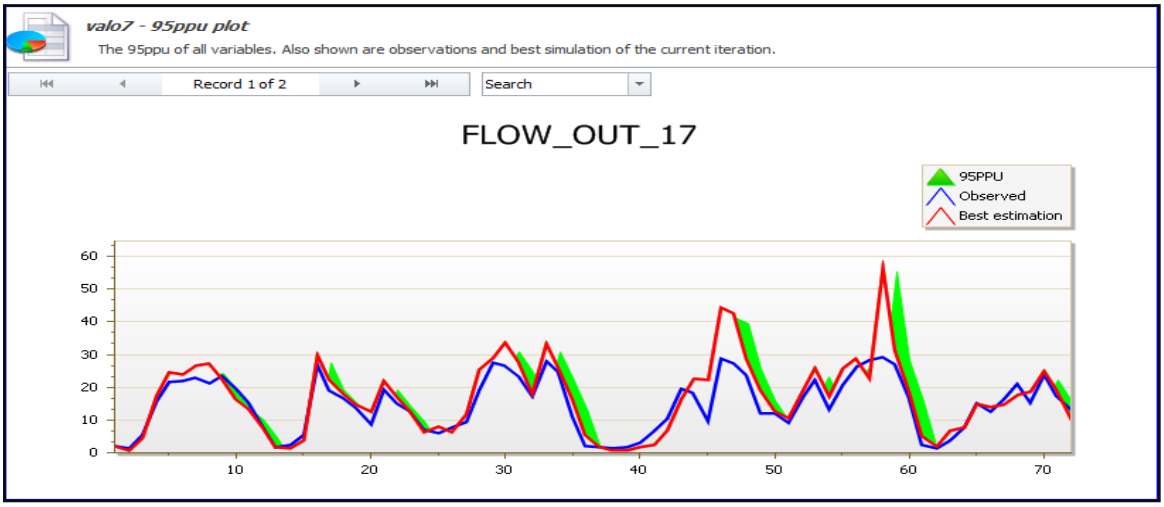


(5)

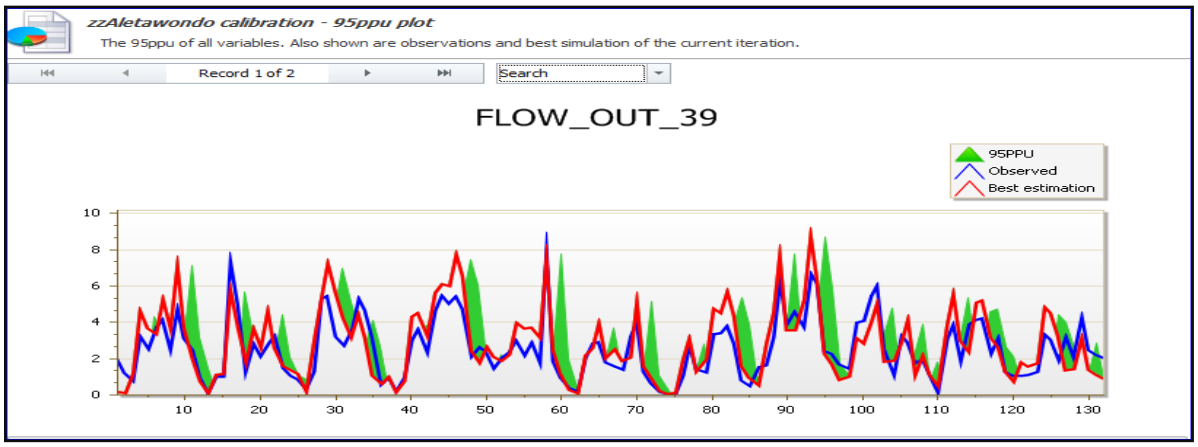
Appendix figure 3: flow out of Observed, Simulated and L95PPU Calibration of Aposto station



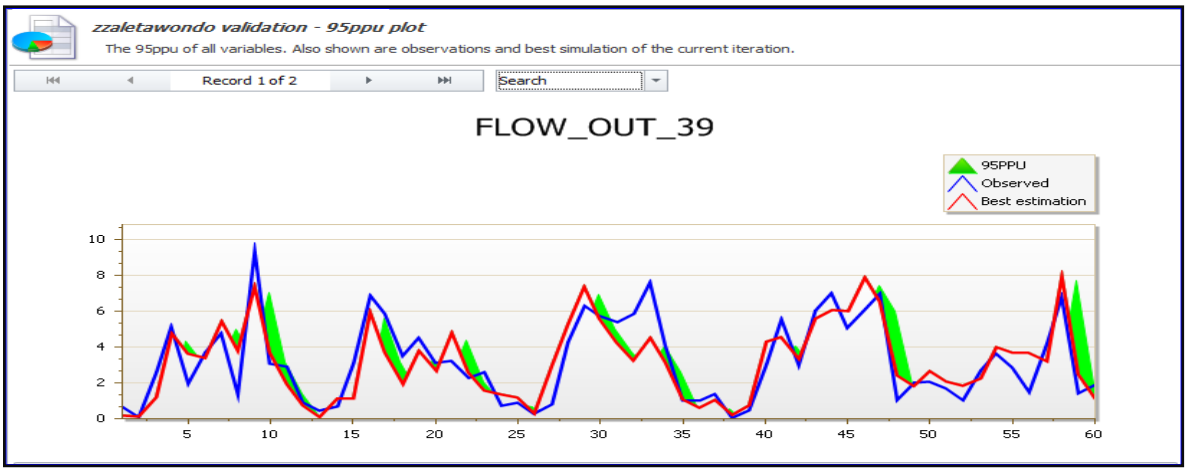
Appendix figure 4: flow out of Observed, Simulated and L95PPU Validation of Aposto station



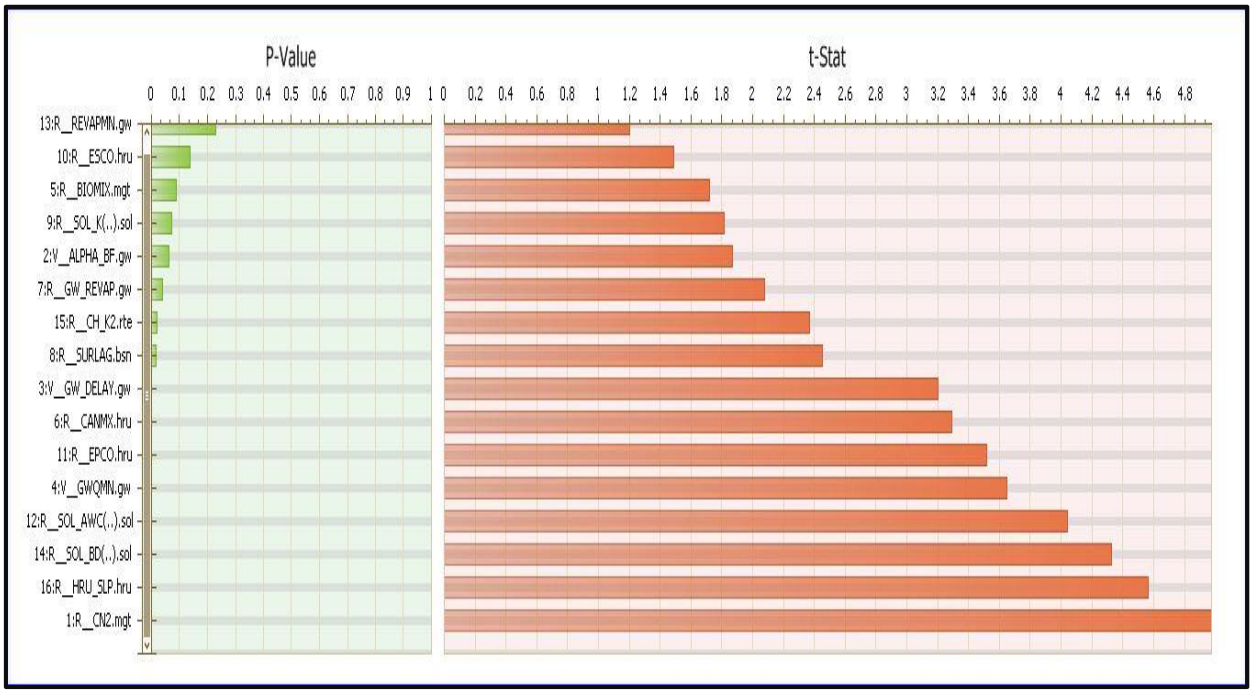
Appendix figure 5: flow out of Observed, Simulated and L95PPU Calibration of Kolla station



Appendix figure 6: flow out of Observed, Simulated and L95PPU Validation of Kolla station

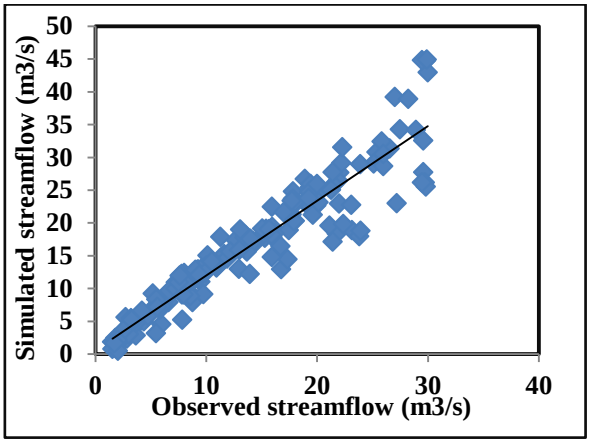


Appendix figure 7: Sensitivity analysis of the model

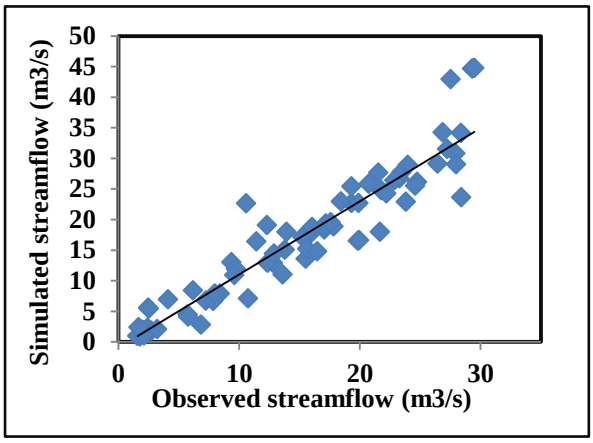


Appendix figure 8: Scatter plot of Calibration & validation period in Aposto and kolla stations

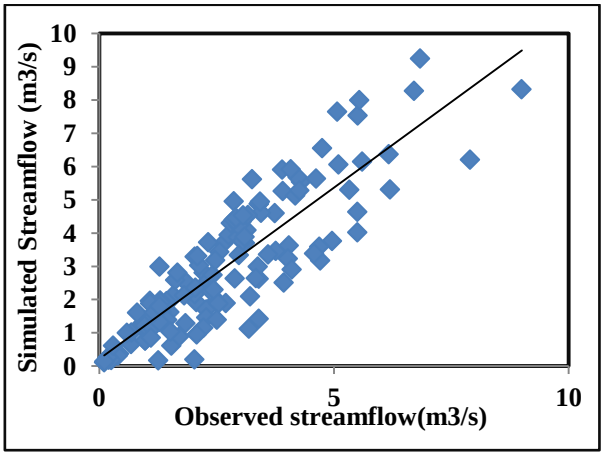
1. Aposto calibration



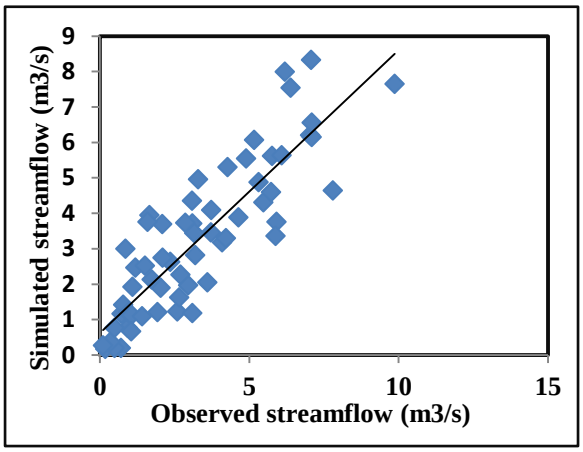
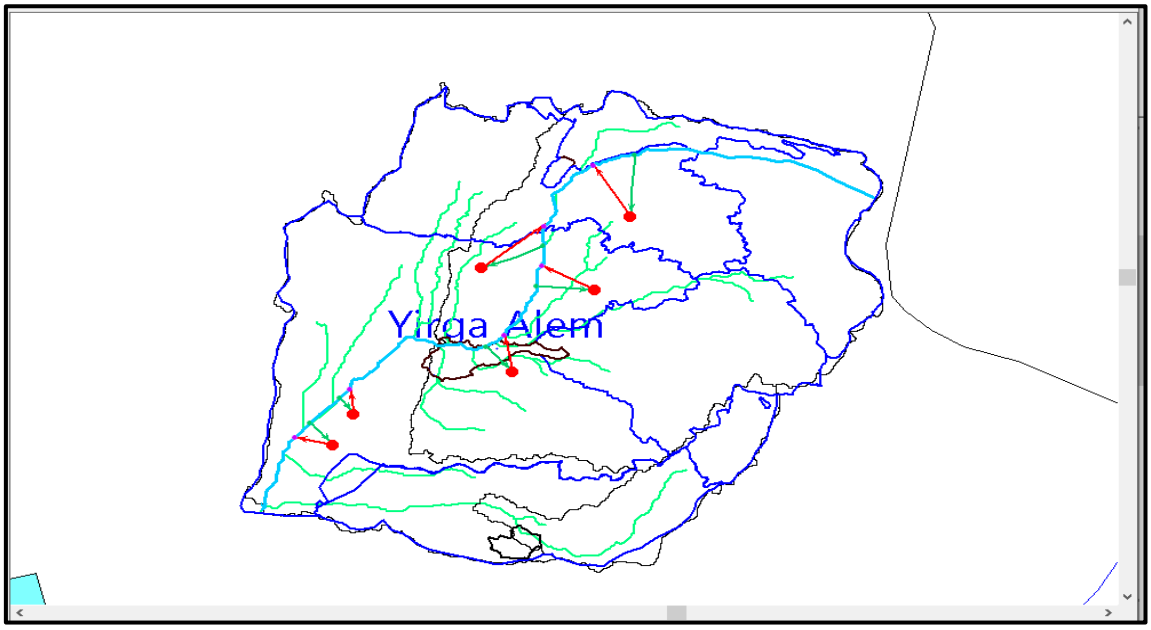
2. Aposto validation



3. Kolla calibration



4. Kolla validation



Appendix figure 9: WEAP schematic view of the study area including Districts