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SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

SURFACE WATER RESOURCE ALLOCATION FOR ABAYA-CHAMO SUB-BASIN USING WEAP MODEL, SOUTHERN ETHIOPIAN RIFT VALLEY

A thesis submitted to the School of Graduate Studies in Partial Fulfilment of the Requirements for the Degree of Master of Science in Civil Engineering.

(Major Hydraulic Engineering)

By

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This is to certify that the thesis prepared by **Eyerus Nigussie**, entitled "**SURFACE WATER RESOURCE ALLOCATION FOR ABAYA-CHAMO SUB-BASIN USING WEAP MODEL, SOUTHERN ETHIOPIAN RIFT VALLEY"** and submitted in partial fulfillment of the requirements for the Degree of Master of Science (MSc) in Civil and Environmental Engineering (Hydraulic Engineering Major) compiles with the regulations of the university and meets the accepted standards with respect to originality and quality.

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ABSTRACT

The development of water resource projects, population growth, and increase in irrigation areas has a higher effect on excessive usage of water resources and causes exploitation of the existing river systems and ecosystem of the natural environment. Therefore, water allocation study is essential to maintain the ecosystem and to balance the water demand with the supply in the catchment.

In the present study, the allocation of surface water resource carried out in Bilate watershed, in Abaya-Chamo sub-basin of Ethiopian Rift Valley Lake Basin. The necessary data used to define the hydrology of study area are: DEM, LULC and soil data, climatic and stream flow data. The main aim of this study is, quantifying the available surface water of the Bilate watershed and allocation to the required demand sites of different activities. There are 25 demand nodes used to estimate water requirements in the study area. This demand sites are domestic demand for urban and rural towns, livestock water demand and irrigation water demand. In addition, to quantify the water available in the catchment, soil moisture method is used for catchment simulation.

Three scenarios were developed to evaluate the effect of population growth and irrigation area expansion on future water demand. The result of the study showed no unmet demand of water requirement in the reference scenario from the years 1987 to 2020 for all cumulative demands with annual water demand of 88 MCM. Under future population growth scenario (2020–2035), the total water requirement demand for domestic , industrial, livestock and irrigation water demand is 121MCM, 39MCM and 27 MCM with 8% unmet demand of total water requirement. For the irrigation expansion scenario II, for mean monthly irrigation water demand of 26.37 MCM, 0.4 MCM of the total monthly irrigation demand is unmet in the analysis. Scenario III (combination scenario) both population growth and irrigation expansion are considered and analyzed. Based on the simulation results from the total demand of 188MCM, the total unmet demand is found to be 9 MCM. Finally, the environmental flow requirement coverage of WEAP out put shows some unmet instream flow requirement in October and November. Therefore, it can be concluded that the occurrence of maximum water shortage in catchment will not happened up to 2035 and also the future water resources development in Bilate sub-basin need to be carefully designed to optimize the balance between demand and supply. More importantly, basin level planning and catchment protection shall be taken as integral component of water resources development.

Key words; - WEAP, Bilate sub-basin, supply and demand, scenario, water allocation

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LIST OF ABBREVIATIONS

AEZ	Agro Ecological Zone
Amsl	above mean sea level
FAO	Food and Agriculture Organization
LU	Livestock unit
GIS	Geographic Information System
EFR	Environmental Flow Requirement
GTP	Growth and Transformation Plan
Ha	Hectare
Kc	Crop coefficient
Kms	Kilometers
m	Meter
M3/s	Meter Cube per Second
MCM	Million Cubic Meter
Mm3	Million meter cube
MoWIE	Ministry of Water, Irrigation and Energy
NMSA	National Metrological Service Agency
NSE	Nash-Sutcliffe efficiency
R^2	Correlation Coefficient
RVLB	Rift Valley Lake Basin
SEI	Stockholm Environment Institute
SNNPRS	Southern Nations Nationalities and People Regional State
UNESCO	United Nations Educational, Scientific and Cultural Organization
WEAP	Water Evaluation And Planning

1 INTRODUCTION

1.1 Background

The increase in demands for water resources will make its allocation to be challenging in the near future. Water consumption has increased about seven-fold since the beginning of the twentieth century (Shumet, 2016).This challenge is more pronounced for developing countries, especially in Ethiopia, because of rapid industrialization and continuously increasing demands. Municipal water needs of water for daily domestic consumption and agriculture requirement become increasing contrary to the available supplies. Some researchers (Liu, 2019; Han, 2013) have suggested various indicators, methods and models that used to allocate water resources in an optimum manner.

In order to meet all water requirement and balance the demand with the supply, efficient use of surface water, development of water allocation plan and management is necessary. Since surface water is the primary source of water, assessment of water potential and availability as well as the requirement plays a great role in increasing productivity of agriculture, improving traditional water management system, meet drinking water requirement and hydropower generation in the coming future.

The present study aims an integrated approach to water allocation for Abaya-Chamo sub basin, which is located in the main rift valley of southern Ethiopia. The Ethiopian Rift Valley Lake basin is situated in the administrative regions of Oromiya and the Southern Nations Nationalities and Peoples Region (SNNPR). According to Bekele (2001), the area of Abaya-Chamo sub-basin covers 18,600 km^2 while about 5500 Km^2 of which form the part of the area used for this study. Bilate River is used to be an important source for food, domestic water supply, agriculture, wildlife, water for livestock and grazing. This makes the issue of water resources very critical and effective water management is at its high demanding stage in the basin. In Ethiopia, where agriculture serves as a backbone of the economy as well as ensures the wellbeing of the people; the availability of water resources in the basins is quite necessary. Bilate river catchment is one of such basins located in the south-central Ethiopia. It emerges from the south western slopes of mount Gurage near 6°2′N 38°7′E, flowing south along the western side of the Great Rift Valley, to Lake Abaya at 6°37′54″N 37°59′6″E. The river is not navigable and has four tributaries but not notable.

In Bilate catchment, due to expansion of future planned irrigation area and population growth, possibility of larger water shortages in the future will be unequivocal. Therefore, providing prior resource evaluation mechanisms and allocating water is very crucial. Surface water allocation should have to be prepared for effective water resource management and to share for downstream users in appropriate manner. Integrated water resource management policies concerns on the correlation of water use and user to reduce the probability of greater water shortage in the future. To address these needs, it is paramount important to assess the impact of irrigation expansion and population growth on available water resources in the upper sub-basin of the Bilate catchment using a decision support system known as the Water Evaluation and Planning (WEAP) Model.

WEAP model is one of the useful and commonly applied tools for the integrated water resources management and water allocation. It is used as a database, forecasting and as a policy analysis tool, depending on the focus of the study. In this regard, the applicability of WEAP was thoroughly explored fore water allocation to balance domestic water demand, irrigation demand and environmental flow with the supply source of Bilate catchment.

1.2 Statement of the problem

In the global context, water is considered to be the oil of the 21st century where there is huge competition on the resource abstraction. As such, the ever-increasing population, which virtually imposes stress on the water resource brought the issue to be more pronounced even at the local scale. Basin level impacts are mostly pressing due to improper land use, deforestation and associated degradation of land and soil nutrients that may further impact downstream sedimentation in reservoirs.

The Abaya Chamo sub-basin is one of the sub-basins in the rift valley lake basins of Ethiopia that experienced the shortage of renewable water for human use. More specifically, the Bilate watershed in Abaya-Chamo sub-basin is facing high computing demand in terms of water use for different purposes that impose serious impact on the downstream environments. As a result of the aforementioned competing demands, the entire river system there is a local inter-regional conflict expected in the near future. Moreover, there is no holistic and integrated watershed management practices in place that can assist as a decision support tool. On the other hand, the water abstraction from the system is still functioning without proper basin plan. In order to solve such impacts, water allocation should be done so as to balance the demand and supply side and also avoid degradation of the basin.

1.3 Objectives of the study

1.3.1 General objectives

The main objective of the study was to develop effective water allocation system for Bilate catchment using WEAP model as a decision support tool.

1.3.2 Specific objectives

- ❖ To quantify the available surface water resource of the Bilate watershed in the Abaya-Chamo sub-basin;
- ❖ To analyse the amount of water requirement for different users. Such as:- domestic with (industrial, institutional and commercial), irrigation, livestock and environmental flow requirement.
- ❖ To evaluate the balance of Bilate catchment water demands and supplement regarding with their priority levels in current and future scenario;

1.4 Research questions

- ❖ What is the amount of mean annual runoff available in Bilate River?
- ❖ How much water is required for different activities at downstream of the catchment?
- ❖ What techniques will be used to fairly distribute current and future water demand allocation?

1.5 The Significance of the study

The significance of the study is linked with the main objective, which is focused to propose effective water allocation plans with the help of Water Evaluation and Planning (WEAP) model for the simulation of water demand and supply system for domestic, irrigation and environmental flow of Bilate watershed. This aims to maintain the water quality, to prevent soil erosion, to recover the polluted lakes, to protect ecological systems, and to enhance availability of water

In the end, this paper contains lists of references that were used during the study and appendixes, which contains some tables, computer outputs, and data used in this research.

1.6 The Limitation of study

The range of this research has been limited to allocate surface water resource for various requirements including irrigation, domestic, industrial, livestock and instream flow requirement with respect to different priority levels in consideration on the factors that affect surface water quantity, demand and supply. Aiming at the objective, this study did not take into account groundwater as a supply source and the effect of climate change, which may happen under future scenarios.

2 LITERATURE REVIEW

Water is the paramount resource of a country and the entire community as a whole, since no life to be convincible without water. The availability of water largely determines the spatial pattern of the Earth's terrestrial biomes (forest, grasslands and deserts) because it covers 71% of the Earth's surface providing habitat for fresh and saltwater ecosystems. Garg (2005) states, water is a major controlling element of the Earth's climate, and it is water that is largely responsible for sculpting the Earth's surface into the" infinitely complex associations of erosion and depositional landforms.

Now a day, water is a limiting and critical resource for society and countries development, and projection of population growth as well as changes in life style suggest the water demand to increase significantly. These projections have energized mission among water resources management, adequacy of future water supplies, the sustainability and preservation of aquatic ecosystems, and the viability of the current water resource research programs and institutional and physical water resource infrastructure.

The water accessibility and its requirements are an outcome of the total flow of a catchment, since its amount, characteristics and structure, economic factors, laws and regulations control its use. Because water availability and water demand are closely linked. Surface water is water that is open to the atmosphere and lie on the Earth's surface, such as in a stream, river, lake, or reservoir. In addition to this, surface water is a precious resource that can be used for domestic, industrial and agricultural, commercial and hydroelectric power supply purposes. Therefore, understanding surface water resources is a key aspect of integrated water resurce assessment, evaluation and planning.

To determine the available water in the catchment, understanding the hydrological characteristic of the watershed and interaction with the environment to be able to determine the inflow and out flow is essential. The necessary data to understand hydrology of watershed are rainfall, runoff, temperature and evaporation.

2.1 Review on water availability and demand assessment

According to Dermawan (2018) the demand for water resources of sufficient quantity and quality for human consumption, sanitation, agriculture, and industrial uses will continue to intensify as the population increases and global urbanization, industrialization, and commercial development accelerate. Water demands predicting is also a process achieved through several techniques and is typically used to predict future water needs for different uses including hydropower, domestic, and agricultural 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. Essentially, future water demand is derived from basic functions. For example, municipal demand is generally projected using population size and the number of households, industrial demand is often based on the number of employees, and agricultural demand commonly relies on crop type and irrigated land (Dale Whittington, 2010). Water demand is an important technical design parameter. It can be measured (for an existing project scheme) or calculated using local data or more typically, established norms and Standards. Such calculations also take into account the number and type of users to be served, the anticipated population growth rate and the expected life span of the infrastructure being provided. It is also important to take into account the seasonal influence on water demand.

Integrated management water needs consideration of current and future water resource availability. It involves a simulation of water demand and supply for agriculture, hydropower production, domestic sector, and the industrial sector. There are various models that can be used for appropriate water sharing based on resource availability. We have also two categories of water allocation models. These are simulations and optimizations models. Simulation-based water sharing models are used mass balance principles for the water allocation in a river watershed.

In order to manage water resources properly, many computer-based Decision Support Systems are being used in worldwide. Allocation of water demand in a given catchment is very important as discussed depending upon the model availability, capability and suitability to design water demand and supply with in the study area (Bilate sub-basin). Actually, there are various models capable for water allocation in a given catchment. The relevant models which are commonly used for water allocation all over the world are presented here to reach at a conclusion that WEAP model was selected as the best suitable to model the water demand in the study area.

Water demand can be assessed considering either of the following categories:

- Domestic water demand for households (Urban and Rural)
- Institutional water demand for public and private offices, agencies and institutions
- Livestock water demand
- Instream flow requirement

2.1.1 Domestic water requirement

The domestic water requirement of the study area was determined based on the Population size (number) within the study area and the Per capita water consumption based on level of development (urbanization) and type of supply. The estimation of water demand for domestic use at a catchment level of rural areas in Ethiopia face many problems due to lack of available measured data. There are two methods to determine rural domestic water needs, the first methods is used by calculating the quantity of consumed water based on the population level and water demand in terms of percapita consumption and it is known as indirect method. The second one uses the socio-economic surveys and participatory techniques involving the relevant stakeholders and estimate the current and future rural water demand and it is known as direct method.

The estimation of rural water requirement is difficult due to many reasons such as, majority of rural domestic water supply systems are unmetered; data concerning domestic rural water need is often expensive and time consuming to collect and the level of service provided by the water supply system is often unknown. For catchment management purposes, indirect methods are the most appropriate for establishing rural domestic water demand and use. For my thesis, indirect method is used to estimate rural water requirement and it is the most practical method for demand estimation on a sub-catchment and catchment basis.

2.1.2 Water Requirement for Irrigation

The main goal of irrigation is providing adequate water for crops in order to get optimum yield and best quality of harvested product. The time and amount of water required is estimated by soil properties such as; water retention capacities, crop and its growth stage and extent root growing. (Dr. Derrel L. Martin, 1993)

Crop water use rate should be accurately estimated for irrigation schedules and irrigation water requirement. The estimation of Daily and weekly crop water use rate are needed to schedule irrigations, while longer term estimation are needed to specify the irrigation, storage, and conveyance system capacities. Annual water use rate is often required to size irrigation reservoirs and establish water rights.

Determination of crop evapotranspiration (ETc) and net irrigation water requirements are critical for water allocation, risk management and irrigation system planning. (Bennetta, Harms, & Entz, 2013).

Based to the RVLB master plan, there is around 8000 ha of irrigation schemes on my study area. But, not fully implemented for the main crops such as maize, cotton, and vegetables. Therefore, irrigation water demand was determined by using the WEAP model by using the total command area and crop water demand per hectare of land to be irrigated.

2.1.3 Water Requirement for Livestock

Water is a vital for livestock health and production. Water requirements for livestock can be determined depending on species, breed, age, growth rate, production status, activity, feed type and weather. Climatic factors, such as temperature highly affect the water requirement and intake. The estimation of water requirements for livestock species (taking into account physiological status and environmental conditions) can be obtained from standard scientific guidelines detailing the nutrient requirements of a given species (FAO, 2019).

According to (Zinash), the estimated livestock population is about 35 million TLU (total livestock unit) in Ethiopia. The total livestock unit is assumed as an average consumption of 25 litres of water/day per TLU, and the daily water consumption is estimated about 875 million litres. This adds up to about 320 billion litres annually and the water requirement then expected to increase with the increase in livestock population and envisaged improvement in productivity (milk, meat, eggs).The water demands of sheep, goats and camels are not as high as those of cattle. The amount of water requirement depends up on growth, and productive processes such as lactation and egg laying. Because lactating cows take more water. Water requirements also largely vary according to other factors such as food intake, quality of the food and air and water temperature.

In the study area, there are no recent counts of livestock population density. The pastoralists are moving with their large herds of cattle and other livestock to Bilate River to find water and food.

2.1.4 Environmental (Instream) Flow Requirement

Environmental flow or release is the amount of water allocated from the conservation section of the catchment for downstream users to maintain the morphology of the river route. This is incorporated with its own independent out let structure, which will be operational. This demand particularly should be given due consideration especially for irrigation dams and hydropower dams for which the tailrace is far from the dam. However fixing the numeric value of the discharge required, needs detail Environmental impact analysis for the thesis.

Environmental flow is important to coordinate upstream-downstream water allocations in order to maintain healthy ecosystems. In the absence of environmental flow, communities risk losing economic and environmental security. Environmental flow provide the means for integrated management of river flows to meet the needs of people, agriculture, industry, energy and ecosystems within the limits of available supply and under a changing climate (IUCN).

Generally, the environmental or Instream flow requirement assigned to give an answer for, how much of the original flow regime of a river should continue to flow down in order to maintain the river ecosystem in a prescribed state.

Integrated water resources management, planning and allocation are most critical elements of EFR. The environmental flow in this study taken as a suitable percentage of mean annual runoff, where streamflow is required at a point on a river to meet the different ecosystem related water demands to maintain river water quality, fish, and wildlife, etc. The outflow of Bilate River enters to Lake Abaya. Therefore, proper percentage that will be necessary for Bilate river flow should be conserved to maintain its ecosystem the water level in Lake Abaya.

2.2 Review on surface water demand and its allocation

Surface water allocation for human and environmental activities needs to be considered and it can be defined as a process which systematically divides the amount of available water in the system for different regions and competing users (OECD, 2015), such as agricultural, domestic, industrial, and environmental components. Precipitation minus evapotranspiration accumulates in a catchment and flows to streams and recharges to aquifers.

Surface water allocation planning and management is typically undertaken, to achieve a series of overarching policy objectives. In many rules including (Speed, 2013)

- Equal distribution (allocation) of water among various user groups and regions.

- Allocating water recognizing fresh water-water dependant ecosystem and environmental water need.
- Water allocation should balance the water supply with the demand in order to manage variation of water availability.
- Development priorities such as supporting social and economic development.
- Allocating water by promoting efficient use of water available.

The water allocation of regional development and planning needs the incorporation of economic objectives with many factors, including historical, technological, and natural and resource constraints and potentials (Azazh, 2008).

Water allocation regarding with a priority helps to balance water requirement with supply. The approaches of water management recognize that, different users will be given various levels of priority and these is essential for development of watershed demands. Water demand allocation Priority represents the distribution of limited resources by giving rank among multiple demand sites. The priority for water demand should be fixed and resolved in allocation cycle of catchment before the remaining water is shared among the catchment water user.Water allocation priority is established by Government level.

2.3 Review on Models used for Water allocation

Water allocation models are classified into two groups. These are simulation and optimization models. Linear and nonlinear programming models for coordinated hydro-economic modelling have been utilized in numerous river. (Ringler, 2004). The optimization models determine the optimum solution for a particular problem whereas; simulation models are widely used by managers for planning and management of complex systems. Simulation based water allocation models use mass balance principles to allocate resources in a river system, as in MODSIM-DSS , (K. Jaiswal, 2008), MEQAA (Dermawan, 2018), WEAP (Yates D, 2005) etc. HEC model also used in a wide range of geographic locations of large river basin to solve a problem regarding with water supply and flood hydrology and small urban or natural watershed runoff. It is also used in water allocation studies in the basins with high water demands (Azazh, 2008).

2.3.1 Water Evaluation and Planning (WEAP) Model

WEAP model is a microcomputer tool of integrated water resource software created in 1988 by the Stockholm Environmental Institute (SEI) with user-friendly, flexible and transparent planning for assessment of current water demand and supply patterns and also, for designing and evaluation of alternative scenarios. The demand sides are; domestic water need for urban and rural site, livestock water need, irrigation water requirement and environmental flow water requirement with the equation of equipment efficiencies, water use rate, re-use and allocation whereas, supply side includes stream flow, catchment, reservoir and ground water.

WEAP model is very important software for planning, management and allocation of constrained water resource and environmental quality.

WEAP is also graphically oriented with programing language software library that utilize Map Objects from the Environmental Systems Research Institute (ESRI) which allows spatial referencing of watershed attributes (e.g. river and groundwater systems, demand sites, wastewater treatment plants, watershed, and river reach lengths). Several scenarios construct WEAP model simulations, where simulation time steps can be as short as one day, to weekly, to monthly, or even seasonally with a time horizon from as short as a single year to more than 100 years (Sieber J. Y., 2005).

2.3.2 Several Applications of WEAP model

The applications of WEAP model include several steps like;

- ❖ Setup of times steps and water resource system;
- ❖ Analysis of water resource, water demand and water supply;
- ❖ Design scenarios with respect to future policies, costs and techniques;
- ❖ Evaluate the scenarios of water requirement, delivered and unmet.

For the past last decades, WEAP models has been used for management of watershed as worldwide (SEI, 2008).In Russia, WEAP model applied for water demand and supply simulation on early 1992 and (Levite, 2003) used WEAP model for water allocation in water stressed river basin in South Africa for the first time.

WEAP model has two primary functions (Sieber J. Y., 2005). Those are, simulation of natural hydrological processes to assess the availability of water with in the catchments (e.g. evapotranspiration, runoff, and infiltration) and simulation of anthropogenic activities superimposed on the natural system to influence water resources and their allocation for consumptive and non-consumptive water requirement for evaluating an impact of human water user rate.

Generally, the applications of WEAP model include a number of steps. Defining problem including time frame, spatial boundary, system components and configuration; establishing current accounts, that can be used for calibration step and provide the actual water demand, resources and supplies for the system.; designing scenarios for future trend based on policies, economic development and other alternative assumptions which has an impact on water requirement, supply and catchment. Finally, evaluation of the scenarios with respect to water adequacy, benefits, cost, effects on the environment, and sensitivity to uncertainty in key variables (SEI, 2019). 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 provides a system for balancing water demand with supply and to maintain environmental flow requirement. After all, WEAP model chosen to model surface water allocation.

2.3.3 Features of WEAP Model

ArcGIS plays a significant role as back ground display of geographic interface based on GIS from grid cells in a matrix (Raster layer) or from points using discrete X-Y locations (Vector layer) for demand and supply nodes. Schematic the user-created spatial layout that visualize the physical characteristics of the water supply and demand system. The schematic is the starting point for all activities in WEAP and for attaching elements on layer using drag and drop (Sieber & Purkey, 2015). WEAP model is user friendly, highly flexible and comprehensive reporting system so, the user may customize reports as graphical, tabular ,excel csv format, or map-based output after entering data elements by selecting from a number of formatting options (e.g., metric or English units, monthly or yearly time series wizard, percent shares, or growth rates). Easy access to save specific report configurations as "favorites," which can be combined into "overviews," or summaries, of key system indicators; these overviews then retrieved quickly for review if needed. (Sieber & Purkey, 2015).

2.4 Rift Valley master plan - short review

The Rift Valley lake basin is a hydrologically closed system, with no surface flow from the terminal lake systems. It is one of the 12 river basins of the Ethiopia with a total annual surface water resource estimate of 5,312 Mm^3/year (MoWR, 2007). This amount was calculated from total annual average river flow into the lake systems under natural conditions without human abstractions streams that enter the lakes occupying the low-lying middle areas of the rift. According to the master plan study, Bilate is the only river in the basin that has a large flow, but limitation of land resources.

2.4.1 Domestic and Livestock water demand in RVLB

Most the community living in the RVLB do not have access to safe water supplies. In urban areas, official statistics are that 54% of residents do have access to safe water. However, the statistics hide the fact that supplies are often intermittent and that very little of the water is potable without in-home treatment such as boiling. In rural areas, access is lower. Official statistics are 44% but the definitions of 'access' and 'safe' obscure the fact that most rural people get their water from open sources. Finally, this leads frequent illness on both urban and rural environments (Azazh, 2008).

Ethiopia is among the least developed area of African nations and the RVLB is the least urbanised area in Ethiopia, with less than 13% living in urban areas. Within the basin, 74% of the population is in SNNPRS and 26% in Oromiya. Population density of the basin as a whole is 167 persons per km^2, which is three times the average for the country. The variability of population density with in the basin is highly notable. Those areas within SNNPRS have a density of 202 persons per km^2, about twice that of areas within Oromiya. Population density ranges from a low of 30 persons per km^2 in Borena to 614 persons per km^2 in Gedeo. The ever-increasing population coupled with an increasing demand on the natural resources in the catchment has profoundly exacerbated environmental degradation. Few lakes shrunk due to excessive abstraction of water; others expanded due to increase in surface runoff and groundwater flux from percolated irrigation water (Elizabeth, 1992). Excessive land degradation, deforestation and over-irrigation changed the hydro meteorological setting of the region as well.

The priority given for water supply is higher for national and regional governments alike. An analysis has been carried out to estimate the levels of investment required to ensure access to safe water. Because of the direct link between access for pure water and health, investment in water supply is of the utmost importance and should be one of the main priorities for government investment during the Master Plan period. Water supply has been given a lot of attention recently and is prioritized by government.

Livestock also places a significant demand on water resources. It is hoped that livestock numbers will actually reduce in the RVLB over the Master Plan period as they are already far too high and, as a result, actually retarding economic development

2.4.2 Irrigation water demand in RVLB

Currently, there is about 22000 ha total irrigation land exists for small household communities in RVLB. The households who get benefit from the irrigated land are around 60000. It is generally simple set-ups of a single pump abstracting water from a lake or river by individual farmers or a few families. There are also larger, commercial irrigation schemes totalling about 7,700 ha.

In my study area, Abaya-Chamo sub basin of Bilate catchment, the total planned irrigation area is 44,800 ha in Abaya and a further 4,000 ha in Chamo. These two lakes are interconnected and mostly the impact is on Lake Chamo because it is the lower one. The estimated allowable irrigation area in Abaya-Chamo sub-basin is 8000 ha. (MoWR, 2007)

2.4.3 Hydropower water demand in RVLB

In Rift Valley Lake Basin, the hydropower development is limited. It is not considerable of high potential area for hydropower development because it lacks physical attributes that is necessary for production.

2.5 Review on Water Resource Management Policy

The participation of water resource development in RVLB plays an important role conservation, watershed protection and management. The RVLB are extremely vulnerable ecologically because it is hydrologically closed basin. A significant proportion of the basin is in areas of high erosion potential and many areas are already badly degraded. Reversing the land degradation trend and rehabilitating those areas already degraded must be a priority in the RVLB where good land for agriculture is scarce and increasing agricultural productivity is necessary for economic growth. Surface water resource management policy in the RVLB can greatly assist in reducing the impacts of climatic variability and improving the equitable use of water within the sub-basins, considering both the human and environmental demands. (MoWR, 2007)

Ethiopian Water Resources Management Policy emphasizes water for irrigated agriculture. The irrigation sub-policy is formulated to guide the development of the irrigable land resources of the country to improve food security and ensure a sustainable supply of industrial raw materials (MoWR, 2007). Different agencies and organization involves in performing a number of functions for a comprehensive water resource management. The functions include water law and policymaking, regulation, technical assistance and coordination, monitoring and evaluation, administration and financing, public education and involvement. Finally, the Water Allocation and Apportionment policy states that the basic minimum water requirement of Ethiopia should be recognized as the reserve (basic human and livestock needs, as well as an environmental reserve). This should have the highest priority in any water allocation plan (MoWR, 2007). This statement is significant when considering the environmental minimum flow requirement for Abaya-Chamo sub-basin

2.6 Overview of associated investigations on water allocation by using WEAP model

WEAP model is used by (Phingsaliao, 2019) in Flinders university of Adelaide, South Australia on Projection of water demand and availability under climate change in the Nam Ngum downstream area, Laos. The Study assessing the available water and allocating the demand for different sectors such as, Domestic, Agricultural, Industry and downstream of Nam Ngum area. Simulation of surface water and ground water interaction of the downstream area done using MODFLOW and then linked to WEAP model. Finally, the calibration outcome shows very good result. Water collection and abstraction points, rapid measurements on water quality were conducted using a Conductivity Meter and GPS were used to obtain the spatial locations of water sources. On WEAP, Simple Rainfall-Runoff coefficient simulation method is used for catchment simulation and the calibration and validation result shows good fit.

On 2016, Omonge Paul Omondi used WEAP model on simulation of water resource use and allocation in Nyangores sub-catchment of the upper Mara basin, Kenya. The study aims to identify existing major water sources and sinks in Nyangores Sub-Catchment, to determine the current water supply, demand and quality in the sub-catchment and estimation on impact of water planning options on the future of water resource use and allocation (Omondi, 2016). The scenarios built in this study considers, high population growth, expansion of irrigation area, improved water efficiency (conservation) and dry season scenario.

Weap has been used in many water related researches in Ethiopia for instance; WEAP software is used for modeling Surface water resources for effective water allocation on Finchaa Sub-basin, Ethiopia (Tesfaye, Yesuf, & Hirko, 2015). WEAP is used for simulation of water supply and demand in current and future water demand. In addition, soil moisture method of catchment simulation method was used to simulate Runoff. Finally, PEST calibration done and its output was good.

On 2015, WEAP and SWAT model is used on surface water allocation in Didessa sub- basin, west Ethiopia (Tena, 2015). In this thesis journal, SWAT model is used to simulate monthly head flows which is used as a head flow for each sub-basin in WEAP model. WEAP model is used for to evaluate the impact of water abstraction on the upstream face of Didesa sub-basin and instream flow requirement is also estimated by Indicator of Hydrologic Alteration (IHA). The obtained result showed very good values of model performance.

According (Fufa, 2016), used WEAP model for allocation and utilization of koka reservoir. Study aimed to evaluate impact of climate change on reservoir water evaporation & to evaluate capacity of reservoir for downstream irrigation water requirement and finally allocating water effectively under climate change. After calibration and validation good result of WEAP, he built climate change scenario and irrigation expansion scenarios to identify volume reservoir evaporation and Irrigation water requirement and supply delivered on base line year, 1st 35 years and 2nd 35 years.

(Ebisa, 2018) Applied WEAP model for Arjo Didessa reservoir water Evaluation and allocation system. He used Records of hydrology and meteorological data as an input data to model. Meteorological and grid climatic data correlated with multi-regression and distribution mapping (DM) method respectively. The demand and the supply of water resource, baseline data and the future development activities of the area compared using the mainly two different scenarios climate change and irrigation expansion. His study analyzed the model calibration, validation and its statistical measure result shows that it is very good and the model can simulate the current and the future scenarios. After all, the results revealed that the minimum flow requirement maintained and the future irrigation demands are unmet in more or less.

3 MATERIAL AND METHODOLOGY

3.1 Background

The Abaya-Chamo sub- basin is situated southwest of Addis Ababa, between 6-8°N latitude and 37- 38.5°E longitude. It forms part of the Main Ethiopian Rift (MER), which in turn is part of an active rift system of the Great Rift Valley. The selected study area, Bilate catchments is found in Abaya-Chamo sub-basin, the sub-basin of the Rift valley lakes basin. Many perennial and intermittent rivers joining the lakes Abaya and Chamo contribute major amount of runoff to the lakes' yield.

The Bilate River Catchment, which was chosen to be the area of study, forms the northern part of the Abaya Chamo Basin. It is located between 7^0 28‘ N and 38^0 02‘ E in with elevation range of 2200m above sea level at Hosana and 1750m above sea level at Alaba Kulito. Bilate River is formed after Boyo swampy lake, which has two main sources Guracha and Weira Rivers, and it drains to Abaya Lake. Bilate River is the longest river in the Abaya Chamo Basin, with a length of about 255 km. It is also the only river which flows into Lake Abaya from the north. In the west, the area of investigation is defined by the watershed of the catchment of the Omo River, and in the east it is characterized by the Awasa lake sub-basin. The southern border is formed by Lake Abaya, into which the Bilate River flows. The upper catchment area of the Bilate is situated on the graben shoulder of the Main Ethiopian Rift. A dense net of tributaries characterizes the complete catchment area of the Abaya Chamo Basin, which is around 18,600 km^2. Whereas the area Bilate catchment is 5500 Km^2.

In the present study, the recorded flow at the upstream gauging station (Alaba kulito station) is 300 Mm^3/year and at the downstream gauging station (Bilate Tena station) the flow is 423 Mm^3/year.

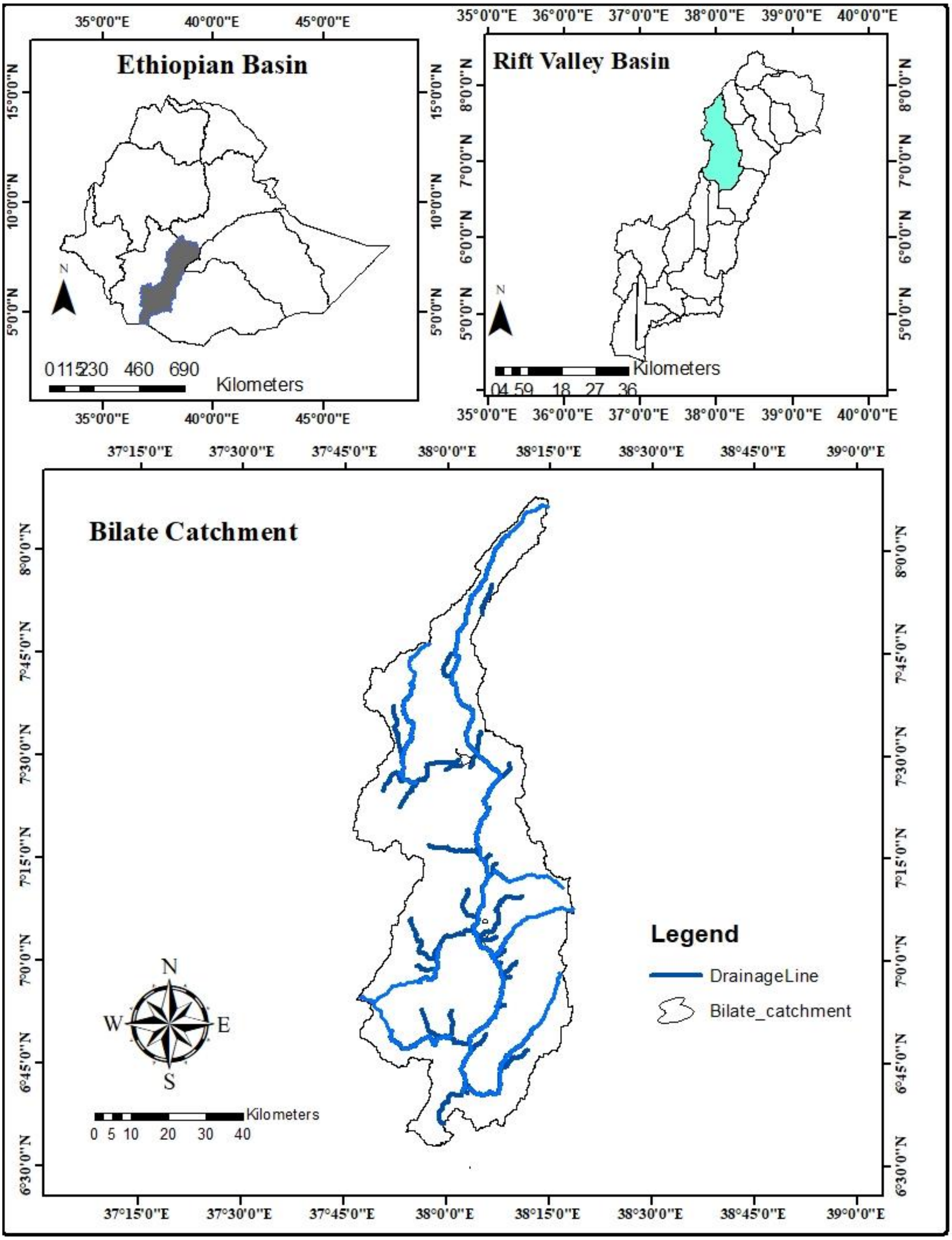

Figure 1 Location map of the Abaya-Chamo Sub-basin

3.1.1 Physical Characteristics of the Basin

The physical characteristics of Bilate River basin is a tectonic valley along with its length and fault scarps or steep slopes on either side surround most part of the valley. The floor of valley is mostly flat plain and appears to be in part a remnant of the depositions floor of the ancient large water basin. The study area is part of the western rift margin, which is characterized by chain ridge, hills, deep and wide valleys of small and large streams, and narrow flatlands between the valleys having gentle slopes.

The altitude of the catchment ranges from 1194m at Lake Abaya to 3365m above sea level at mountain Ambaricho and at Alicho Wiriro Woreda. This indicates that the topography of the area ranges from lowland plain areas to highly mountainous elevated terrains.

The small streams flows towards Abaya Lake along with the Bilate River. Most of its tributaries, as well as a large volume of water, come from Gurage, Silte, Hadiya, Kambata and Wolaita zone high lands of the catchment. The increased use at downstream could be influenced by the corresponding low rainfall, high evapotranspiration, relatively slow drainage and thermal springs that join the river downstream Hirko et.al. (2015).

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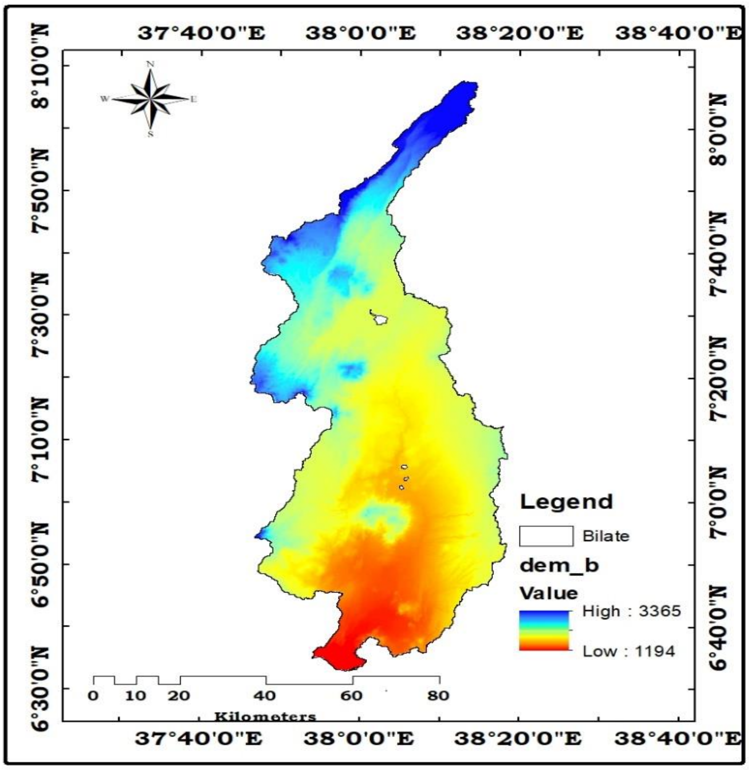


Figure 2: Digital Elevation Model map of the Bilate Watershed

3.1.2 Climate and Hydrology

Our country Ethiopia is situated in tropics with small seasonal variations in temperature. The temperature and rainfall tend to vary as a function of elevation and, in consequence, so do relative humidity and potential evapotranspiration.

3.1.2.1 Rainfall

There are two principal patterns of rainfall season apparent in the RVLB. In the northern sub-basins, there is a single wet season from April to September, which changes to a bimodal pattern towards the south. In the north of Lake Abaya, the main rains occur July through September, with a secondary peak in March or April while in south of Lake Abaya, the main rains occur earlier in the year, between March and May. In the study area of Abaya-chamo sub-basin in particular bring small rains on January, February, November and December) to most parts of the country. Therefore, gets its first maximum rainfall during on April to September. There are 9 metrological station in my study area and their average annual rainfall approaches to 1101 mm/year.

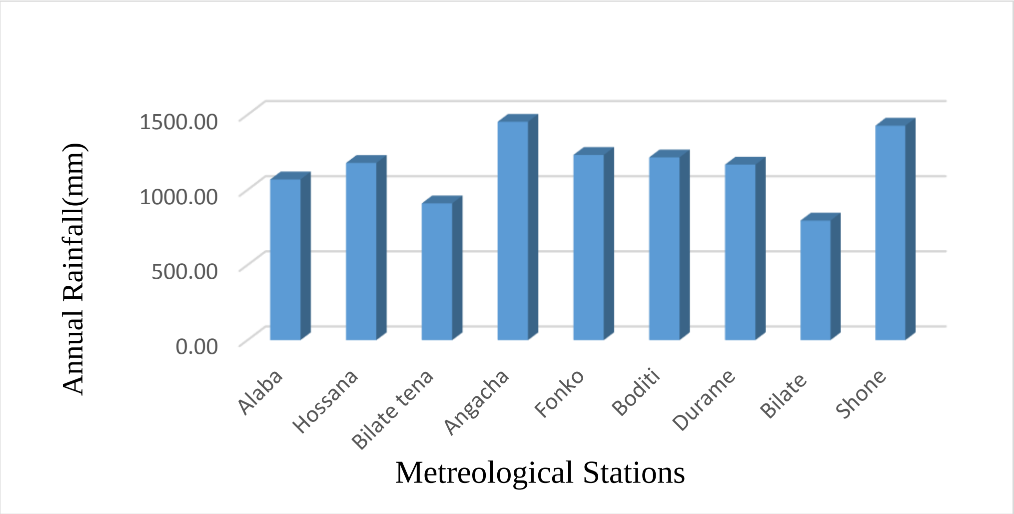


Figure 3: Annual Rainfall of each station in the catchment

3.1.2.2 Temperature

The temperature varies considerably in the basin with altitude. The mean annual maximum temperature of the study area varies from 16.51^{O}C to 33.04^{O}C; while the mean minimum temperature varies from 9.29 ^{O}C to 13.64^{O}C. The mean annual temperature of the area estimated according to the data of the all stations varies from 14.94 ^{O}C to 22.92 ^{O}C.

3.1.2.3 Evapotranspiration

The daily potential evapotranspiration was calculated using extra-terrestrial radiation, minimum and maximum temperatures. Studies using the Hargreaves equation to estimate PET in Ethiopia found satisfactory results . The Hargreaves equation is derived through regression of the temperature reduction coefficient and relative humidity factor, as in the following:

$$ETo = 0.0023*(0.408)*(T_{mean}+17.8)*(T_{max} - T_{min})^{0.5}*R_a \text{ ----------------------------------Equation } \mathit{3\text{-}1}$$

Where;- ETo is the potential evapotranspiration by the Hargreaves method (mm/day), Ra is the extraterrestrial radiation (mm/day) that is dependent on latitude, sunshine hours and solar constant. Tmean is the average temperature (°C); Tmax and Tmin are the maximum and minimum temperature (°C), respectively. Based on the Hargreaves's method the average monthly potential evapotranspiration (PET) of Bilate sub-basin was estimated to be 137mm. Daily average potential evapotranspiration varies from approximately 5 mm day^{-1} and the maximum and minimum temperature varies 32 ^{0}C and 10 ^{0}C in the catchment.

3.1.2.4 Stream Flow

In the present study, the daily flows for all available gauging stations was collected from the Ministry of Water, Irrigation and Energy (the sole provider of river flow data). In the area of investigation, five gauging stations are available for the measurement of river flow. Three of them are situated in the upper reaches of the Bilate River, one in the middle portion and one in the lower reaches of the river. All stations in the upper reaches does not lie on the Bilate River itself: one is in the middle portion of the Guder, a tributary of the Bilate, and another station is located on the Batena, a tributary of the Guder. The Guder flows through Lake Boyo with its bordering wetlands before it flows into the Bilate River. For this study, two nearby stations Alaba kulito and Bilate Tena of stream flow data is used. The total annual inflow of Bilate river into the Abaya lake system has been estimated 830 Mm$^{3.}$ (MoWR, 2007).

3.1.3 Land Use and Land cover

The actual meaning of land use is the way in which land is used by people in an area to produce what is needed by the people for use through involvement of labour, capital and available technology. Whereas land cover refers observed physical cover on the earth's surface. In other words, land cover is physically appearing on the surface of the ground as a natural or manmade entity. Built up areas (settlements and infrastructures), cultivated land, afro-alpine and sub afro-alpine vegetation, forest, woodland, bushland, grassland, exposed surface (bare land) and water body are the main land cover types in the basin.

Land use land cover map of the study area collected from water and land management office. This data will be used for land suitability analysis of the study area. The land use condition in the Bilate catchments includes mainly of cultivated agricultural land, grassland, Water body and forest land, rural and urban settlements. It is estimated that 19.94% is cropland, 23.59 is woodland, 11.79 % is grassland, 0.32% is wet land and 10.86 % is barren land.

Table 1: Percentage of Land use Land cover used in WEAP model

LULC	**Area(ha)**	**%age**
Forest	6830.37	1.36
Wood land	14778.45	2.95
Shrub/bush	38609.1	7.71
Crop land	332855.37	66.47
Grass land	66936.69	13.37
Barren land	36507.33	7.29
Wet lend	1073.61	0.21
Water body	383.85	0.08
Rural Settlements	2763.18	0.55

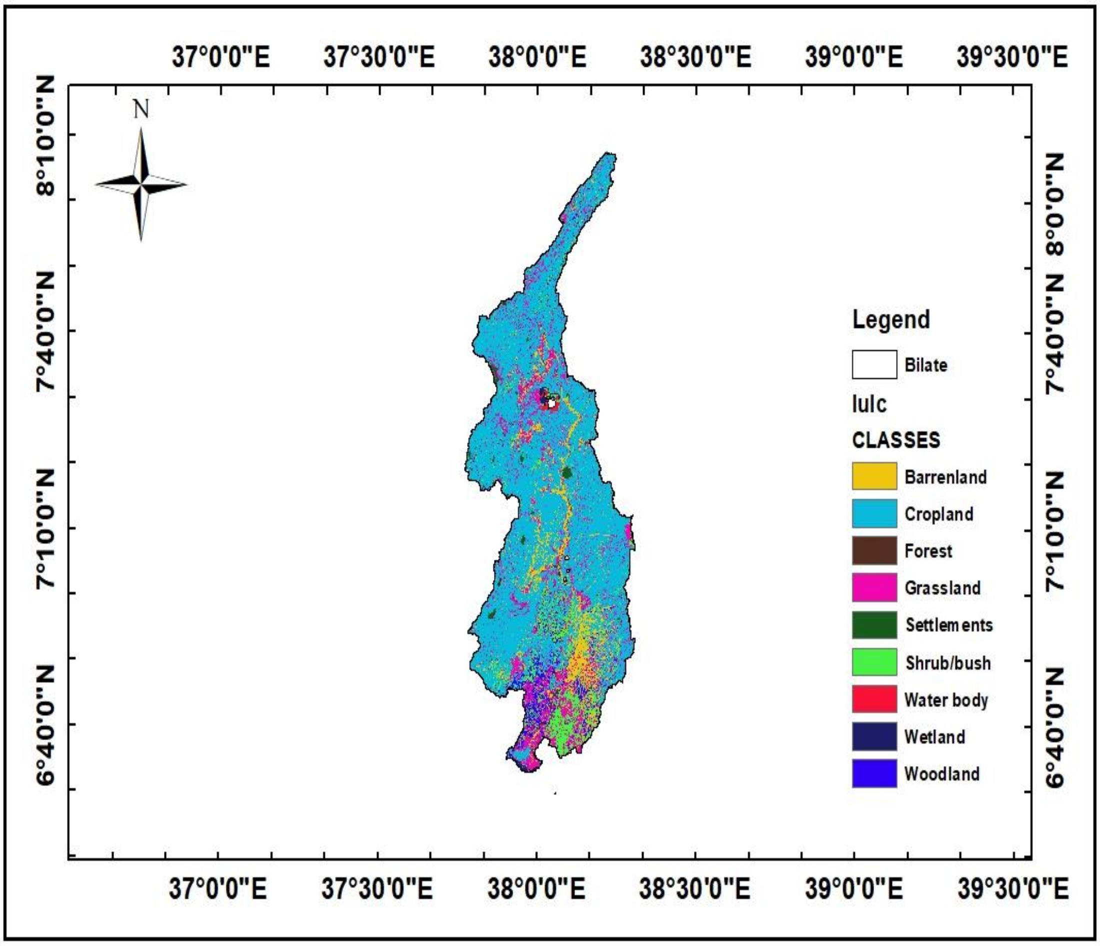


Figure 4: Land cover land use map of Bilate River

Source: Water and Land Management (AAU Research office, 2017 data)

2.1.5.1 *Agriculture*

The Rift Valley Lakes Basin (RVLB) is primarily an agricultural basin and agriculture will continue to be an important part of the economy. Related sectors of livestock and industry based on processing of agricultural and livestock products will also be of importance. Most of the agriculture in the RVLB is subsistence and rain fed farming. There is a strong correlation between GDP and annual rainfall in Ethiopia and this will continue unless changes are made in the approach to agriculture. Water can be made to contribute to the national economy through the development of the countries water resources and expanding irrigation schemes so that agriculture production is improved by solving the problem of water shortage caused by the unpredictability of the rainfall (MoWR, 2007).

One of the factors that retard productivity is the small size of land holdings. This has been driven by population growth as land was divided and re divided among generation. There is some potential to increase the area under irrigation, but all new irrigations must be developed with caution as all water abstractions will impact the sensitive lakes of the RVLB and may not be sustainable.

3.1.4 .Geology

The geological map of the FAO (1998) shows that, Oligocene-Miocene basalts dominate in the Bilate River Catchment. These basalts can be found in the central area between Alaba Kulito and Bilate Tena, accompanied by Quaternary rhyolites and trachytes in the north and Holocene lacustrine sequences in the south of the catchment. Furthermore, on the southwest border, many subordinated Oligocene and Miocene volcanics can be found.

3.1.5 Soil

According to the FAO Soil Map (1998), and the data on the ArcGIS, soil types such as Luvisols, Nitisols and Leptosols dominate in the area of investigation. They can be found throughout the catchment. Cambisols are present in the north, Vertisols can be found in the south and the southwest, and Andosols are present in the central area of the catchment between Alaba Kulito and Bilate Tena. The soil depths are between 1.00 and 2.00 m.

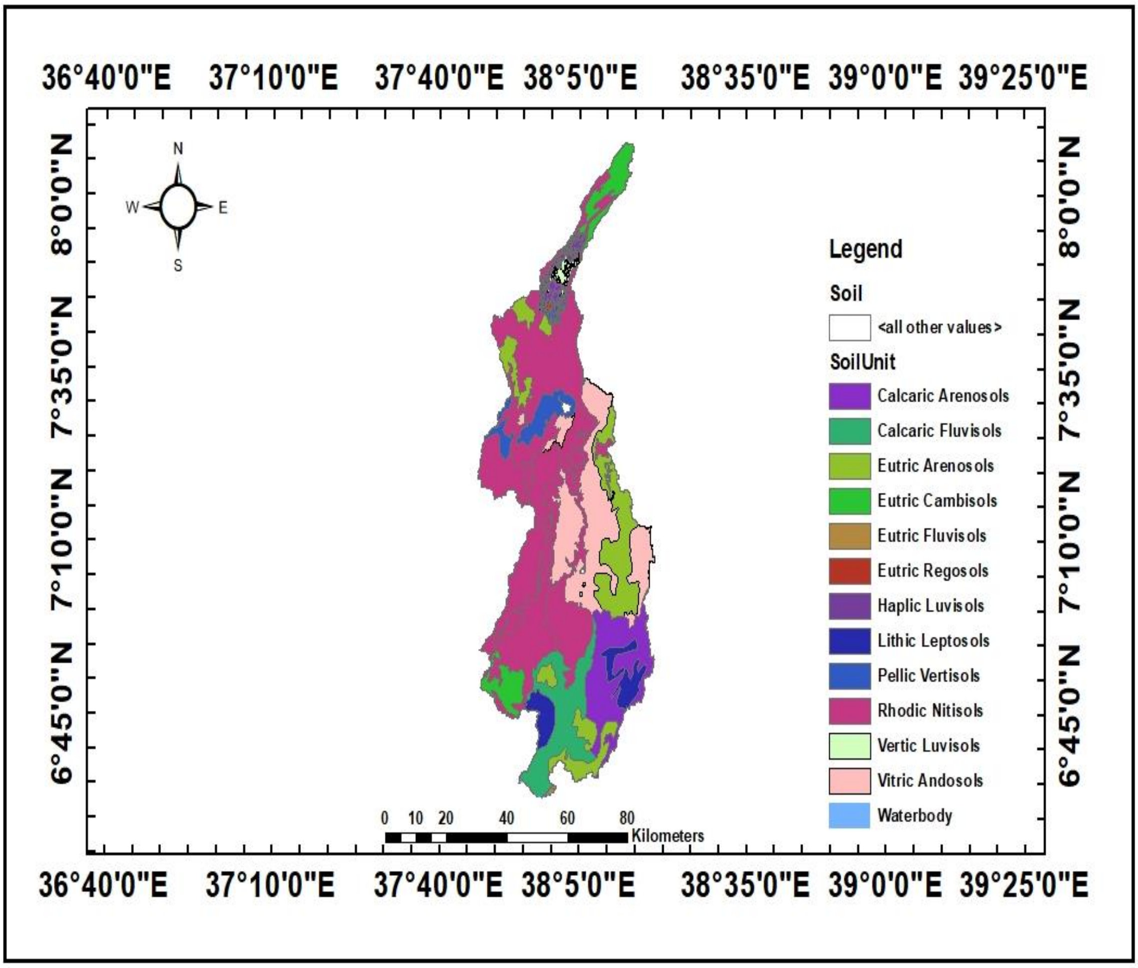


Figure 5: Soil map of Bilate watershed

3.1.6 Population

According to 2009 master plan of the basin, the population in RVLB estimated as 8.9 million. Ethiopia is among the least urbanised African nations and the RVLB is the least urbanised area of Ethiopia, with less than 13% living in urban areas. Within the basin, 74% of the population is in SNNPRand 26% in Oromiya. Population density of the basin as a whole is 167 persons per km^2, which is three times the average for the country. There is significant variation of population density within the basin. Those areas within SNNPR have a density of 202 persons per km^2, about twice that of areas within Oromiya. Population density ranges from as low as 30 persons per km^2 in Borena to 614 persons per km^2 in Gedeo.

According to the masterplan report, the medium variant projection , the population of the RVLB is expected to double before 2025, and grow to 22.9 million by the end of the Master

Plan period. The corresponding average growth rate is 3.15%, but it is much higher (3.8%) in the early years of the Master Plan period. This is a very high growth rate and is an obstacle to the economic development of the basin. (MoWR, 2007).

For this study, population data of 2020 is taken from central statistical agency of Ethiopia with current growth rate of 2.56 %.

3.2 Method used

Several methods are used in the study area, starting from data collection from different institution such as MoWIE, National Meteorological Service Agency, Central statistical Agency, and Water, Irrigations, and Mines departments from different zones. Coming to the next duty, filling of missed data and checking the data quality, catchment delineation and preparation of necessary input datas for WEAP model in a suitable format in order to estimate the water demand and supply as well as review of literature on related studies.

3.2.1 Catchment Delineation

Topography is defined by a DEM that describes the elevation of any point in a given area at a specific spatial resolution. SRTM 30 × 30 DEM of Abaya-Chamo sub Basin was collected from Water and Land management research office. These data sets have been further analysed and used in the extraction of catchment characteristics. The elevation of Bilate watershed ranges between 3365 meters above sea level (m.a.s.l.) in the north and 1194 m in the south with a mean elevation of 2279.5 m. Prior to data collection, the boundary of the study area was delineated by using ArcHydro tool.

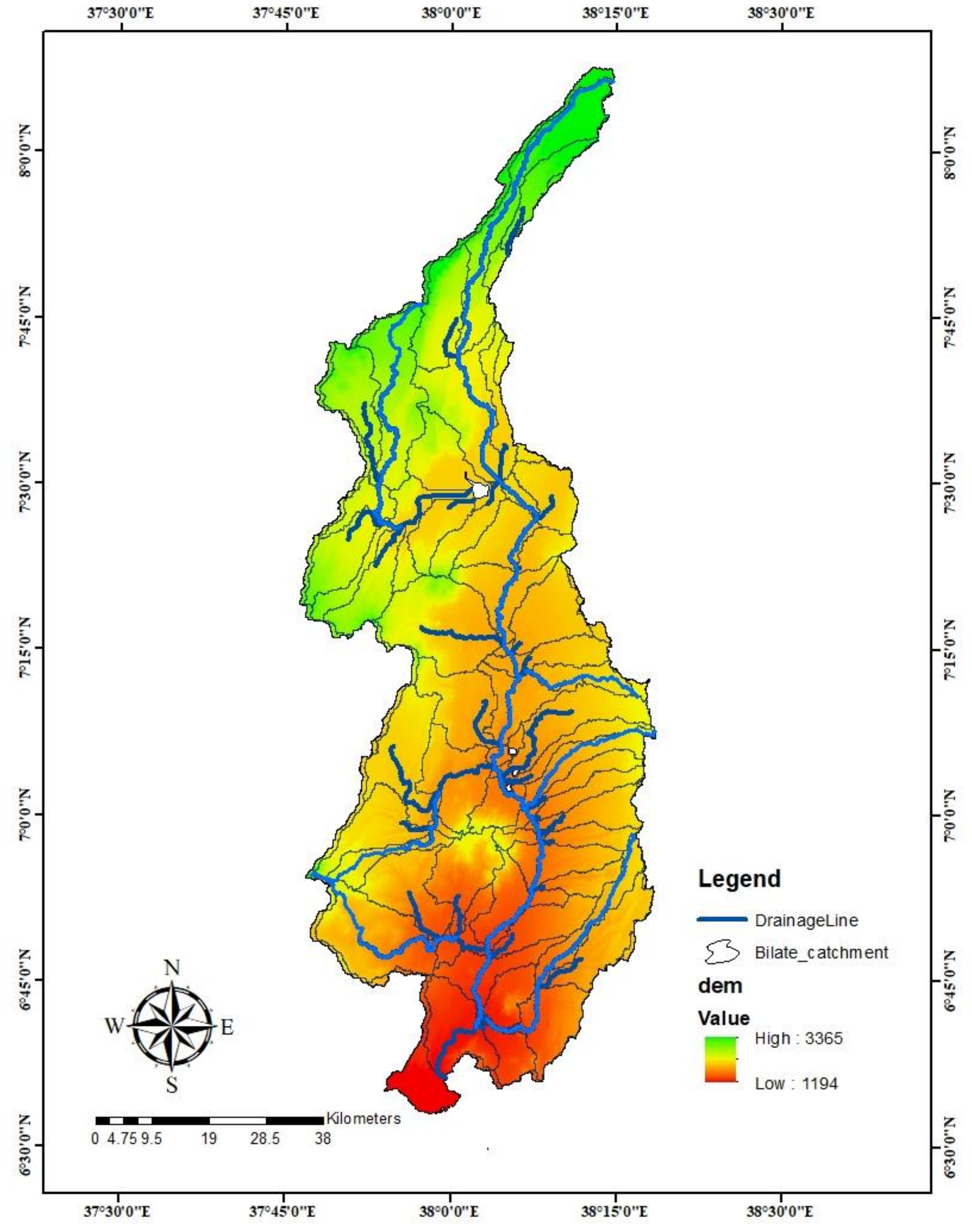


Figure 6: Bilate catchment delineation

3.2.2 Data sources and Collection

Before using and processing of any research, the primary task of the study is getting and collecting relevant information or data of the study area. Several necessary data's collected from multiple organizations and then analyzed to check their qualities and consistencies.

3.3 Material used

The materials used for this research depending on the objective were ArcGIS tool to obtain hydrological and physical parameters and spatial information of the study area, DEM data used as an input data for ARC-GIS software for catchment delineation and estimation of catchment characteristic, Hydrological and meteorological data, WEAP model for basin simulation and Microsoft EXCEL to analyze WEAP outputs. To allocate surface water, data such as daily rainfall, maximum and minimum temperature, relative humidity, wind speed, sunshine hours, stream flow and soil data's collected from responsible agencies such as Ethiopian National Meteorological Service Agencies, Ethiopian Water Resource, Irrigation and Energy Minister and from other sources.

3.3.1 Hydrological Data

Hydrological gauging stations in Bilate Sub-basin are mainly maintained by the Hydrology Department of the Ministry of water and energy (MoWIE) which processes and files data. For this study, the hydrological data were collected from Ministry of Water, Irrigation and electricity (MoWIE), Daily flow data of two stations of different years have been collected.

In the Bilate sub basin there are about 4 hydrological gauging stations that records the river flow. The stations in the upper reaches do not all lie on the Bilate River itself , one is in the middle portion of the Guder, a tributary of the Bilate and another station is located on the Batena, a tributary of the Guder. Whereas, the rest two stations in the middle and lower reaches, are located on the Bilate River near Alaba and Bilate Tena. Due to some cases, only two gauges (Bilate near Alaba and Bilate near Bilate Tena station) work properly and taken for simulation in Weap. The fugure below shows the basic spatial distribution of stream flow gauging stations in the Bilate sub basin.

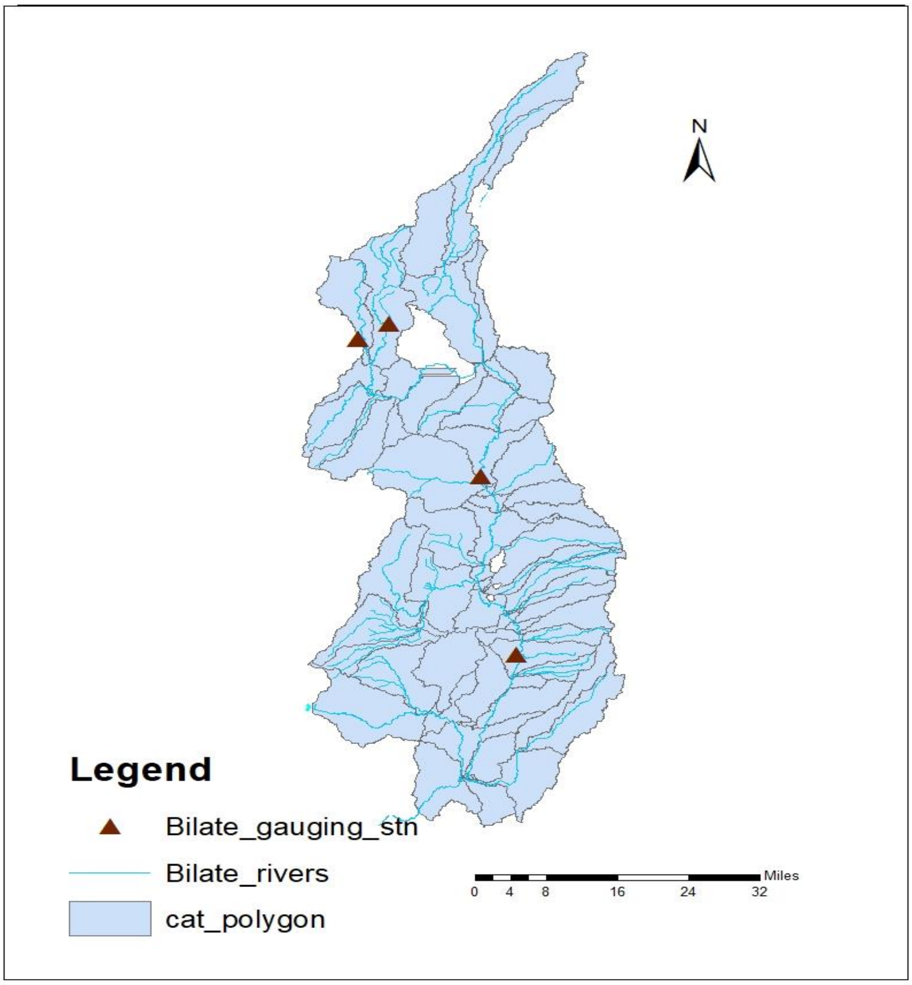


Figure 7: Stream flow gauge stations of Bilate watershed

Table 2: Stream flow gauging station in Bilate watershed

Station No	River	Station	Latitude	Longitude	Period	River Basin
082041	Batena	Nr. Hosana	$7^0 33'$	$37^0 52'$	1987-2006	Rift Valley
082005	Bilate	@ Bilatentena	$6^0 56'$	$38^0 08'$	1987-2006	Rift Valley
082008	Bilate	Nr. Alaba Kulito	$7^0 17'$	$38^0 04'$	1987-2006	Rift Valley
082031	Weira/Bate	Nr. Hosana	$7^0 35'$	$37^0 55'$	1987-2006	Rift Valley

3.3.2 Meteorological Data

Meteorological data of this study is mainly based on daily rainfall data, Temperature (maximum and minimum), humidity, and wind speed. It is collected from the National Meteorological

Service Agency of Ethiopia (NMSA). The quality of the studies is dependent on the quality of required elements and quantity or long term records of data. Meteorological data of this study was mainly based on rainfall data and temperature (minimum& maximum) data, filling missing this data, Homogeneity test, Consistency test, Areal rainfall determination is done to make the data's complete and sufficient.

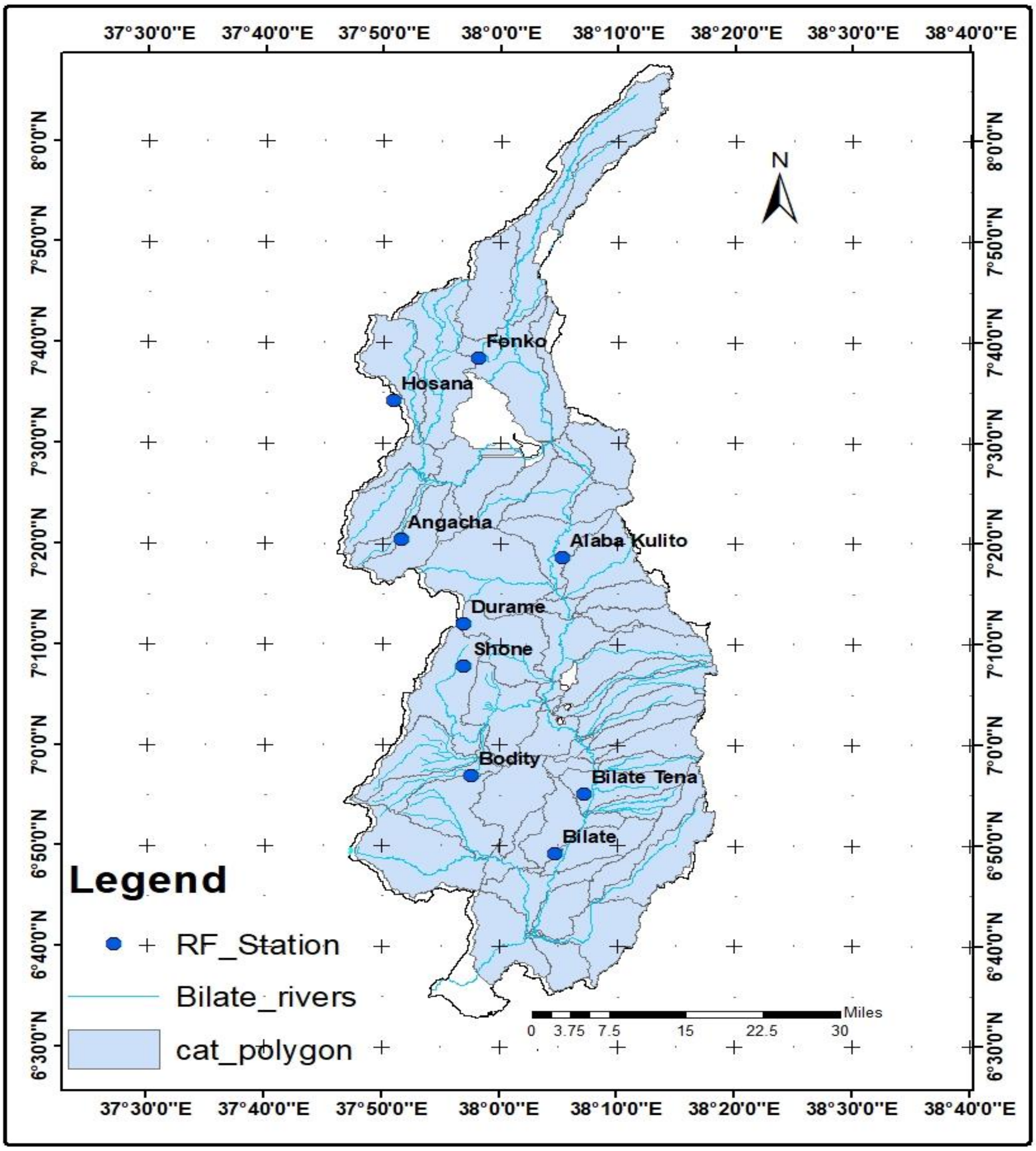


Figure 8: Meteorological station in Bilate river catchment

Table 3: Selected Rainfall stations with in Bilate watershed

Stn_Name	Latitude	Longtude	Elevation	Years of data used	Missed data (%)	Sub basin
Bilate	6.8167	38.0833	1361	1987-2017	3.347	Bilate
Hosana	7.5673	37.8538	2307	1987-2017	3.135	Bilate
Alaba Kulito	7.3106	38.0939	1772	1987-2017	2.656	Bilate
Angacha	7.3405	37.8572	2317	1987-2017	10.146	Bilate
Fonko	7.6423	37.9680	2246	1987-2017	1.442	Bilate
Boditi	6.9537	37.9550	2043	1987-2017	2.87	Bilate
Durame	7.2400	378915	2116	1987-2017	6.55	Bilate
Bilate Tena	6.91667	38.11667	1496	1987-2017	7.51	Bilate
Shone	7.1335	37.9527	1959	1987-2017	7.77	Bilate

3.3.3 Data Quality Controls

The continuity of a recorded data may be broken with missing due to many reasons such as damage or fault in gauging station during measuring period. So, before starting any model simulation, it is important to check whether the data were homogenous, consistence, sufficient and complete with no missing data. If the missing data exists, it should be estimated using the data filling methods. Because incorrect data leads to inconsistency and ambiguous results that may contradict to the actual value. Most of the meteorological stations have no data record or have short period and random records. Such types of stations with no data record or short period and random data records and also stations located out of the study area or at the periphery are dropped out. .I have selected nine stations which has better quality and long period daily records which are well distributed over the study area. These data passes through some tests such as:-

- Filling missing of all collected data
- Homogeneity Test
- Consistency Test

3.3.3.1 Gap Filling of Rainfall and Streamflow data

The consistency and completeness of these time series is important in processing of raw data sets by filling data gaps is the necessary procedure. (Azazh, 2008) However, it is well known that various hydrological research databases contain missing values (Elshorbagy, 2002).For gauges requiring periodic measurement, failure or absence of the observer to make the required visit to the gauge, destruction of the recording gauges and failure of the instrument due to mechanical or electrical malfunctions, which result in missing data. (Tadesse, 2016). For any such cause of instrument failure reduces the length and information content of the precipitation record. The multi-regression and long average filling method was used to compute missing data for the analysis of rainfall data.

Measurement of any flow data plays a great role to many problems in hydrologic analysis and design. Since there are costs related to data collection, it is imperative to have complete records at every station. The actual condition in most of the data records this is not satisfied for different reasons. For gauges that require periodic observation, the failure of the observer to make the necessary visit to the gauge may result in missing data. Vandalism of recording is another problem that results in incomplete data records, and instrument failure because of mechanical or electrical malfunctioning can result in missing data. Any such causes of instrument failure reduce the length and information content of the flow on record (Levite, 2003). In order to make use of partially recorded data, missing values need to be filled in sequence. To fill the missing recorded stream flow gauging data various methods are available. The most common methods are the simple Arithmetic Mean Method and Normal-Ratio Method and these methods are used for filling of missing data in this study.

After selecting which station better matches the station records in a query using less percentage of the missing data process, multi-regression between them indicates the equation in which the given value should be determined in order to obtain the approximate missing data records for the corresponding time.

3.3.3.2 Homogeneity Test

Homogeneity analysis was used to separate a change in the statistical properties of the time series data. The causes can be either natural or man-made. These include alterations to land use and relocation of the observation gauging station. Therefore in order to select the representative meteorological station for the analysis of areal rainfall estimation, checking homogeneity of group stations is essential, the homogeneity of the selected gauging stations daily rainfall records were carried out by non-dimensional equation:

$$P_i = \frac{\overline{P_i}}{\overline{P}}$$ --*Equation 3-2*

Where: - Pi = Non-dimensional Value of precipitation for the month i

$\overline{\text{Pi}}$ = Over years averaged monthly precipitation for the station

$\overline{\text{P}}$ = Over year's average yearly precipitation of the station

3.3.3.3 Consistency test

Consistency of Rainfall data analyzed based on theory of a plot of two cumulative quantities that are measured for the same time period should be straight line and their proportionality unchanged, which is represented by slop. Therefore, inconsistency of the record was done by the double-mass curve technique. This technique used to check the consistency of Rainfall data. This is a method by which we can easily identify which of the neighboring gauges, if any, around the station, which is to be filled, best corresponds to fill the missing records. The method comprises of simple plotting of the cumulative time series volume of flow between the records of the station to be infilled and other nearby station. This will be repeated as many as the available nearby stations. The best neighbor then will result in more or less a straight line plot and it's R^2 result will be closer to 1 which must be greater than 0.6. Then that station will surely be relatively the best. If significant change in the system of the curve observed, it should be corrected by:

$$P_x^{'} = P_x * \frac{M^{'}}{M}$$ --*Equation 3-3*

Where:- Px' = Corrected precipitation at station x

Px = Original recorded precipitation at station x

M' = Corrected slope of the double mass curve

M = Original slope of the double mass curve

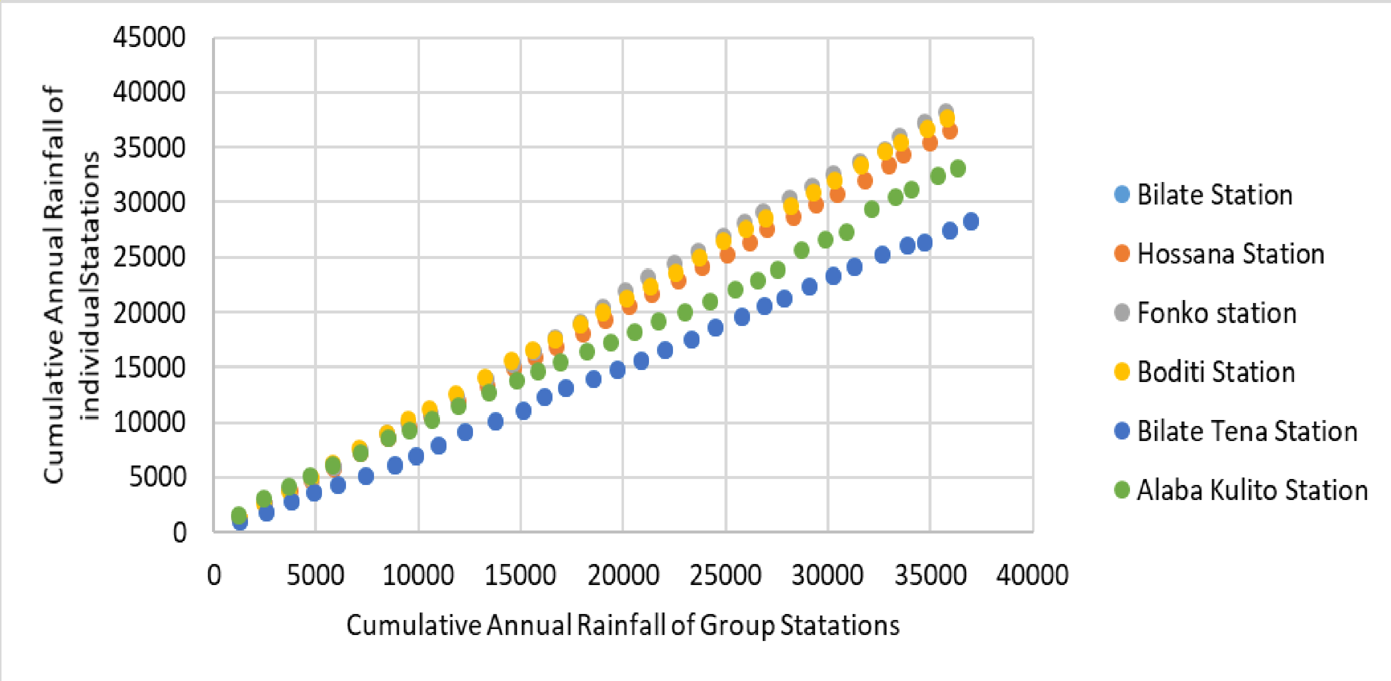


Figure 9: Consistency Test for Bilate, Hossana, Fonko, Boditi, Bilate Tena, and Alaba metrological stations

3.3.3.4 Outlier Test

Outlier is an observation, which lies abnormal or out of the given data trend. The skewness coefficient determines the whether the higher or the lower outlier or both tests required. If station skewness coefficient (Cs) is greater than (+0.4), high outlier test applied; if the station skew is less than (-0.4), lower outlier test is applied. Where the station skew is between (+ 0.4), both higher and lower outliers should be applied before eliminating any outliers from the data set.

Equation used for determination of higher outliers:

$$XH = Xav + KnS \text{ ---} \textit{Equation 3-4}$$

Where, XH: - Logarithmic higher - outlier test limit,

S - Standard deviation

K - Level critical value for outlier test statistic for samples size of N from the normal distribution (Appendix D).

Equation used for estimation of lower outliers:

$$XL = Xav - KnS \text{---} \textit{Equation 3-5}$$

XL: - logarithmic lower- outlier test limit,

The graph of outlier test for each station is kept on Appendix E.

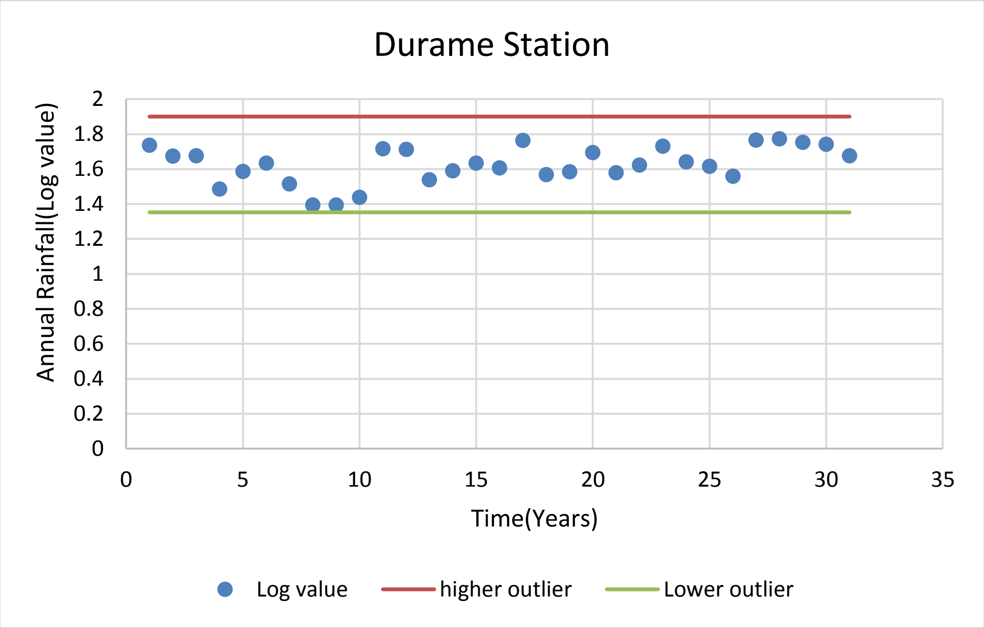


Figure 10: Meteorological station in Bilate river catchment

3.3.3.5 Areal Rainfall

In a given catchment, rain gauge stations are evenly distributed into sub-basin. The rain of one station in a basin may be different from that of the second station in the same catchment. From this concept, the average precipitation value on the entire catchment is worked out, so as to get average rain catchments to have the limits of the catchment carefully defined. Therefore, rainfall over an area of interest has to be estimated from these point measurements. There are usually three ways of determining the areal precipitation over a catchment from rain gauge measurement. These methods are the Arithmetic means, the Thiessen polygon and the Isohyetal method. However, the Thiessen polygon was used for this study for its sound theoretical basis and availability of computational tools. But the method is dependent on a good network of representative rain gauges and does not allow the hydrologist to consider factors, such as topography (Daniel, 2008).

To determine the mean areal rainfall, the rainfall amount of each station was multiplied by the area of its polygon and the sum of these products was divided by the total area of the catchment. If P1, P2, P3…Pn are the rainfall magnitudes recorded by the gauging stations 1, 2…….n, respectively and if the areas of Thiessen Polygon A1, A2, and A3...…An, are formed as representative of the respective stations then the average rainfall over the catchment is given by:

$$P_{avg} = \frac{P_1A_1 + P_2A_2 + P_3A_3 + \ldots P_nA_n}{A}$$ ---*Equation 3-6*

Where: - Pavg = areal precipitation over the sub-basin (mm);

P1, 2…n = precipitation depth in each station (mm);

A1, 2 …n = area of each polygon (km^2);

A = total watershed area of sub-basin (km^2)

In a given river catchment rain gauge stations are evenly distributed into sub-basin. The rain of one station in a basin may be different from that of the second station in the same catchment. From this idea the average precipitation value on the entire basin is worked out, to get average rain catchments to have the limits of the catchment carefully defined. Therefore, rainfall over an area of interest has to be estimated from these point measurements.

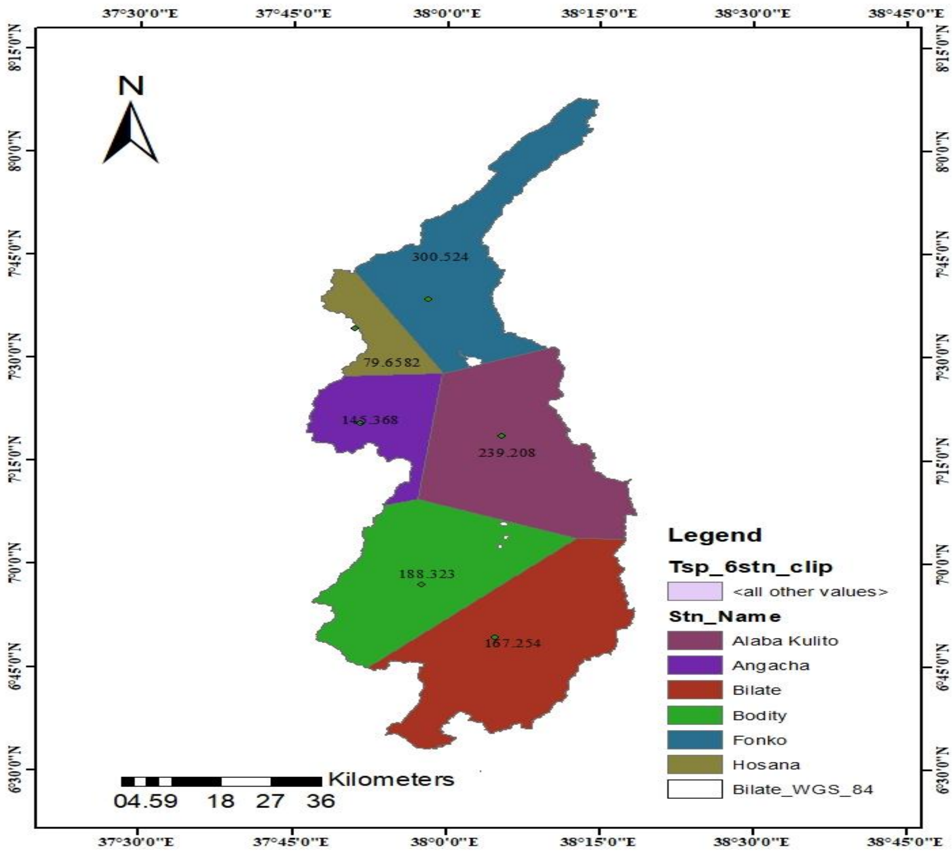


Figure 11: Areal rainfall of Bilate watershed

The average of monthly areal rainfall profile with in each sub- catchment clarifies seasonal rainfall variation besides the spatial differences within the Bilate watershed. The corresponding profiles are graphically presented in figure 3-11 above and the pertinent series rainfall values of the selected key stations within this region are given in table 3-4 below. The monthly catchment profile indicates the occurrence of the dry, wet, and intermediate season of monthly rainfall in the different locations of the watershed area. These rainfall patterns of Bilate catchment display the Bi-Modal regime.

Table 4: Mean Monthly Areal Rainfall of the sub-basin (mm)

Catchment	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Upper Bilate	26	49	111	147	149	131	161	176	155	74	19	21	1219
Lower Bilate D/S	28	30	57	96	90	71	73	75	68	78	48	24	737
Batena	31	51	102	150	155	135	167	186	163	80	26	25	1272
Middile Bilate	31	51	94	128	127	102	129	134	121	75	33	24	1050
Lower Bilate U/S	29	43	81	129	127	98	117	118	104	78	41	28	991
Amessa	29	46	90	164	165	125	152	150	127	84	42	36	1210

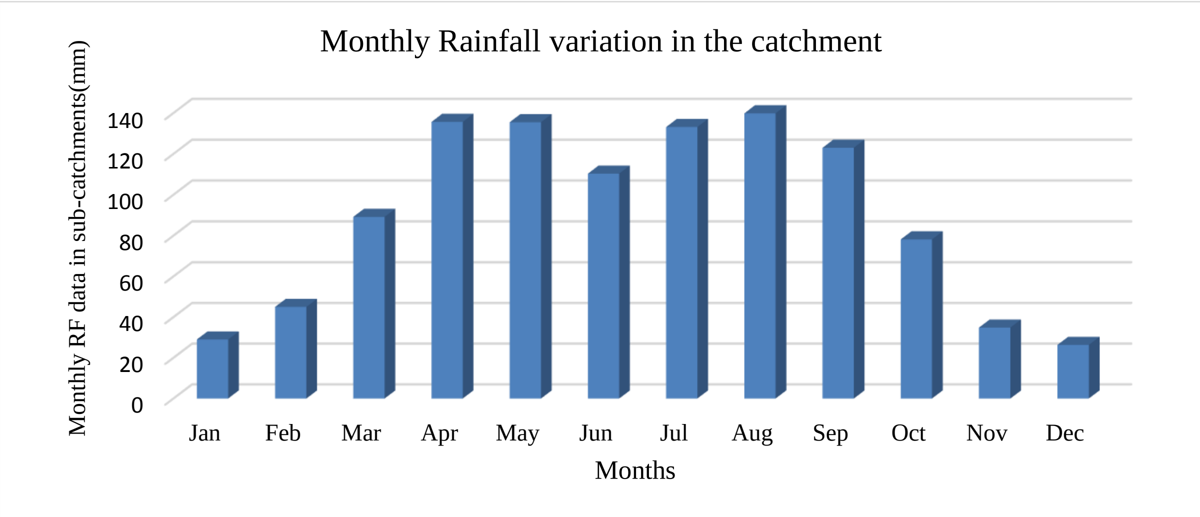


Figure 12: Monthly mean areal rainfall of sub-catch

3.4 Calculation of Water Requirement

The assessment water demand in the study area is mainly, population water demand (i.e. urban and rural), livestock water demand, Irrigation water demand and environmental flow requirement in the catchment. The water demand calculation is done depending upon its guidelines with various consideration.

3.4.1 Water Demands Guidelines

The projections and calculations of water requirement estimation consider multiple water requirements such as; domestic water demand, commercial and institutional water demand, industrial water demand, livestock water demand and water losses in systems. The guidelines are prepared by Ministry of Water and Irrigation for all demand categories and additional climatic factors that affect consumption variation with in specific river basin (Rift Valley Lake basin) under their master plan study based on the practical situation and lifestyle of the basin population. The following are the guidelines:

1. Domestic Water Demand (DWD)

The domestic water demand is the water requirement for domestic household use; the water consumption per capita demand per day. The per capita demand of the basin considered, based on the newly revised water demand standard of the second Growth and Transformation Plan of Ethiopia (GTP-II, which goes from 2015 - 2020). Based on the newly revised water demand standard of GTP-II, it ranges from 40 to 100 lpcd depending on the population size for urban and 25 lpcd for rural up to the year 2020.

As per the GTP-2 water supply service level standard, it is required to provide safe water in minimum 25 l/c/day within a distance of 1 km for rural areas while in urban areas it is required to provide safe water in minimum 100 l/c/day.

According to master plan study, the percapita water demand determined for town/cities with their categories that is given based on population range (See the following table).

Table 5 Percapita water demand for each category of towns/cities

Town/cities	population Estimated	Percapita
Category 1	> 1 Million	80 l/c/day
Category 2	1million - 100,000	60 l/c/day
Category 3	50,000-100,000	50 l/c/day
Category 4	20,000 - 50,000	40 l/c/day
Category 5	<20,000 (rural)	25l/c/day

2. Commercial and Institutional Water Demand (CIWD)

The commercial and Institutional Water Demand is the water requirement in towns which is needed for public schools, clinics, hospitals, offices, shops, bars, restaurants, and hotels. The water demand for commercial and institutional need usually linked directly to the population and taken as 5% of the domestic demand for Bilate catchment.

3. Industrial Water Demand (IWD)

Industrial water demand consumed by industries is not usually linked directly to the population. For planning, it is assumed to use 10% of domestic water demand for all towns in the basin.

4. Livestock Water Demand (LWD)

Livestock water demand estimated based on FAO livestock standard water demand for East-Africa countries mainly Ethiopia is applied 20litres, 5litres and 12 litres per head of cattle, sheep/goat and Equine per day respectively.

5. Average Daily Demand (ADD): **-** The average daily demand is the total of the domestic, commercial, institutional, industrial and livestock demands and the system losses.

6. Maximum Daily Demand (MDD):-The maximum daily demand is daily water consumption in a town that varies depending on the time of day, season and climatic conditions. So that, the Maximum Daily Demand is taken as 1.15 times the Average Daily Demand.

3.4.2 Current Water Demands

The current water demand in the sub-basin for different water users are the domestic water supply, livestock requirement, and agricultural or irrigation demands. The calculation of done at each demand node by using the disaggregated end-use based approach. The demands for domestic, livestock, and agriculture entities estimated based on a disaggregated accounting approach for various measures of social and economic activities. Therefore, the user can fix appropriate activity levels such as persons, heads, and ha of command area by standard water use technique for each disaggregated level and multiplies these by the appropriate annual water use rate for every activity.

As described in the WEAP User Guide, the calculation process is based on a mass water balance for each node, and the link is subject to demand priorities and supply preferences. The estimate begins from the current account year's first month until the last month of the last scenario. For non-storage nodes like points on a river, calculation of the current month is independent of calculation of the previous month. For storage nodes like reservoirs, soil moisture, or aquifer storage, storage for the current month depends on the value of the preceding month. Whatever water enters the system in the course of a month, it will either be deposited in a reservoir, aquifer, or catchment soil, or exit the system through consumption or evapotranspiration from demand site. In the schematics configuration, the identified sites were included in the model as individual demands rather than group demands, but it could reduce the flexibility in modelling how each irrigation site can make demands on the surface water network according to its particular cropping pattern.

WEAP will determine the allocation order to be followed when assigning water demand Using demand priorities and supply preferences the Allocation Algorithm processes demand sites with higher priorities first and the rest in numerical order assigned. These assigned priorities are useful in the representation of a system of water rights and are also important during water shortages (SEI, 2015). Supply Preferences indicate the preferred supply source where there is more than one source at the demand site.

Table 6: Given priority levels for different demand

Demand Type	Priority
Domestic water supply with Industrial water demand and Environmental flow requirement	1
Irrigation and Livestock water demand	2

3.4.3 Future Water Demands

Scenarios to estimate future water demand define an alternative or a set of assumptions based on increasing population, irrigation and future development or policies. Changes in these assumptions could grow water demands. However, scenarios in the WEAP model encompass any factor that can change over time including those factors, which may change due to particular policy interventions, and reflect different socioeconomic assumptions. WEAP model set up

WEAP consists of five main views: Schematic, Data, Results, Overviews and Notes. The schematic view is GIS-based tools for easy arrangement of the system including objects like demand nodes, rivers, reservoirs, catchment, Transmission link, return flow and any others. The data view allows creating variables and relationships, entering assumptions and projections mathematical expressions, and dynamically link to Excel. The result view allows detailed and flexible display of all model outputs, in charts and tables, and on the Schematic. On the other hand, the overview highlights key indicators of the system for quick viewing. Finally, the note view provides a place to document your data and assumptions.

Here are necessary steps to develop WEAP model;

i. Create a geographic representation of the catchment area,
ii. Enter analysed necessary data for the different supply and demand sites,
iii. Compare results with observations and simulated model data,
iv. Define scenarios and
v. Compare and present the results of different scenarios.

The Priority assignment recommendation for each demand is between1 to 99. Level 1 is the highest demand priority for water in the system. This means that WEAP tried to satisfy all the demands at this level before any other level of priority demand. The model uses these priority levels when allocating water for the demand sites. The model delivers water to all the level one priority sites at the same time and, if there is any water remaining in the system, it will then deliver water to the remaining priority levels.

3.4.4 Configuration of WEAP model

In the schematic view of WEAP, the boundary of delineated watershed, rivers, demand sites and catchments are specified. GIS maps of rivers and catchments (watershed), are used to determine the exact location of the streams in WEAP. Importantly, these features act as storage within the model and as local sites of evaporation losses. The Bilate River is schematized in this approach. The total inflows to Bilate river are, Batena, Amesa, MBUS (middle Bilate upstream River), LBUS (lower Bilate upstream), LBDS (lower Bilate downstream) rivers enter as head water.

Demand sites from the surface water in the study area were integrated into twenty-six groups for setting up of the WEAP model. The model considers the return flows from each irrigation and livestock demand sites. However, return flow from domestic water supply was not included since the quantity is insignificant it is preferred to overlook. The figure below shows the schematic configuration of the WEAP model of the study area for the existing condition.

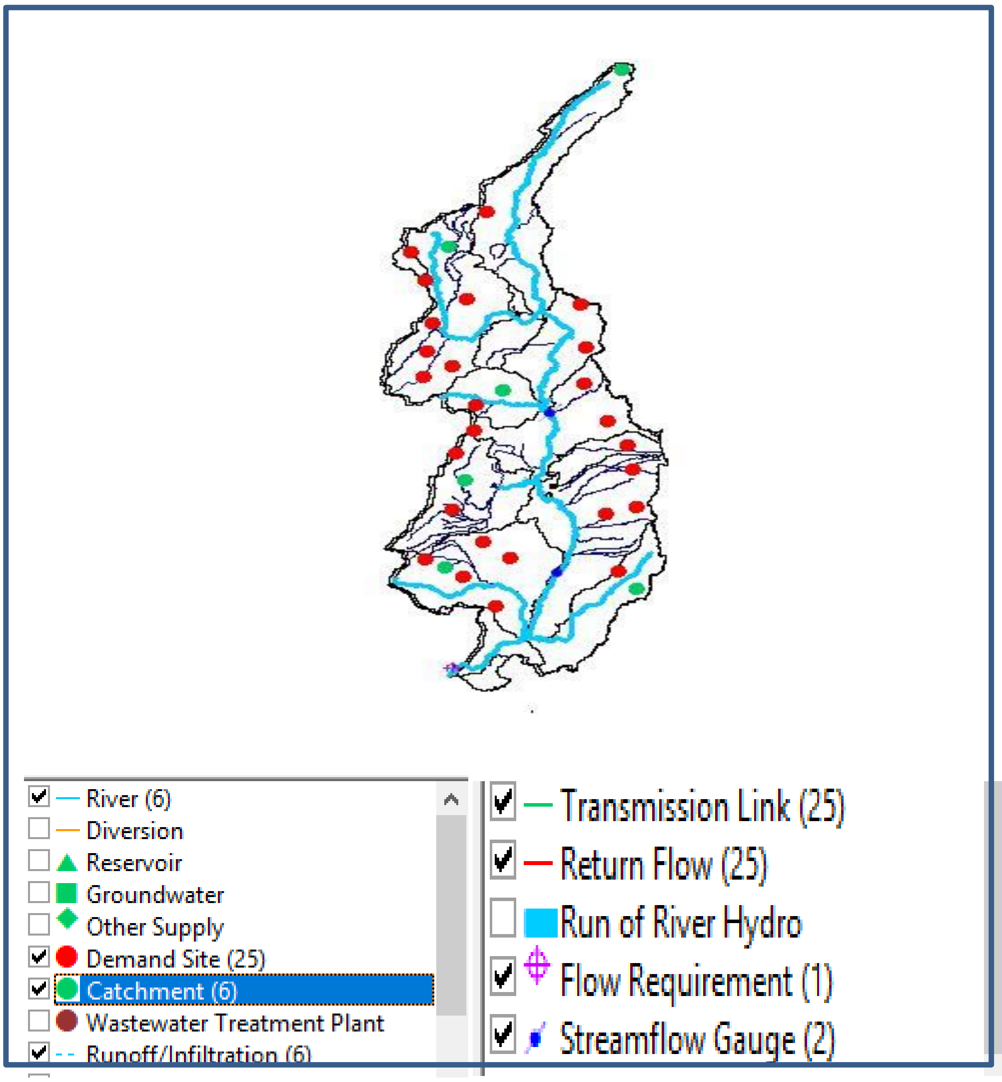


Figure 13: Schematic representation of WEAP model and Demand nodes

3.4.5 Input Data to WEAP Model

Population Data and Population Forecasting

One of the basic inputs in WEAP model is the population data. The population data on 2020 is collected from Central Statistical Agency, and the population growth rate of the basin is found to be 2.56 %. Hence, the population on 2020 is taken and it is the current account year in my model. The populations of the selected sites with their projections are given in table below.

One of the basic inputs in the WEAP model is the population data. The population the number in the catchment on 2020 was around 832,334 and the population growth rate of the basin is found to be 2.56%. The populations of the study area with their projections are given in table below. Using the growth rate of 2.56%, the population is expected to double just after 2035, which is 1,343,368. The total consumptive water requirement was based on the population of the 2020 Towns (district) level.

Table 7: Current and future forecasted population data in Bilate

Year	Current scenario 2020	Population growth scenario2035
Growth rate	2.56 %	3.2%
Total Population	832,334	1,343,368

The population data is forecasted by using geometric increase method because WEAP model by default use this method to project future population size and it was also valid for Bilate.

Annual Water Use Rate

The annual water uses rate is basic input for WEAP model based on the specific guidelines given by Ministry of Water, Irrigation, and Energy, the annual water use rate per person in the basin is calculated below:

The Urban area per capita water demand is determined based on the category of woredas and the rural area per capita water demand is taken to be 25 lpcd (=0.025 m^3/day = 9.125 m^3/year). Therefore, livestock water demand is taken 25 L/hd/ d = 9.125 m^3/year for cattle, 12 L/hd/d for Equines and 5 L/hd /day for Sheep and Goats. Finally, the livestock water use rate for those woredas in the catchment is aggregated into one demand node.

Irrigation Water Requirement

The agriculture demand is estimated based on land use land cover percentage area, Crop coefficients (Kc) value were used which was obtained from FAO paper 56, and agro ecological zones (AEZ) for annual water use rate and irrigation variation. The crop water requirement is calculated using monthly irrigation duty considering irrigation that takes place within 6 hrs. According to the RVLB master plan, there are 8000ha previously identified irrigation schemes but not yet fully implemented for the main crops such as maize, cotton, wheat, potato, and vegetables. As a result, these crops were chosen to estimate the requirement of water for crops proposed irrigation. Since there are no existing large scale irrigation schemes in the basin.

For Irrigation data input, the irrigation duty taken based agro-ecological zone (AEZ) of the irrigation woredas for irrigation annual water use rate that is irrigated per 6 hrs with efficiency of 0.45. The AEZ of irrigation sites in my study area is situated on woyna-dega and dega. Annual irrigation water use for woyna-dega and dega demand sites are taken 2047 and 1470 cubic meter per hectare with consumption rate of 70 %.

Water Requirement for Environmental flow

Since there are no hydropower generation plants existing at present and no data for the proposed dam in the sub-basin, the only water requirement for non-consumptive uses considered as environmental flow requirement. To estimate the availability of water resources, environmental flow requirement should be considered to maintain the ecosystems of the river and to maintain the river flow for downstream users. In this study, 20% of mean annual runoff is considered for environmental flow requirement. Whereas streamflow is required at a point on a river to meet the different ecosystem related water demands for downstream users such as maintaining river water quality, fish, and wildlife and water level of Abaya Lake.

3.4.6 Scenario Definition and Implementation

Scenarios used to compare various “what if” cases and provide a structured method of thinking about possible future water resource development and management options, opportunities and risks, and how these might interact. The results are useful for consensus building and decision-making.

3.4.7 Current Accounts Year

Current accounts year is chosen to serve as a base year of the model where we feed basic data. With WEAP; we first create current accounts of the water system under study. The year 2020 is chosen as current accounts year in study area because the data we have collected was until year 2020. All data entered here are the basic raw data, which actually exist in the base year without any projection. Hence, every data fed to this Current Account year to serve as base year for all processes of the WEAP model.

All data entered here are the basic raw data that actually exist in the base year without any projection. Hence, every data fed to this Current Account year to serve as the base year for all processes of the WEAP model.

3.4.8 Reference Scenario

The reference scenario is developed from the current account to simulate the likely evolution of the system without intervention. This scenario serves as reference to all other scenarios created to show different trends. Hence, every scenario developed to show its own trend on the model result is compared to the reference scenario, as there are interventions in the reference scenario other than projecting the current account year to the future year.

Therefore, the total population within the basin was projected around 832,334 for the year 2020 based on the 2020 data. The current account (the year 2020) was extended to the future (2020-2035). No major changes were imposed in this scenario.

3.4.9 Scenario I: High Population Growth Scenario

These scenarios can address a broad range of "what if" questions, such as; what if population growth pattern and impact of population growth rate on the watershed compared to reference scenario. One of the dominant factors affecting the water supply demand is population growth. The trend of the population growth in the future may not be as expected today. The population growth rate varies erratically from time to time; hence it is important to simulate the water demand considering assumptions on the population growth rate variation in the future based on the historical nature of the of the basin population.

3.4.10 Scenario II: Irrigation Expansion Scenario

The land in Bilate watershed is suitable for irrigation and agriculture and it is rapidly growing in terms of area and yield. According to the masterplan study, the future expected potential irrigation area is to be 40,000 ha on the year 2035. Therefore, different institutions should decide on study on additional irrigation projects, since the current developed irrigation projects are quite small.

This scenario addresses the variation in irrigation water demand due to expansion of irrigated lands. Therefore, the impact of increased irrigation areas on irrigation water demand is shown in this scenario. This will also affect the volume of water required in the downstream side. For this study of this scenario, I used the area of potential irrigable land of each irrigation demand.

3.4.11 Scenario III: Combination Scenario (Population growth & irrigation expansion)

This scenario addresses the impact of both population growth and irrigation expansion on water demand from year 2020-2035. This scenario was modeled to assess the impact of consuming more water than the current water requirements as well as high population growth & irrigation expansion scenarios and it is considered as worst-case scenario.

3.5 Catchment Simulation Methods

There is a choice among five methods to simulate catchment processes such as evapotranspiration, runoff, infiltration and irrigation demands. These methods include (1) the Rainfall Runoff and (2) Irrigation Demands Only versions of the Simplified Coefficient Approach, (3) the Soil Moisture Method, (4) the MABIA Method, and (5) the Plant Growth Model or PGM. The choice of method should depend on the level of complexity desired for representing the catchment processes and data availability.

The Soil Moisture Method was chosen for this work, to simulate the relationship of rainfall runoff in the region of study. In addition, the method allows for the characterization of land use and soil type impact to these processes. This method divided soil into two layers the upper soil layer simulates evapotranspiration, considering rainfall and irrigation on agricultural and non-agricultural land, runoff and shallow interflow (SEI, 2015). Base flow routing to the river and soil moisture changes are simulated in the lower soil layer.

Each watershed unit was representing different land use, and a water balance was computed for each fractional area, j of N. Climate is assumed uniform over each sub-catchment, and the water balance of the sub-catchment was given as,

$$Rd_j \frac{dz_{1,j}}{dt} = p_e(t) - PET(t)K_{c,j}(t)\left(\frac{5z_{1,j} - 2z_{1,j}^{\;2}}{3}\right) - p_e(t)z_{1,j}^{\;RRF_{j1}} - (1-f_j)k_{s,j}z_{1,j}^{\;2} - f_jk_{s,j}z_{1,j}^{\;2}$$

------- *Equation 3-7*

Here z1,j = [1,0] is the relative storage given as a fraction of the total effective storage of the root zone, Rdj (mm) for land cover fraction, j. Pe is the effective precipitation. PET is the Penman Montieth reference crop potential evapotranspiration where kc,j is the crop/plant coefficient for each fractional land cover. The third term (Pe (t) z1,jRRFj) represents surface runoff, where RRFj is the Runoff Resistance Factor of the land cover. The higher values of RRFj lead to less surface runoff. The third and fourth terms are the interflow and deep percolation terms, respectively, where the parameter ks,j is an estimate of the root zone saturated conductivity (mm/time) and fj is a partitioning coefficient related to soil, land cover type, and topography that fractionally partitions water both horizontally and vertically. The total runoff (RT) from each sub-catchment at time t is,

$$RT\ (t) = \sum_{j=1}^{N} A_j (p_e(t) z_{1,j}^{RRF_j} + f_j k_{s,j} z_{1,j}^{2})$$

------------------------- *Equation 3-8*

Base flow emanating from the second bucket is computed as:

$$S_{\max} \frac{dz_2}{dt} = \left(\sum_{j=1}^{N} (1 - f_j) k_{s,j} z_{1,j}^{2} \right) - k_2 z_2^{2}$$

--------------------------------*Equation 3-9*

Where the inflow to this storage, Smax is the deep percolation from the upper storage and Ks2 is the saturated conductivity of the lower storage (mm/time), which was given as a single value for the catchment.

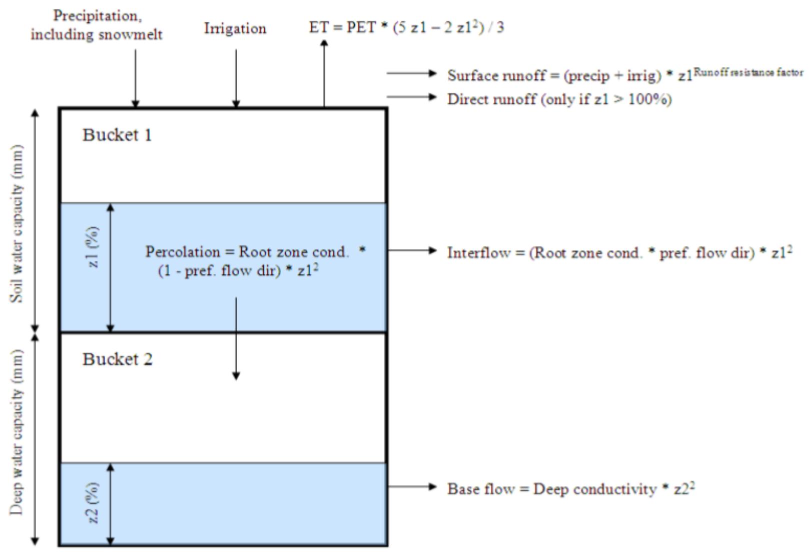


Figure 14: Concept of soil moisture and equations (source: WEAP User Manual).

3.6 Model Calibration

Calibration is a repetitive exercise used to establish the most suitable or sensetive parameter in modelling studies and a means by which model parameters is arranged to make the model input identical with the output . It is very important because reliable values for some parameters can only be found by calibration (Reuben, 2007). It involves the identification of the most important model parameters and changing the parameter set. Model parameters changed during calibration were classified into physical and process parameters. Physical parameters represent physically measurable properties of the watershed; while the process parameters are those not directly measurable. Model calibration can be manual, automatic and a combination of the two methods (Tigist, 2009). Manual calibration uses trial and error techniques in parameter adjustment through a number of simulation runs. It is subjective to the modeler's assessment and can be time consuming. Computer based automatic calibration involves the use of a numerical algorithm which finds the extreme of a given numerical objective function. Model performance is assessed statistically by comparing the model output and observed flow values. The statistical measures commonly used are the coefficient of determination (R2), Nash-Sutcliffe Efficiency (NSE) and the Root Mean Square Error (RMSE) (Tigist, 2009).

3.7 Model validation

Model Validation is the process of representing that a given site-specific model is capable of making accurate predictions. This was done by applying the calibrated model using a different data set out of the range of calibration without changing the parameter values. The model is said to be validated if its accuracy and predictive capability in the validation period have been proven to lie within acceptable limits (Reuben, 2007). Observed and simulated hydrograph values were again compared as in the previous calibration procedure. If the resultant fit is acceptable then the model's prediction as valid.

3.8 Model Performance Evaluation

The model performance was evaluated using three well-known statistical criteria, the determination coefficient (R^2), the Nash-Sutcliffe efficiency (ENS) and percent of bias (PBIAS) (Singh, 2014). The regression coefficient (R^2) is the percentage of variance in the measured data that is explained by the simulated data. If the (R^2) value is equal to zero, there is no incentive to use two regression parameters to summarize the data. The closer the value of R^2 to 1, the higher is the agreement between the simulated and the measured flow.

The R^2 value is calculated as:

$$R^2 = \frac{\left[\sum_{i=1}^{n}(YSi-YS)(Yos-Yo)\right]^2}{\sum_{i=1}^{n}(Ysi-Ys)-\sum_{i=1}^{n}(Yoi-Yo)^2}$$

... ---------------------- *Equation 3-10*

The Nash-Sutcliffe simulation efficiency (ENS) shows that how well the plot of observed values versus simulated value the 1:1 line fits.

It can be calculated as follows:

$$ENs = 1 - \frac{\sum_{i=1}^{n}(Y_{oi} - Y_{si})^2}{\sum_{i=1}^{n}(Y_{oi} - Y_o)^2}.$$
-----------------------*Equation 3-11*

Where: - Ysi is the simulated values of the quantity in each model time

Yoi is the measured value of the quantity in each model time

Ys is the average simulated value of the quantity in each model time

Yo is the average measured value of the quantity in each model time

Percent bias is the measure of the mean values of the simulated flow to be greater than or smaller than their streamflow 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:

$$P_{BIAS} = \left(\frac{\sum Xi - \sum Yi}{\sum Xi}\right) * 100\%.$$
----------------------------*Equation 3-12*

There is an intimate relationship between calibration and uncertainty and reporting uncertainty is not a luxury in modeling, it is necessity. Without uncertainty calibration is meaningless and misleading (Stockholm Environment Institute (SEI), SEI, 2008).

4 RESULTS AND DISCUSSIONS

4.1 Results of WEAP Model

Before starting with the actual calibration and validation procedure it should be necessary an understanding of the influence potential of calibration and validation parameters on model performance. Therefore, the parameters were adjusted in variable possible ranges to overlap the mean monthly observed stream flow with the model simulated data and the model response was evaluated. Table 8 shows a possible parameter range of calibration of the catchment.

Table 8: Methods of Calibration parameters in allowable ranges

Calibration parameters	**Range**	**Unit**
Soil water capacity	> 0	mm
Deep water capacity	>0	mm
Runoff Resistance Factor	0 – 1000	----
Root zone Conductivity	20	mm/Month
Deep Conductivity	20	mm/Month
Preferred flow direction	0 – 1	----
Initial Z1	0-100	%
Initial Z2	0-100	%

Table 9 Calibration parameter values used in upstream and downstream catchments

	Runoff resistance factor for each catchment LULC			**Soil water capacity for each catchment LULC**		
	Batena	**LBUS**	**MBUS**	**Batena**	**MBUS**	**LBUS**
Jan	2.79	8	2.8	1000	1500	3500
Feb	4.19	10	4.31	1000	1000	1000
Mar	3.7	7	3.69	1000	1600	1000
Apr	3.45	7.3	3.5	1000	1000	1000
May	3.9	6.5	3.9	1000	1000	3500
Jun	3.43	4.87	3.43	1300	1300	1000
Jul	2.6	3.5	2.6	1000	1000	1000
Aug	2.31	2.7	2.31	1000	1000	800
Sep	1.59	10	1.6	1000	1000	4800
Oct	1.48	2.45	1.48	1000	1000	1000
Nov	0.7809	4.5	0.78	1000	1000	1000
Dec	1.8	10	1.79	1000	1000	3500

4.2 The output of calibration and validation

In this section, comparison between the observed steam flow and the simulated model output takes place with respect to the statistical performance parameter of correlation coefficient (R^2), and Nash-Sutcliffe Coefficient (NSE). The model considered various input data’s to the catchment (i.e Kc value, LULC, rainfall, temperature …etc) and the result must be related (matched) with the observed steam flow data. The calibration and validation of stream flow data’s were done at different gauge stations with different period of time and data range. Generally, the outcome shows the model is capable of indicating the hydrological process of the catchment based on the recorded data. The following two Figures 4-1 and 4-2 show the calibration and validation results.

4.2.1 Calibration Result

Calibration is the iterative process of adjusting the most sensitive parameters of the watershed to the model that consider the catchments reality while simulating the result. It is the necessary step confirm that the WEAP model is exactly representing the situation of the study area. The WEAP Model calibration was performed using observed stream flow of two gauging station located at upstream and downstream of Bilate catchment. In WEAP model calibration process, the performances of downstream gauge is affected by (depends on) the performance of upstream gauge. Thus, the head flow gauge or the upstream one should be calibrated first, to have a stable upper boundary condition for the downstream gauges. The WEAP model calibration and validation done before scenario development.

The monthly model-simulated and observed stream flows for the calibration of 13 years (from 1987-1999) shown in figures 15 the upstream stream flow gauging station Alaba kulito and in figure 16 downstream gauging station Bilate tena depending on continuous data availability without missing values. Calibration was performed by comparing observed stream flows and a simulated result of the model in the watershed.

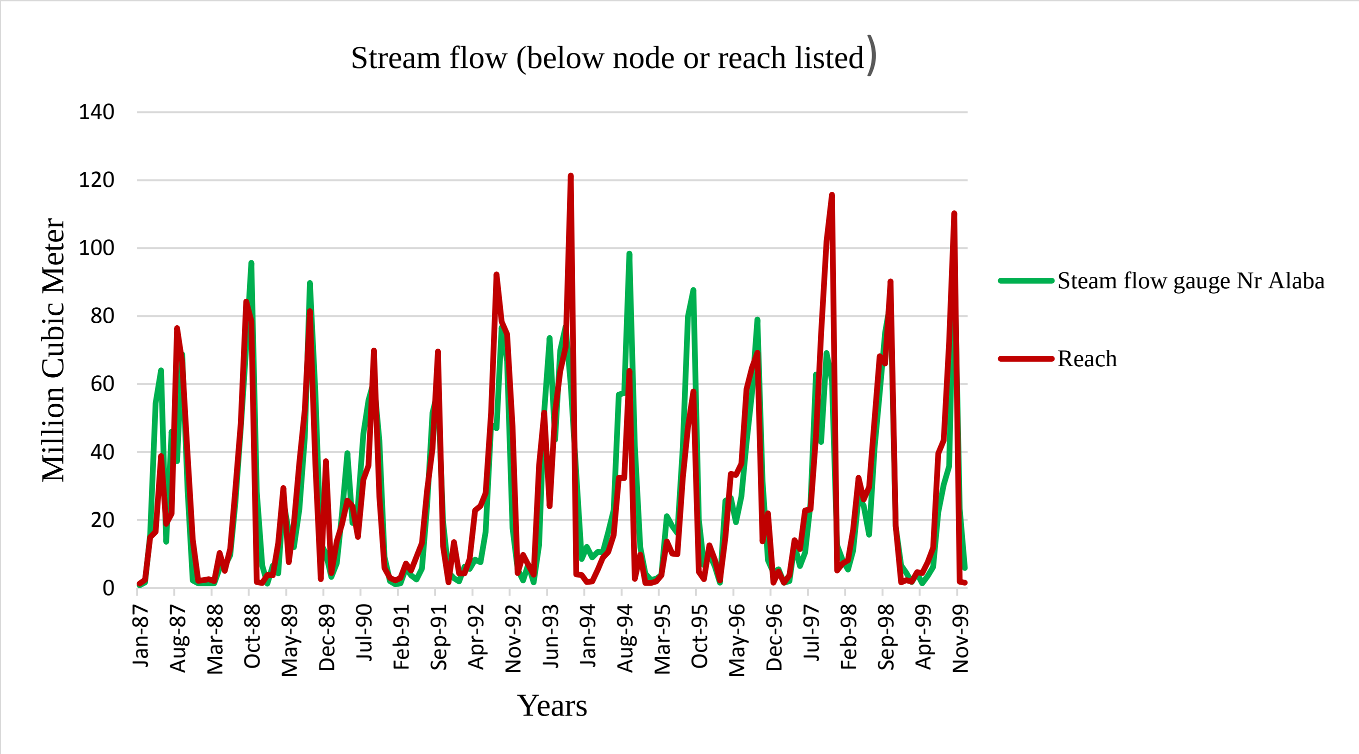


Figure 15: Calibration result of Alaba Kulito Gauge station

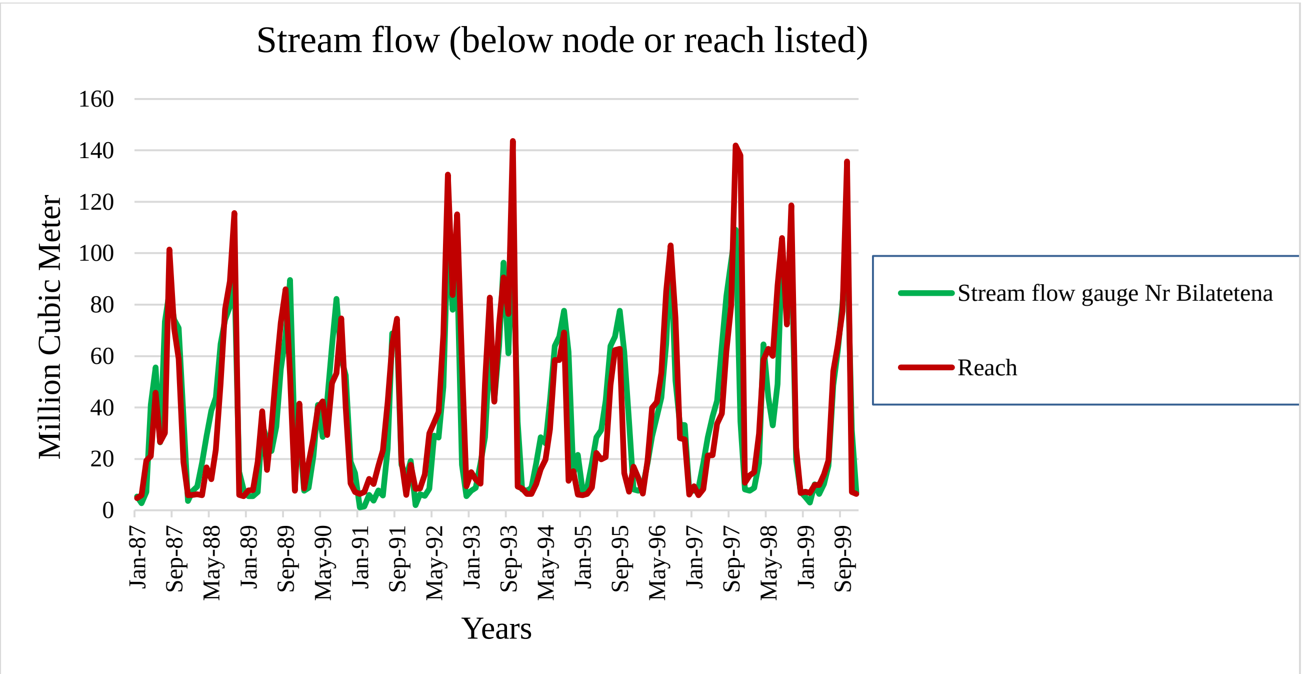


Figure 16: Calibration result of Bilate Tena Gauge station

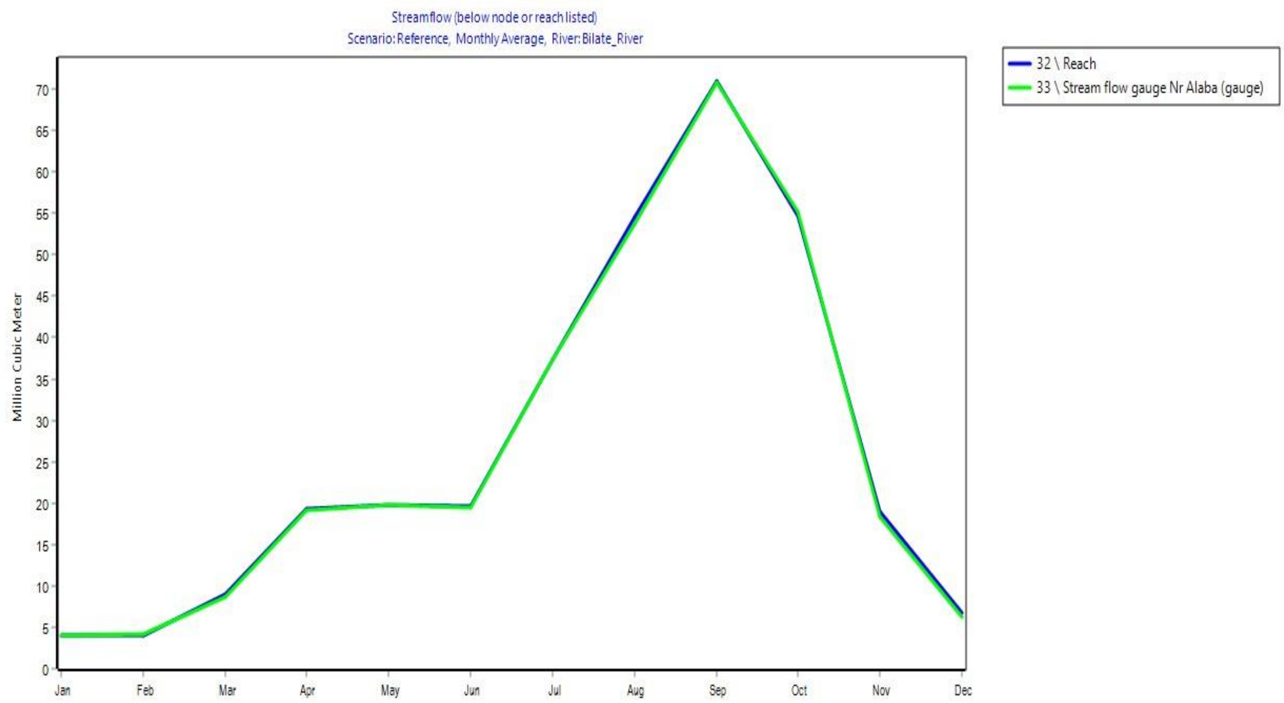


Figure 17: Monthly Mean Calibration Result of Alaba Kulito gauging station

Figure 18: Monthly Mean Calibration Result of Bilate Tena gauging station

Table 10: Summaries of statistical performance between modelled and gauged stream flow

No.	Gauge Location River	Gauge Station Name	Calibration Period	NSE	R^2
1	Bilate River	Alaba kulito Gauge	1987-1999	0.636	0.83
2	Bilate river	Bilate TenaGauge	1987-1999	0.742	0.89

The above table shows, the statistical performance of the correlation coefficient (R^2), and Nash-Sutcliffe Coefficient (NSE) comparison between modelled and observed streamflow values for the calibration period. These two statistical performance estimators are used to measure the calibration between the model outputs and the observed flows. Therefore, correlation coefficient (R^2) result shows a very good fit at Alaba Kulito station and at Bilate tena station while Nash- Sutcliffe Coefficient (NSE) result shows a good fit at both gauging station of simulated and observed stream flows.

4.2.2 Validation Result

For validation process, the hydrological model should run without consideration of calibrated time range, which is 1/3 of the whole years; this more represent the catchments characteristic than calibration to make sure the output results are valuable. The results of the model validation were presented in Figures 19. For both stations, simulated monthly flows were closed to the naturalized or observed flows. On the other hand the relationship between these flow data indicates a good correlation for the selected stations. Now the model statistically validated result shows good performance in reproducing all its outputs needed for analyzing the scenarios result.

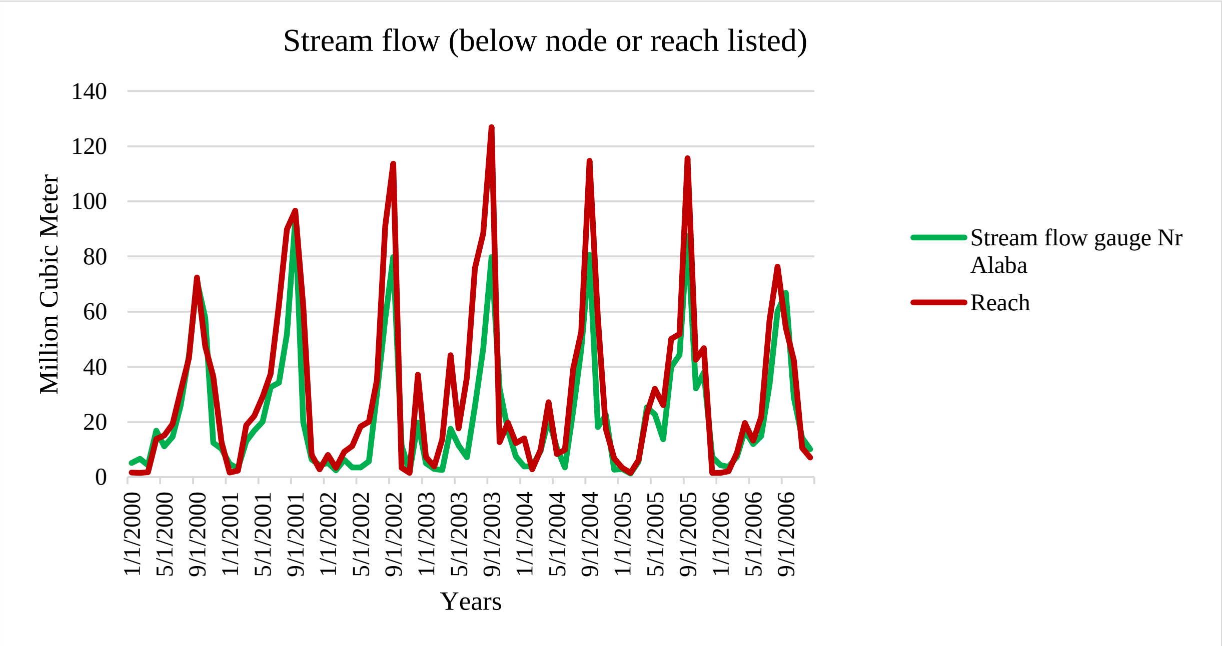


Figure 19: Validation result of Alaba kulito Gauging Station

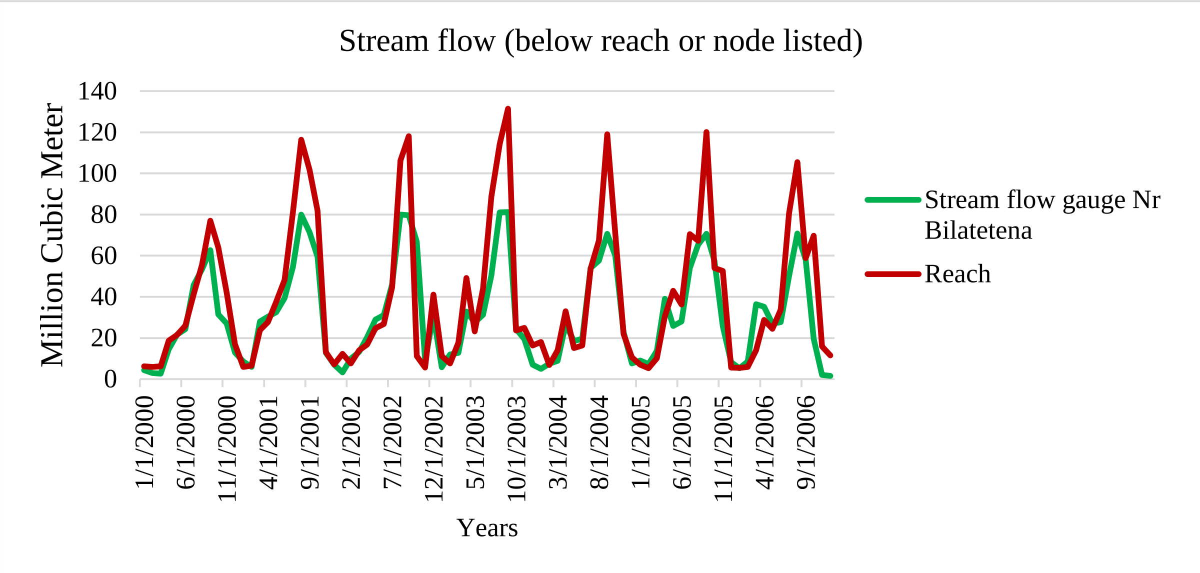


Figure 20: Validation result of Bilate Tena Gauging Station

Table 11: Summaries of statistical performance between modelled and gauged stream flow

No.	Gauge Location River	Gauge Station Name	Validation Period	NSE	R^2
1	Bilate River	Alaba kulito Gauge	2000-2006	0.719	0.91
2	Bilate river	Bilate TenaGauge	2000-2006	0.709	0.90

The above table shows the statistical summary of the comparison between modeled and observed streamflow values for the validation period and again the correlation coefficient (R^2), and Nash Sutcliffe Coefficient (NSE) were used to measure the variation between the model outputs and the observed flows. The statistical summary for the validation period, the Nash-Sutcliffe Coefficient (NSE) is 0.72 and 0.71 indicating a good agreement between modelled and observed flows. On the other hand, the correlation coefficient is 0.91 and 0.90 for the Validation period this shows there is a very good agreement result between the modelled and observed station flow data.

4.3 Water Demand for Current and Future scenarios

In this section, the water demand for three sectors of the study area in different periods found in the catchment presented. These three sectors are domestic, livestock and irrigation water demands. The water supply demand used in common nodes on WEAP model are domestic, industrial, commercial and institutional water demand while the domestic water demand includes urban + Rural water demand. The water demand for livestock taken 20 l/hd/day for cattle, 5 l/hd/day for Sheep/ Goats and 12 l/hd/day for Equine based on FAO d. It is also applied in RVLB master plan. The domestic and livestock water demand of all town's in Bilate catchment is taken from current (2020) and future term years 2035. Population projection was based on the data from CSA last projection report of 20 and using WEAP expression build the model project the population growth of each year up to 2035.

Table 12: Livestock water demand (Source: International Livestock Research Institute, Ethiopia, and FAO)

Livestock	Total number of animals (hd)	Per capita water demand
Cattles	981876	25 l/hd/day
Sheep+Goats	508746	5 l/hd/day
Equines	156736	12 l/hd/day

Table 13: Domestic and Livestock water requirement in current and future scenarios

Period	Total population (Million)	Water Demand (Mm^3/yr)
Current (2020)	0.83	47
Population growth Scenario (2035)	1.34	121

According to irrigation inventory research on Rift Valley Lake Basin, the recent irrigation coverage is about 8000 ha while the potential irrigation expansion area is ha and 13500 ha for Irrigation expansion scenario respectively.

Table 14: Irrigation Water Requirements at different in current and future scenarios

Period	Irrigation Area (ha)	Water Demand (Mm^3/year)
Current (2020)	8000	15.5
Irrigation expansion Scenario (2035)	13500	27

4.4 WEAP Model Scenario Results

4.4.1 Reference Scenario

On reference Scenario, all demand site annual and monthly water requirement was fully covered. There is no unmet demand.

4.4.1.1 Domestic and Livestock Water demand

The Current Accounts represent the starting or base year of all scenarios. Hence, it is important to look at the nature of the demand in the current account year, as it is the base for all scenarios and future demands. The annual water demands for the domestic including industrial and commercial demand sites for the current account year 2020 is 47 MCM. And also the Following figure and table shows the water demand in reference scenario.

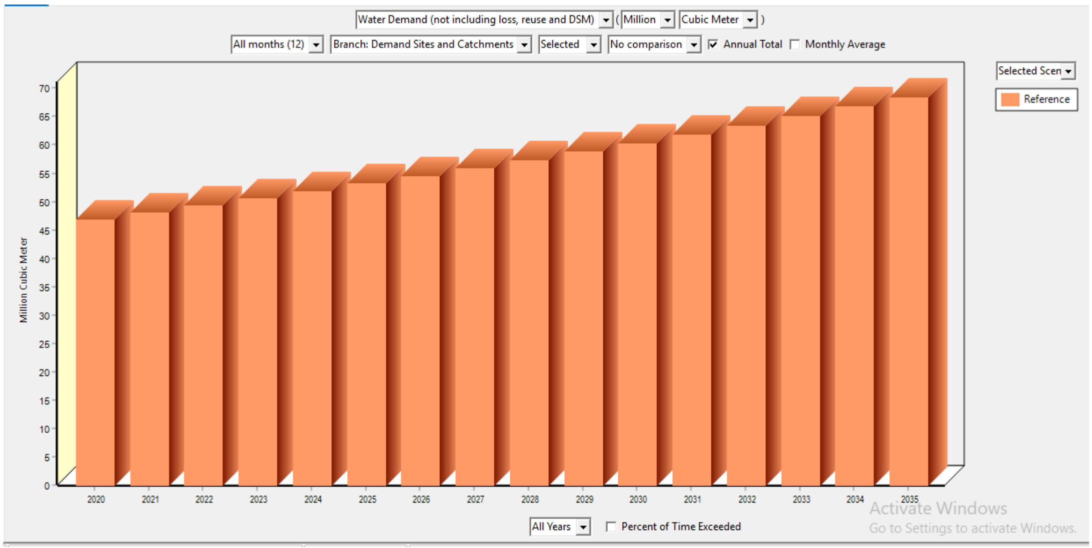


Figure 21: water demand for domestic

Table 15 : water demand on reference scenario

Year	Domestic + industrial water demand (MCM)	Livestock water demand (MCM)
2020	47	25
2021	48	26
2022	49	26
2023	51	27
2024	52	27
2025	53	28
2026	54	28
2027	56	29
2028	57	30
2029	59	30
2030	60	31
2031	62	31
2032	63	32
2033	65	33
2034	67	33
2035	68	34

4.4.1.2 Supply delivered

The total net amount of water required to meet the domestic and livestock water demand sites in current account is 2020 is 47 MCM and 25.25 MCM respectively.

Table 16: Supply delivered domestic & industrial water requirement in current account

Towns	**Supply Delivered (MCM)**
Alaba_WS	4
Angacha_ws	4
Badawocho_WS	5
Dale_WS	9
DamotG_WS	5
Humbo_WS	4
Kacha B_WS	3
Kedida G_WS	7
Shebedino_ws	6
Sum	47

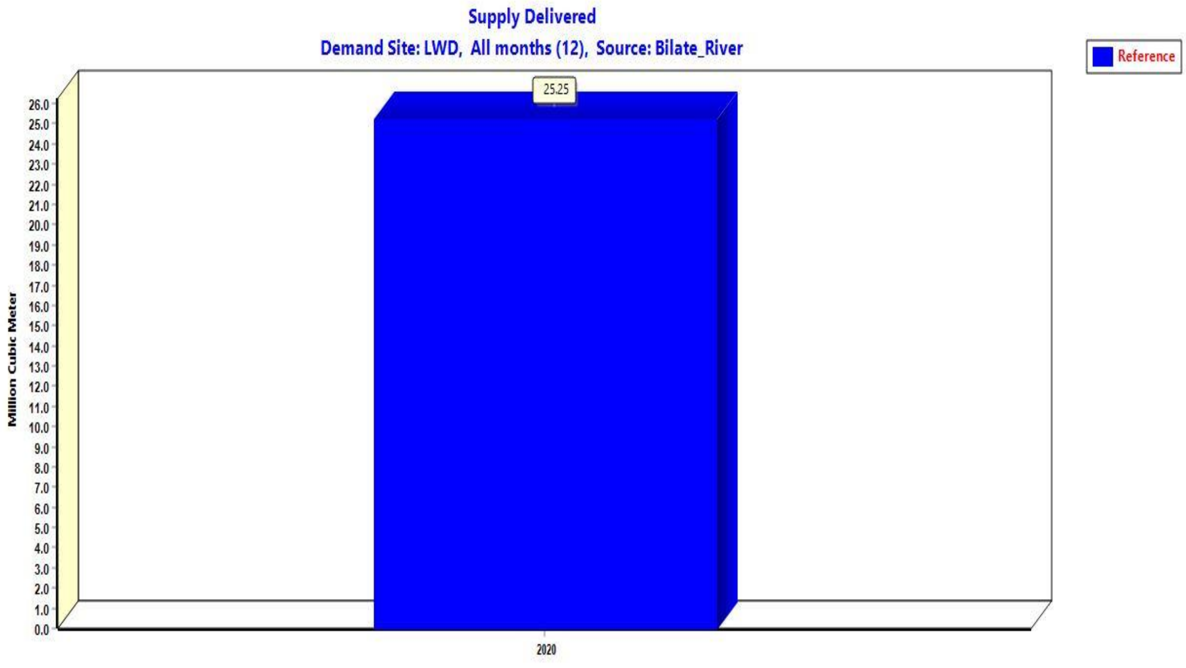


Figure 22:Supply delivered for Livestock

4.4.1.4 Irrigation water demand

The model result gives the monthly average water demand and annual summation demand for downstream Irrigation Scheme. The total net amount of water required to meet the irrigation demands of all the sites from 1987 to 2020 was 15.5 MCM. Jan, Feb, Mar, Apr, Nov and Dec months relatively with minimum demand requirements while May to Sep show the minimum demand requirements than other months because of rain season. The table below shows average monthly irrigation water requirement in thousand cubic meters.

Table 17: Monthly average irrigation water demand for each site in current scenario (Thousand m^3) (1987-2020*)*

Water Demand (not including loss, reuse and DSM) (Thousands cubic Meter) Selected Demand sites (15/78), Scenario: Reference, All months (12), Monthly Average														
	Area (ha)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Sum**
Alaba_Irr	193	60	60	49	31	20	28	9	17	17	40	31	35	395
Angacha_Irr	420	144	164	138	67	0	0	0	0	0	0	12	94	618
D_Fango_Irr	2957	924	914	748	468	308	426	132	264	256	616	468	528	6053
Dale_Irr	120	38	37	30	19	13	17	5	11	10	25	19	21	246
Damot_G_Irr	70	22	22	18	11	7	10	3	6	6	15	11	13	143
Damot_w_Irr	128	40	40	32	20	13	18	6	11	11	27	20	23	262
Humbo_Irr	2618	818	809	662	415	273	377	117	234	226	546	415	468	5359
Kacha_b_Irr	282	97	110	92	45	0	0	0	0	0	0	8	63	415
Kedida_Irr	154	48	48	39	24	16	22	7	14	13	32	24	28	315
Lemu_Irr	89	20	20	16	10	7	9	3	6	6	13	10	11	131
Sankura_Irr	365	114	113	92	58	38	53	33	32	76	64	58	65	624
Shebedin_Irr	151	47	47	38	24	16	22	7	14	13	32	24	27	309
Siraro_Irn	17	5	5	4	3	2	2	1	2	2	4	3	3	35
Sodo_zurya	45	15	18	15	7	0	0	0	0	0	0	1	10	66
Soro_Irrn	367	63	62	51	32	21	29	9	18	17	42	32	36	409
Sum	**7976**													**15503**

From 1987 to 2020 of current account year, monthly irrigation water demand for each irrigation woredas at the downstream Bilate river shown on Figure 4-4 below.

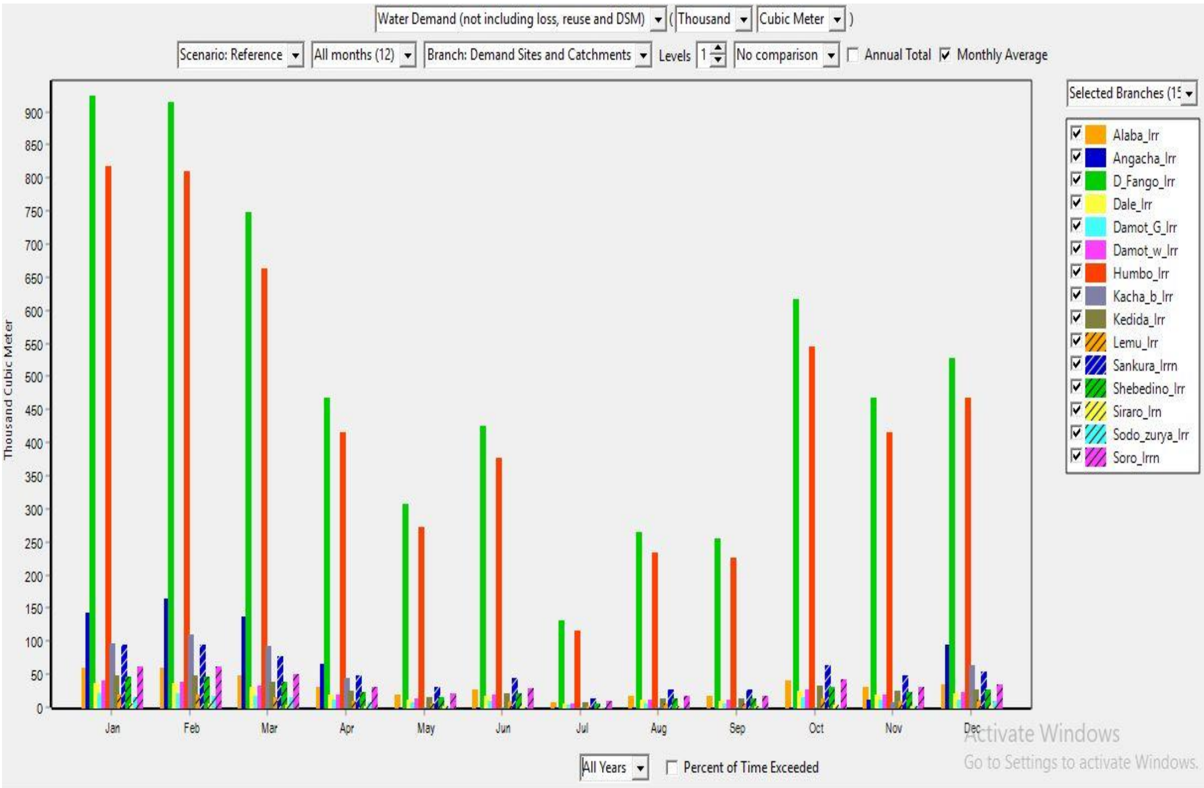


Figure 23: Monthly average Current irrigation water demands (without including losses)

4.4.1.5 Supply delivered

The total net amount of water delivered to the irrigation site to meet the irrigation water demands of all the sites from 1989 to 2020 with the efficiency of 0.45 was 15.5 MCM. Similarly, Jan, Feb, Mar, Apr, Nov and Dec months relatively with maximum demand requirements while May to Sep show the minimum demand .The difference between the amount of water demand and the amount of water delivered shows no unmet demand. The table below shows the monthly delivered water demand that meets irrigation water requirement.

Table 18: Monthly average supplies delivered for Irrigation demand site in current scenario

Supply Delivered (MCM)													
Irrigation Demand Sites (15/32), All months (12), Monthly Average													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Sum**
Reference scenario	2.46	2.47	2025	1.23	0.73	1.01	0.31	0.63	0.61	1.47	1.14	1.42	15.5

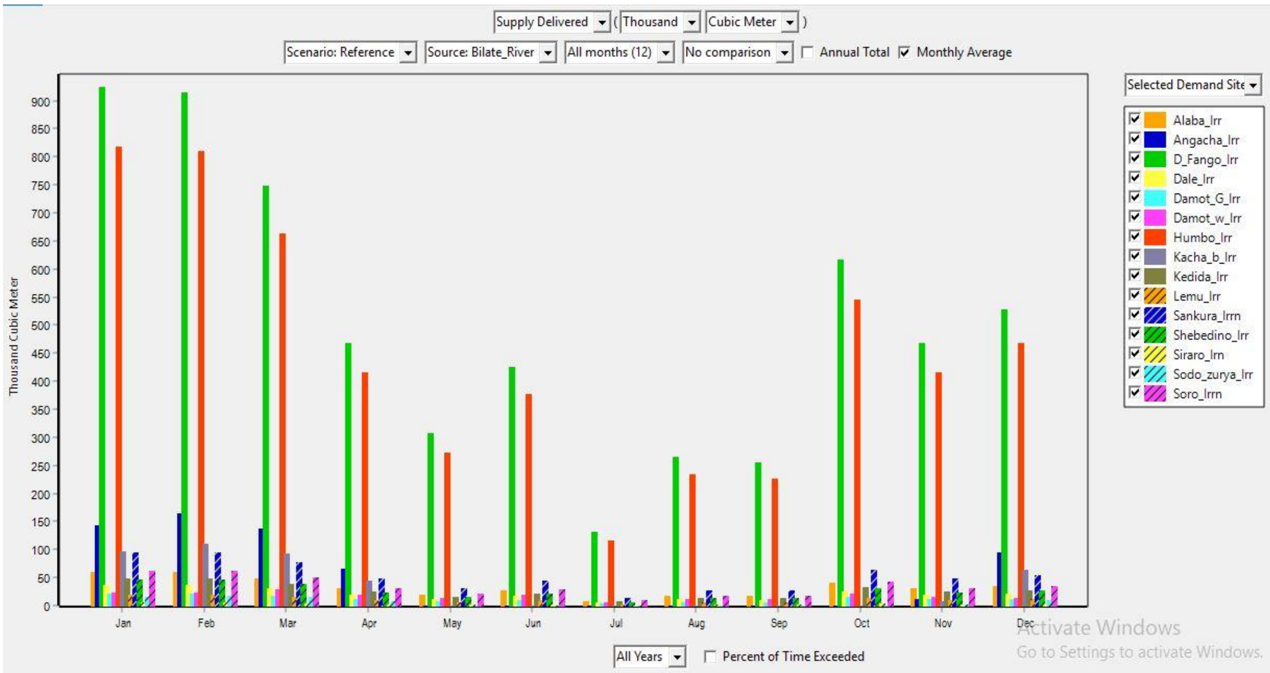


Figure 24: Monthly Supply delivered for all irrigation demand site

4.4.1.6 Unmet water demand

Unmet demand is the supply requirement that is not met. In other words unmet demand is the differences between supplies require and supply delivered at particular demand site and in the time duration. In this analysis of the reference scenario, monthly as well as annual unmet demand for all irrigation site is zero.

Table 19: Mean monthly unmet demands for each demand site (Thousand m^3) on current scenario.

Unmet Demand (Thousand cubic Meter) Selected Demand Sites (15/32), Scenario: Reference, All months (12), Monthly Average													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
Reference	0	0	0	0	0	0	0	0	0	0	0	0	0

4.4.2 Scenario I Population growth scenario (2020-2035)

This scenario determine the estimation of "what will happen if the population growth rate is set to a higher growth rate than the reference scenario population growth rate?" In this case, the population growth rate was raised to 3.2% from 2.56% to simulate the water demand in the future.

4.4.2.1 Water Demand

The net water demand for each sector was incorporated within the WEAP model and shows the expected water quantity for the year 2020 - 2035. As expected from the result, the increase in population growth of the domestic water demand projected in the year 2035, the total annual water demand increased to 121 MCM. The livestock water demand also increases to 39 MCM with livestock growth rate of 3%, which was 2.4% on reference scenario. The figure below, illustrates the water requirement in reference & high population growth.

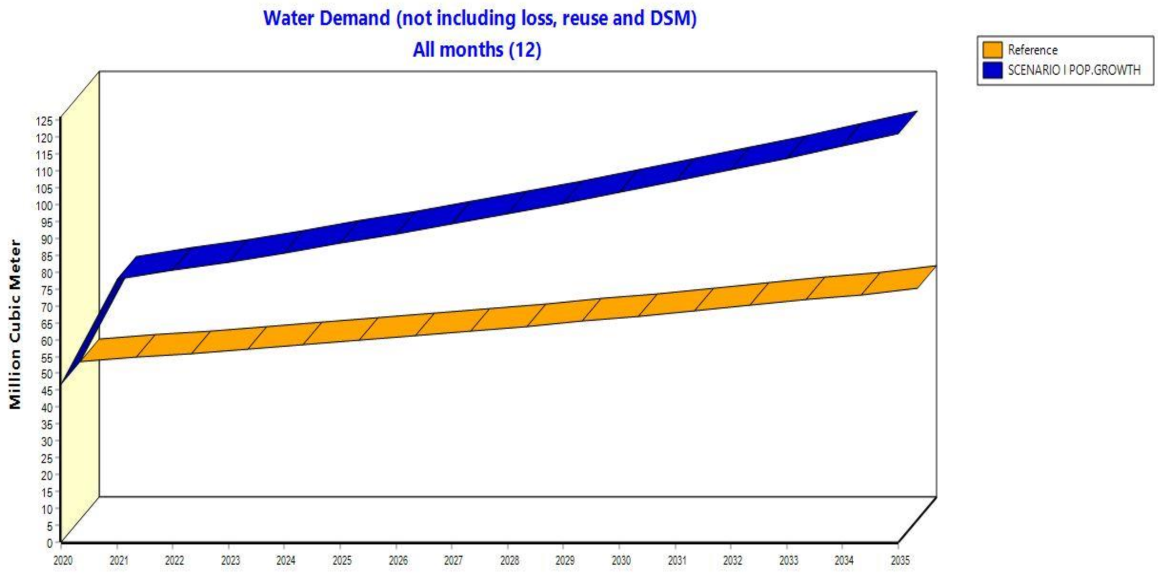


Figure 25: Domestic water demand with respect to reference scenario

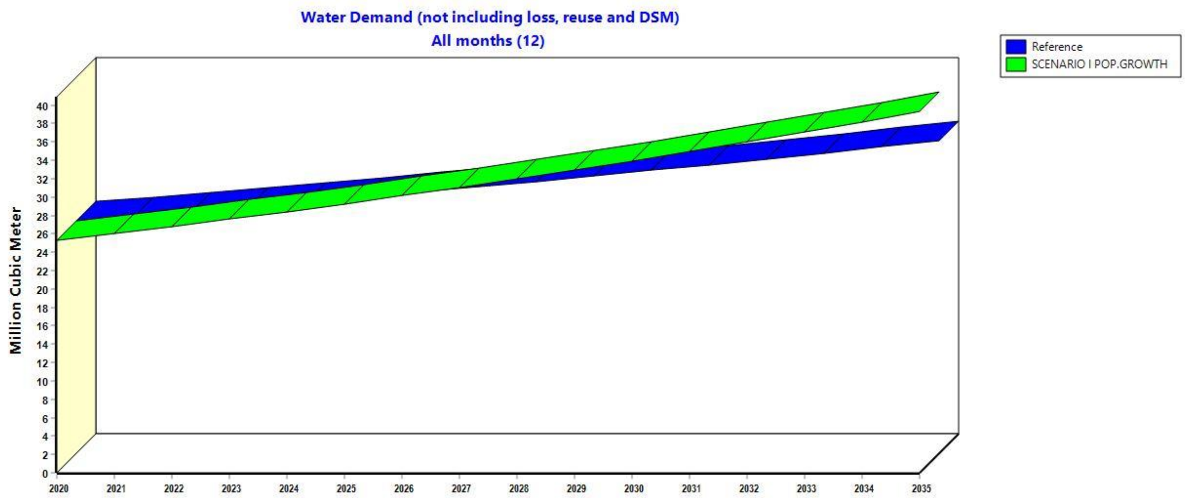


Figure 26: Livestock water demand with respect to reference scenario

4.4.2.2 Supply Delivered

The supply delivered to meet the domestic and livestock water requirement which is 117 MCM and 39 MCM on these scenario of 2020- 2035. As a result, in population growth scenario the unmet water demand for domestic and industrial is 4 MCM and Livestock demand site 7 MCM which is 3.3% and 17.9% of their total water requirement.

Table 20: Supply delivered for domestic and livestock

`Year	Supply delivered for livestock	Supply delivered for domestic
2020	25	47
2021	26	77
2022	27	80
2023	28	83
2024	28	86
2025	29	88
2026	30	91
2027	31	94
2028	32	97
2029	33	100
2030	34	104
2031	35	107
2032	36	110
2033	37	114
2034	38	117
2035	33	117

4.4.3 Scenario II Irrigation Expansion scenario

This scenario describes the possible future irrigation situation in Bilate catchment have been defined. The starting point for the scenarios is an assumption that in line with the new Water Resources Management Strategy, the overriding policy is to prioritize the development of irrigation areas to their full potential. The monthly of water requirement for all irrigation demand is 26.37 MCM with 25.92 MCM of supply delivered for all irrigation demand sites in the current scenarios. The scenario shows the utilization of the full irrigation potential of all demand sites on Bilate river.

4.4.3.1 Water demand

The annual total irrigation water demand in this scenario increases to 26.37 MCM because of increased irrigable area. As a result, the irrigation water demand is much lower than the domestic and livestock water demand because, the domestic water demand includes urban and rural water demand with a consideration of industrial water demand and irrigation water demand only contain the agricultural water demand and the irrigable area in the study area is 8000 ha ,which is not large.

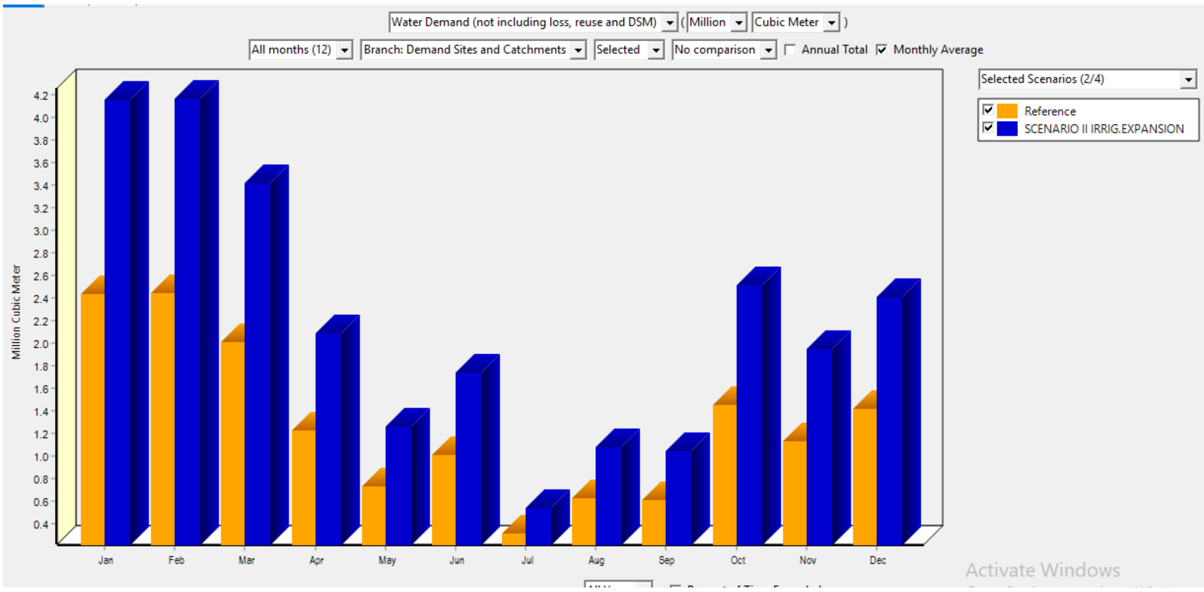


Figure 27: water demand of irrigation expansion scenario with respect to reference scenario

Table 21: Mean monthly irrigation water demand (Thousand cumecs)

Water Demand (not including loss, reuse and DSM) (MCM)													
Levels, Selected Branches (15/78), Scenario: SCENARIO II IRRIG.EXPANSION All months (12), Monthly Average													
Demand sites	**Area (ha)**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Sum**
Alaba_Irr	193	0.08	0.08	0.06	0.04	0.03	0.04	0.01	0.02	0.02	0.05	0.04	0.04	0.50
Angacha_Irr	420	0.23	0.27	0.22	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.15	1.00
D_Fango_Irr	2957	1.86	1.84	1.51	0.94	0.62	0.86	0.27	0.53	0.51	1.24	0.94	1.06	12.18
Dale_Irr	120	0.08	0.07	0.06	0.04	0.03	0.03	0.01	0.02	0.02	0.05	0.04	0.04	0.50
Damot_G_Irr	70	0.04	0.04	0.03	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.24
Damot_w_Irr	128	0.08	0.08	0.06	0.04	0.03	0.04	0.01	0.02	0.02	0.05	0.04	0.05	0.52
Humbo_Irr	2618	1.13	1.12	0.92	0.57	0.38	0.52	0.16	0.32	0.31	0.75	0.57	0.65	7.41
Kacha_b_Irr	282	0.12	0.13	0.11	0.05	0.00	0.00	0.00	0.00	0.0	0.0	0.01	0.08	0.49
Kedida_Irr	154	0.09	0.09	0.07	0.05	0.03	0.04	0.01	0.03	0.03	0.06	0.05	0.05	0.60
Lemu_Irr	89	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.15
Sankura_Irrn	365	0.24	0.23	0.19	0.12	0.08	0.11	0.03	0.07	0.07	0.16	0.12	0.13	1.55
Shebedino_Irr	151	0.09	0.09	0.07	0.05	0.03	0.04	0.01	0.03	0.03	0.06	0.05	0.05	0.60
Siraro_Irn	17	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
Sodo_zurya_Irr	45	0.03	0.04	0.03	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.14

Demand sites	**Area (ha)**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Sum**
Soro_Irrn	367	0.07	0.07	0.06	0.04	0.02	0.03	0.01	0.02	0.02	0.05	0.04	0.04	0.46
Sum	7976	4.16	4.17	3.42	2.09	1.26	1.74	0.54	1.08	1.04	2.52	1.95	2.41	**26.37**

4.4.3.2 Supply Delivered

The mean monthly supply delivered to meet all irrigation water requirement from in 2035 increased to 25.98 MCM while the total annual water delivered from 2020-2035 is 128 MCM. The table & figures below shows the mean annual water delivered in Thousands of meter cubes and its difference with respect to reference scenario.

Table 22: Mean monthly Supply delivered in **(MCM),**

Supply Delivered (MCM),													
Levels, Selected Branches (15/78), Scenario: SCENARIO II IRRIG.EXPANSION All months (12), Monthly Average													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Sum**
Alaba_Irr	0.08	0.08	0.06	0.04	0.03	0.04	0.01	0.02	0.02	0.05	0.04	0.04	0.50
Angacha_Irr	0.23	0.27	0.22	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.15	1.00
D_Fango_Irr	1.86	1.84	1.51	0.94	0.62	0.86	0.27	0.53	0.51	1.24	0.94	1.06	12.1
Dale_Irr	0.08	0.07	0.06	0.04	0.03	0.03	0.01	0.02	0.02	0.05	0.04	0.04	0.50
Damot_G_Irr	0.04	0.04	0.03	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.24
Damot_w_Irr	0.04	0.05	0.06	0.04	0.03	0.04	0.01	0.02	0.02	0.04	0.03	0.03	0.41
Humbo_Irr	1.13	1.12	0.92	0.57	0.38	0.52	0.16	0.32	0.31	0.75	0.57	0.65	7.41
Kacha_b_Irr	0.12	0.13	0.11	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.08	0.49
Lemu_Irr	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.15
Sankura_Irrn	0.24	0.23	0.19	0.12	0.08	0.11	0.03	0.07	0.07	0.16	0.12	0.13	1.53
Shebedino_Irr	0.09	0.09	0.07	0.05	0.03	0.04	0.01	0.03	0.03	0.06	0.05	0.05	0.60
Siraro_Irn	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
Sodo_zurya_Irr	0.03	0.04	0.03	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.14
Soro_Irrn	0.07	0.07	0.06	0.04	0.02	0.03	0.01	0.02	0.02	0.05	0.04	0.04	0.46
Kedida_Irr	0.09	0.09	0.07	0.05	0.03	0.04	0.01	0.03	0.03	0.06	0.05	0.05	0.60
Sum	4.16	4.14	3.41	2.09	1.26	1.74	0.54	1.08	1.04	2.51	1.94	2.39	**25.98**

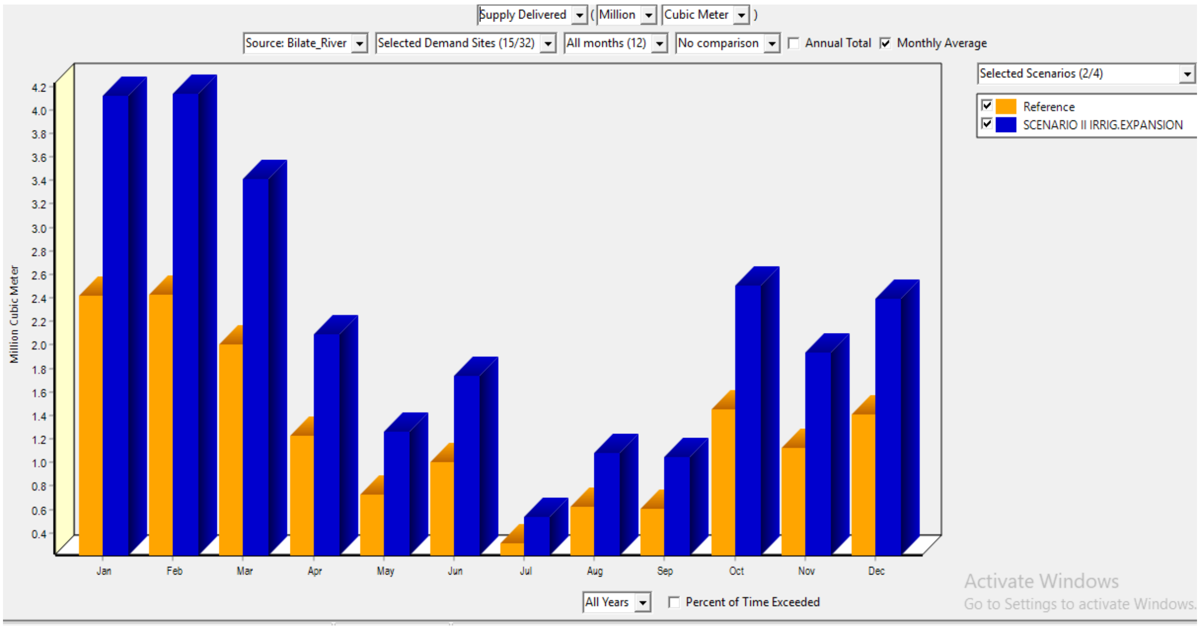


Figure 28: Mean monthly supply delivered for all irrigation sites

4.4.3.3 Unmet demand

The mean monthly water demand which is not delivered to the required irrigation sites is 0.4 Mm^3 which is 1.5 % of total monthly water requirement. Mainly the water shortage for irrigation demand site occurs on October and November.

Table 23: Mean monthly unmet demand of all irrigation sites (Thousand cubic meter)

	Area (ha)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
Alaba_Irr	193	0	0	0	0	0	0	0	0	0	3	5	0	8
Angacha_Irr	420	0	0	0	0	0	0	0	0	0	0	2	0	2
D_Fango_Irr	2957	0	0	0	0	0	0	0	0	0	80	116	0	196
Dale_Irr	120	0	0	0	0	0	0	0	0	0	0	3	5	8
Damot_G_Irr	70	0	0	0	0	0	0	0	0	0	2	2	0	4
Damot_w_Irr	128	0	0	0	0	0	0	0	0	0	3	5	0	8
Humbo_Irr	2618	0	0	0	0	0	0	0	0	0	48	70	0	118
Kacha_b_Irr	282	0	0	0	0	0	0	0	0	0	0	1	0	1
Lemu_Irr	154	0	0	0	0	0	0	0	0	0	1	1	0	2
Sankura_Irrn	365	0	0	0	0	0	0	0	0	0	10	15	0	25
Shebedino_Irr	151	0	0	0	0	0	0	0	0	0	4	6	0	10

	Area (ha)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
Siraro_Irn	17	0	0	0	0	0	0	0	0	0	0	0	0	0
Sodo_zurya_Irr	45	0	0	0	0	0	0	0	0	0	0	0	0	0
Soro_Irrn	200	0	0	0	0	0	0	0	0	0	3	4	0	7
Kedida_Irr	367	0	0	0	0	0	0	0	0	0	4	6		10
Sum		0	0	0	0	0	0	0	0	0	162	238	0	**400**

4.4.4 Scenario III population growth & Irrigation Expansion Scenario (Combination)

This scenario determines the amount water required & delivered from 2020-2035 due to the increase in population size by 3.2 % , livestock growth by 2.4% and full usage of potential irrigation area. From the simulated WEAP output, in this scenario the water requirement increased to 188 MCM at the end of 2035. Whereas the total annual water supply delivered is 179 in 2035. Finally, total annual unmet demand increased to 9 MCM that is 4.8% total water requirement.

The main negative impact of irrigation expansion and population growth, is increasing the water demand and unmet demand in the catchment that causes the instream (environmental) river flow reduction. Although when the population growth rate is high, the need and use of water increases. The environmental flow coverage mainly decreases in October and November and also the unmet demand increases in these scenarios.

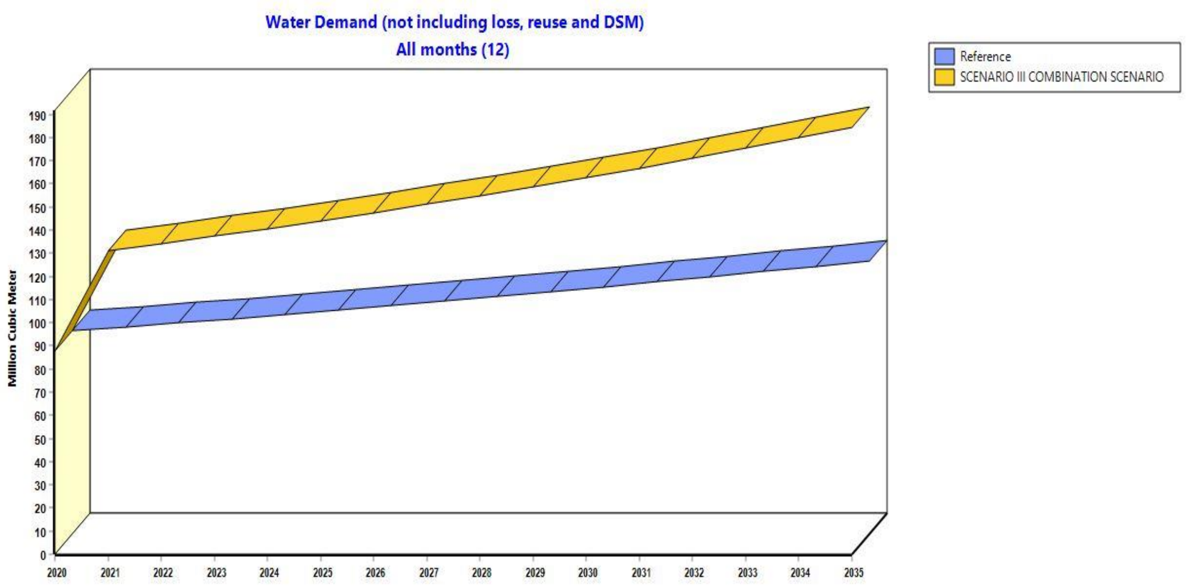


Figure 29: Annual water requirement without loss and reuse of all demand site

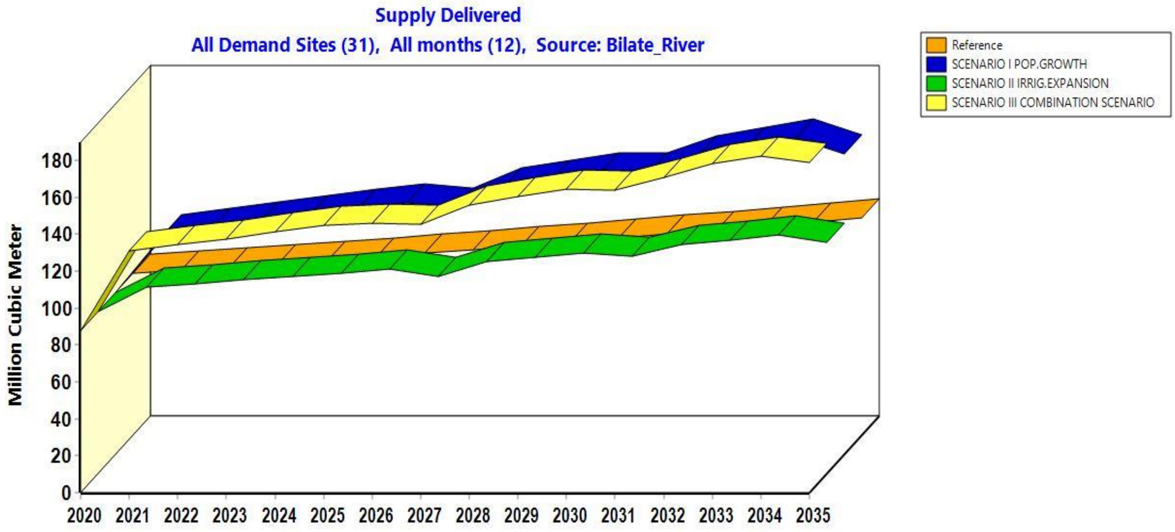


Figure 30: Supply delivered for all demand sites in all scenarios

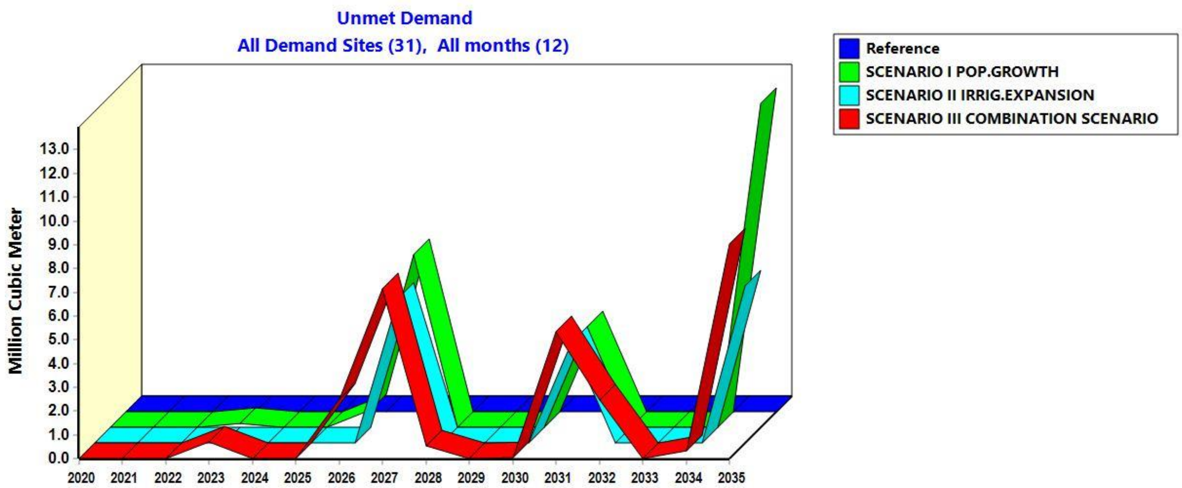


Figure 31: unmet of all demand site all in all scenarios

The environmental flow requirement is shown in the figure below

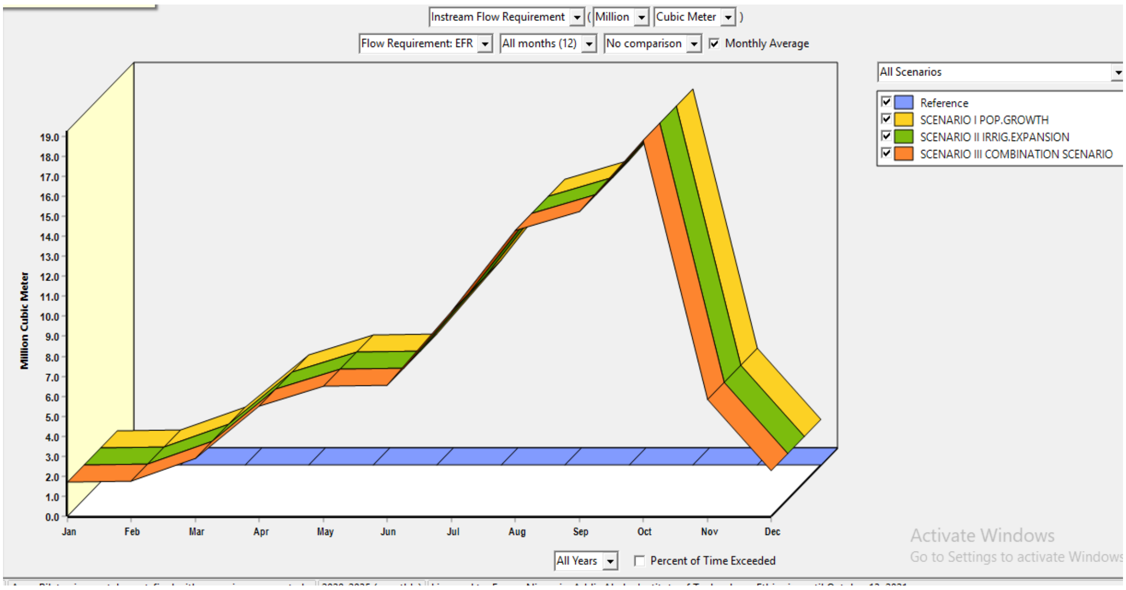


Figure 32: monthly Instream flow requirement

The environmental flow requirement coverage fully met from January to September and on December but there is unmet demand on October and November in population growth, irrigation area expansion and combination scenarios.

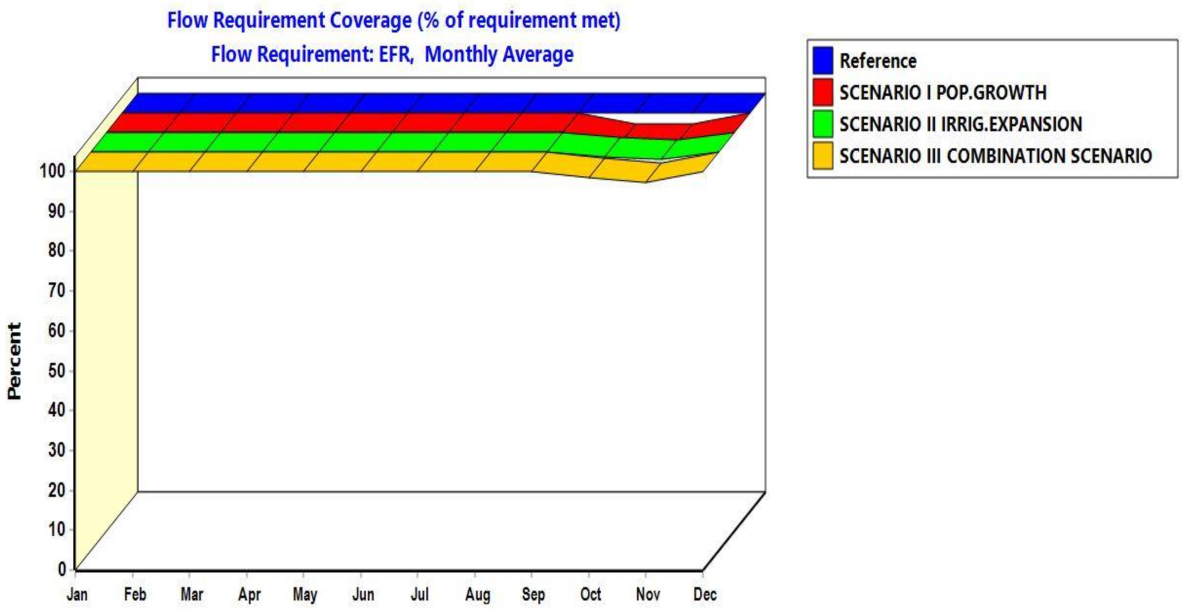


Figure 33: Met instream flow requirement all demand sites in Combination vs Reference scenario

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusions

The study analyzed surface water resource allocation of Bilate catchment by assessing the available water and evaluating the water requirement that exists in the catchment concerning with necessary input data. In line with the objective of the study, the available water demand is quantified and the water requirements for domestic, irrigation and for environmental flows were analyzed.

To determine the available water in the catchment, catchment delineation and kc, LULC, areal precipitation, areal temperature, stream flow data are taken as an input to WEAP model. The analyses of metrological and hydrological data were done and rigorous data filling and quality control were carefully undertaken. After providing the necessary input data, the WEAP model calibrated and validated using observed stream flow data of the two upstream and downstream stations Alaba kulito & Bilate Tena gauge station. The available annual modeled streamflow in the upstream and downstream section is 338MCM and 460MCM. In addition, the performance evaluation of the WEAP model shows that the statistical measure parameters of observed and simulated result were very good. Therefore, the model is able to simulate future stream flow with the population growth and irrigation expansion and environmental flow requirement effect in the study area.

The water requirement is estimated for 25 demand sites 15 of which are irrigation demand nodes (woredas), 9 demand nodes for domestic demand and 1 node for livestock water requirement of all woredas were considered. For irrigation water requirement the actual irrigated area, monthly irrigation duty and irrigation efficiency plays an important role while the domestic water requirement is analyzed based population number and growth rate and livestock water demand is considered based on livestock population with growth rate. Thus, the annual water demand with in the study area for domestic, livestock and Irrigation in the current account year 2020 is 47 MCM, 25 MCM and 15.5 MCM.

This thesis also evaluates the effect of population growth and Irrigation area expansion using different scenarios in Bilate river water allocation using WEAP model. On the reference scenario, there is no unmet demand. Almost all domestic, industrial, livestock and irrigation water demands are met from year 1987 to 2020. Likewise in the coming future Development Scenario of 2020-2035 population growth scenario, the water requirement for all towns domestic and livestock is 121 MCM for 1.3 Million population and 39 MCM for 1.6 Million Livestock unit in the catchment. The unmet demand in this scenario is 8% of total water requirement including irrigation water demand of 15.5 MCM.

In the second future development of 2020-2035 irrigation expansion scenario, the unmet demand for 13,500 ha of monthly water requirement 26.37 MCM is 0.4 MCM, which is 1.5% of monthly irrigation water requirement.

In the last future development scenario, which is a combination of population growth by 3.2% , livestock population growth by 3% and full potential irrigation area expansion, the total water requirement is 188 MCM while the unmet demand is, 9 MCM (4.7 % of total water requirement) respectively.

Finally, the Water Evaluation and Planning System (WEAP) Model has been found to be helpful as an Integrated Water Resources Management tool for balancing water supply and demand for current and future scenarios with respect to different priority level of each demand node.

5.2 Recommendations

This thesis followed through multi computer programs and model input data's such as -climatic and stream flow data of less quality (incomplete) which leads a certain degree of uncertainty. Therefore, these results should be taken with care and should be taken as an initial assessment to picture surface water allocation of supply and demand analysis in the study area.

This study mainly focused on the consideration surface water resources in the river catchment and its allocation. However with the increase of scarcity of water, groundwater resources in the sub-basin should come to play a major role in future water resources development. A detailed assessment of groundwater resources in the sub- basin is required for acquiring data needed for future studies on groundwater use.

It is necessary to make a detail study on environmental flow requirement before developing any other projects in the watershed for a better water resource allocation pattern within the basin and to keep the ecological balance and of Lake Abaya whose main contributory river is Bilate.

There is a limitation of land resources in Bilate River and construction of a storage dam is necessary to meet the water requirement and to expand Irrigation area. In addition, watershed conservational measure structures like bunds; terraces, planting trees should be constructed on the upper part of the Bilate.

In my thesis, water quality is not included because of data limitation. The Water quality assessment is necessary on Bilate catchment and it should be considered on future water allocation studies.

6 REFERENCES

Azazh, B. (2008). *WATER ALLOCATION STUDY OF UPPER AWASH.* Addis Ababa: Addis Ababa University.

Bekele, S. (2001). *Investigation of water resourcses aimed at multi-objective development with respect tolimited data situation.* Addis Ababa: Central Statistical Authority.

Bennetta, D. R., Harms, T. E., & Entz, T. (2013). Net irrigation water requirements for major irrigated crops with variation in evaporative demand and precipitation in southern Alberta. *Canadian Water Resources Journal*, Vol. 39, No. 1, 63–72.

Dale Whittington, C. N. (2010). Estimation of water demand in developing countries. *Water supply and sanitation*, vol 25, No. 2.

Dermawan, A. M. (2018). Water Allocation Computation Model for River and Multi-Reservoir System with Sustainability Efficiency-Equity Criteria. *Water*.

Dr. Derrel L. Martin, D. J. (1993). Irrigation Water Requirements. In H. A. Radwan, *part 623 National Engineering Handbook ; Soil Conservation Service (SCS).* USA: United States Department of Agriculture.

Ebisa, A. (2018). Arjo Didessa reservoir water Evaluation and allocation system . *MSc.Thesis*.

Elizabeth, K. (1992). Eutrophication of Lake Hayq in the Ethiopian Highlands. *Journal of Plankton Research*.

Elshorbagy, A. (2002). Estimation of Missing Stream flow data using principles of Chaos Theory. *Journal of Hydrology 255 (1-4)*, 123-133.

FAO. (1998). *The Soil and Terrain Database for northeastern Africa (CDROM) Major Soils of the World.* Rome, Italy: Land and Water Digital Media Serie.

FAO. (2019). *Water use in livestock production systems and supply chains – Guidelines for assessment (Version 1).* Rome: Livestock Environmental Assessment and Performance (LEAP) Partnership.

Fufa, T. (2016). *Development of Water Allocation and Utilization System for Koka Reservoir under Climate Change and Irrigation Development Scenarios.*

Han, M. (2013). Integrated Approach to Water Allocation in River Basins . *Journal of Water Resources Planning and Management* , 2.

Ingrid, A., & Gerd, F. (2009). Water Balance Modelling in the Southern Ethiopian Rift Valley: The Example of the Bilate River Catchment. *CICD Series Vol.3: Summary of Master Theses from Arba Minch University, Ethiopia*.

K. Jaiswal, 1. N. (2008). Application of a hydrodynamic MIKE 11 model for the Euphrates river in Iraq. *Slovak Journal of Civil Engineering*.

Köppen/Geiger. (1928). *Climate classification.*

Levite, H. S. (2003). Testing water demand management Sceanrios in water stressed basin in South Africa. *Application of WEAP model*, 779-786.

Liu, J. (2019). How to allocate interbasin water resources? A method based on water flow in water-deficient areas. *Environmental Development*, 4.

Mounir. (2011). *WEAP model to investigate scenarios of future water resource development in the Niger River Basin .* Niger Republic.

MoWR. (2007). *Rift Valley Lakes Basin Integrated Resources development master plan study project.* Ethiopia: Halcrow Group Limited and generation integrated rural development (GIRD) consultants.

OECD. (2015). *Water Resources Allocation : Sharing risks and opportunities.* Paris: OECD Publishing.

Omondi, O. P. (2016). *SIMULATION OF WATER RESOURCE USE AND ALLOCATION IN NYANGORES SUB-CATCHMENT OF THE UPPER MARA BASIN, BOMET COUNTY, KENYA.* Kenya: Kenyatta University.

Phingsaliao, S. (2019). Projecting water demand and availability under climate change through the application of WEAP in the Nam Ngum downstream area, Laos. *MSc.Thesis ,Flinders university of Adelaide, South Australia* .

Raskin, P. H. (1992). *Simulation of water supply and demand in the Aral Sea, Region .*

Reuben, N. (2007). *Application of the WEAp Model in Integrated Water Resources Management of the Nyando River Basin.* Kenya: Jomo Kenyatta University.

Ringler, C. &. (2004). Water allocation policies for Dong Nai River basin in Vetenam:An integrated perspective. *EPTD discussion paper* (p. No. 127). Washington, D. C: IPTRI.

Rosenzweiga, C. S. (2004). *Water resources for agriculture in a changing climate: international case studies, Global Environmental Change.*

SEI. (2019). *WEAP-Water Evaluation and Planning System.* Stockholm Environment Institute (SEI).

Setegn, S., Srinivasan, R., Melesse, A., & Dargahi, B. (2009, 24). SWAT model application and prediction uncertainty analysis in the Lake Tana Basin, Ethiopia.

Sieber, J. Y. (2005). WEAP21 - A Demand, Priority, and Preference-Driven Water Planning Model Part 1: Model Characteristics. *Water International*, Pages 487–500.

Sieber, J., & Purkey, a. D. (2015). *Water Evaluation And Planning System.* USA: Stockholm Environment Institute.

Speed, R. Y. (2013). *Basin water allocation planning: Principles, procedures and approaches for basin allocation planning.* Asian Development Bank, GIWP, UNESCO, and WWF-UK.

Stockholm Environment Institute (SEI). (SEI, 2008). *WEAP (Water Evaluation and Planning).* Boston: StockholmEnvironment Institute.

Tadesse, F. (2016). *Development of Water Allocation and Utilization System for Koka Reservoir under Climate Change and Irrigation Development Scenarios.* Addis Ababa , Ethiopia: Addis Ababa University.

Tena, B. A. (2015). WEAP modeling of surface water resources allocation in Didessa Sub-Basin, West Ethiopia.

Tesfaye, N. J., Yesuf, M. B., & Hirko, D. B. (2015). Modeling Surface Water Resources for Effective Water Allocation Using Water Evaluation and Planning (WEAP) Model, A Case Study on Finchaa Sub basin, Ethiopia. *Applied Journal of Environmental Science*, 402-419.

Thiemann. (2004). *Water resource potential with respect to precipitation variability.*

Tigist, T. (2009). *WATER RESOURCE UTILIZATION AND ITS RELATED EFFECTS.* Addis Ababa: Addis Ababa University.

Yamout G and El-Fadel M. (2005). An optimization approach for multi-sectoral water supply management in the Greater Beirut Area. *Water Resource Mnangment 19(6)*, 791–812.

Yates D, S. J.-L. (2005). a demand, priority, and preference driven water planning model: part 2,. *aiding freshwater ecosystem service evaluation*, Water Int 30 (4):487–500.

Zena, K. (2011). *Hydrological Study and Development of WEAP Software on Lepenc and Morava e Binces River.* KOSOVO.

Zinash, S. A. (n.d.). Water resources for livestock in Ethiopia: Implications for research and development. 66-76.

APPENDICES

Appendix A: - Average monthly Rainfall of stations used

Month	Bilate tena	Hossana	Alaba	Angecha	Boditi	Durame	Bilate	Shone	Fonko
Jan	29.99	28.32	30.13	38.30	28.70	27.02	28.29	40.06	25.67
Feb	32.75	44.35	49.01	59.76	46.30	44.92	29.59	52.91	48.83
Mar	77.27	100.85	92.17	102.70	89.68	84.48	57.05	111.40	110.88
Apr	130.42	134.01	135.44	181.72	164.23	145.03	113.84	183.59	146.63
May	117.61	148.03	125.17	169.39	171.36	158.79	103.31	170.18	149.17
Jun	88.44	127.59	91.82	148.82	125.02	102.76	76.38	135.51	130.85
Jul	92.46	153.88	116.53	188.21	151.83	152.89	90.88	169.63	160.97
Aug	93.21	175.38	152.74	208.04	150.42	153.68	74.51	194.92	176.11
Sep	93.34	153.73	120.97	181.84	126.59	141.12	68.16	184.65	155.49
Oct	97.44	69.76	71.57	96.06	84.48	97.64	82.43	100.66	87.34
Nov	34.29	21.60	60.86	47.29	42.14	37.27	47.58	44.91	19.15
Dec	22.94	21.97	23.13	31.40	35.56	22.95	23.87	38.99	21.47

Appendix B**:** - Average Annual rainfall of the Stations used in the study

Year	Fonko	Bilate	Alaba	Hossana	Boditi	Angecha	Bilate tena	shone	Durame
1987	116.94	60.85	129.19	106.71	108.33	96.84	84.45	136.18	110.88
1988	92.63	80.28	124.83	101.35	114.81	105.59	62.37	135.94	104.59
1989	111.36	66.11	90.29	99.98	91.48	128.60	79.91	112.97	131.73
1990	86.37	61.92	80.67	88.24	101.91	125.04	71.37	99.57	87.33
1991	86.21	61.10	81.04	87.64	101.08	93.14	62.90	126.07	106.44
1992	130.08	81.35	96.88	115.63	121.97	112.66	67.50	154.31	110.56
1993	125.92	66.39	106.02	117.79	108.67	126.59	74.03	197.10	93.10
1994	74.24	68.22	67.18	77.06	99.93	78.82	72.71	154.04	67.73
1995	78.84	51.43	81.30	96.73	89.92	121.41	82.00	118.26	78.55
1996	117.17	89.65	96.67	97.35	111.59	118.91	97.82	163.78	74.85
1997	138.74	70.94	99.46	120.21	120.83	130.42	87.17	204.03	100.35
1998	114.81	52.70	102.72	129.70	127.17	112.09	82.57	152.05	114.88
1999	96.13	41.28	63.62	84.28	83.54	121.34	97.65	100.26	88.83
2000	98.35	51.37	73.00	82.66	79.03	121.61	73.23	106.75	96.85
2001	118.42	44.74	78.68	95.46	117.67	167.24	65.84	114.70	110.31
2002	117.18	43.38	66.33	112.20	92.13	139.04	66.48	106.93	97.46
2003	124.43	70.92	78.61	97.30	96.91	160.21	74.65	78.41	87.79
2004	99.70	68.08	82.72	99.80	91.40	147.80	73.52	106.82	88.73
2005	103.16	83.39	72.21	98.25	112.24	164.89	83.07	107.12	122.54
2006	100.31	86.03	72.82	100.14	111.24	139.17	89.33	92.57	78.32
2007	105.89	79.44	90.13	91.57	127.32	157.73	85.59	95.68	86.09
2008	105.71	65.58	79.19	100.23	84.18	117.97	84.08	96.85	83.65
2009	84.08	57.14	70.69	97.70	81.73	104.66	59.00	77.75	71.15
2010	104.44	90.19	150.03	93.46	99.89	102.86	94.79	118.31	84.16
2011	88.70	71.69	79.67	92.91	100.63	109.09	75.53	124.07	100.37
2012	90.23	57.26	62.69	81.80	90.37	110.30	65.90	101.61	90.00
2013	97.48	98.10	168.14	94.21	116.85	111.62	98.26	92.74	109.56
2014	91.66	69.48	97.89	120.71	107.00	94.96	63.45	120.56	134.26
2015	99.51	54.48	48.80	82.86	60.42	60.11	65.00	75.80	70.00
2016	102.88	58.30	105.02	94.70	100.50	135.40	85.29	124.21	134.95
2017	82.55	54.22	66.52	88.39	91.38	87.84	66.14	92.09	109.42

Appendix C: - Annual average maximum and minimum temperature of selected stations

	Hossana		Angecha		Alaba		Bilate		Boditi	
Year	T max	Tmin	T max	Tmin	Tmax	Tmin	Tmax	T min	Tmax	Tmin
1987	22.90	17.15	24.12	13.91	27.57	8.00	30.81	11.75	23.83	11.50
1988	22.18	10.82	26.31	15.80	27.21	6.09	30.44	10.95	23.52	10.25
1989	21.45	10.21	25.76	15.45	26.85	7.27	30.54	13.70	23.04	8.96
1990	21.85	10.51	25.27	15.95	27.41	8.82	29.67	16.47	23.48	8.10
1991	22.48	10.90	25.78	15.99	27.34	9.33	29.87	16.16	24.09	7.23
1992	22.18	10.97	24.62	14.53	27.07	9.08	29.79	16.33	23.60	6.87
1993	22.77	11.05	24.71	14.72	26.46	8.15	29.97	15.83	23.62	12.89
1994	22.77	11.05	24.87	15.16	27.48	13.26	30.35	15.79	24.43	12.76
1995	22.87	10.85	25.00	15.02	27.72	13.66	30.95	16.06	24.74	13.45
1996	22.17	10.65	24.65	14.75	27.30	13.31	29.94	15.57	24.41	13.17
1997	22.80	11.15	24.30	13.54	27.80	13.80	30.14	16.40	25.07	13.49
1998	22.46	11.30	23.81	12.81	27.52	14.25	30.17	16.79	24.71	13.73
1999	22.65	10.42	23.79	13.36	27.68	12.62	30.07	16.58	25.13	13.10
2000	22.75	10.14	23.46	13.24	27.61	13.45	30.44	16.89	25.42	13.24
2001	22.26	10.96	23.06	13.25	27.36	13.54	30.13	16.65	24.79	13.41
2002	22.75	10.65	23.52	13.62	28.16	14.12	30.26	16.35	24.90	12.67
2003	22.83	11.05	23.44	13.42	27.94	13.76	30.38	16.31	24.62	13.56
2004	22.60	10.34	23.48	13.19	28.19	13.30	30.69	16.16	24.61	13.55
2005	22.82	11.06	23.20	13.21	28.04	13.43	30.26	16.74	24.65	13.54
2006	22.82	11.26	23.39	13.10	27.94	13.95	29.89	16.80	24.35	13.69
2007	22.94	11.12	23.58	13.29	28.25	13.40	29.91	16.64	24.44	13.48
2008	22.93	10.42	23.46	13.26	28.87	13.07	30.26	16.67	24.98	13.27
2009	23.54	10.61	23.65	13.31	29.71	13.54	31.21	16.86	25.87	13.78
2010	22.53	10.96	23.48	13.07	27.72	13.10	29.69	17.15	24.57	13.82
2011	23.28	10.98	23.67	13.32	29.04	13.86	29.32	18.24	25.47	13.80
2012	23.58	10.61	23.89	13.72	29.42	13.52	31.30	16.72	25.42	13.46
2013	23.04	10.39	23.69	13.63	27.79	14.36	30.22	16.67	24.63	13.42
2014	22.90	10.75	23.15	13.23	28.55	17.69	30.77	16.89	24.63	13.76
2015	24.00	11.51	24.21	13.51	30.64	17.99	31.86	17.61	25.67	13.83
2016	23.17	11.70	23.82	13.34	28.95	17.10	31.05	17.99	24.94	14.03
2017	23.72	11.05	25.10	12.47	29.06	12.83	31.36	17.77	24.81	13.66

Appendix D: - Outlier Test KN Values

OUTLIER TEST K VALUES

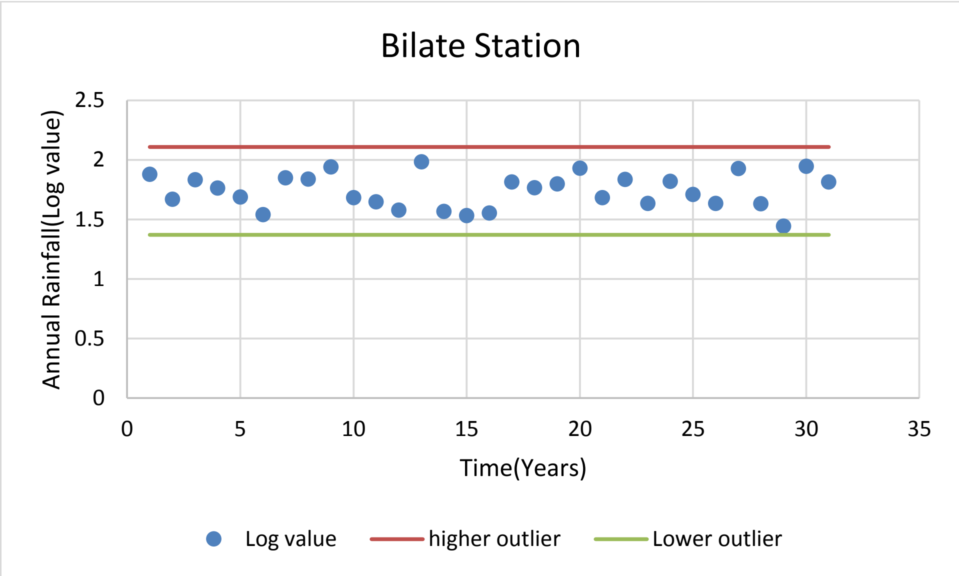
10 PERCENT SIGNIFICANCE LEVEL K VALUES

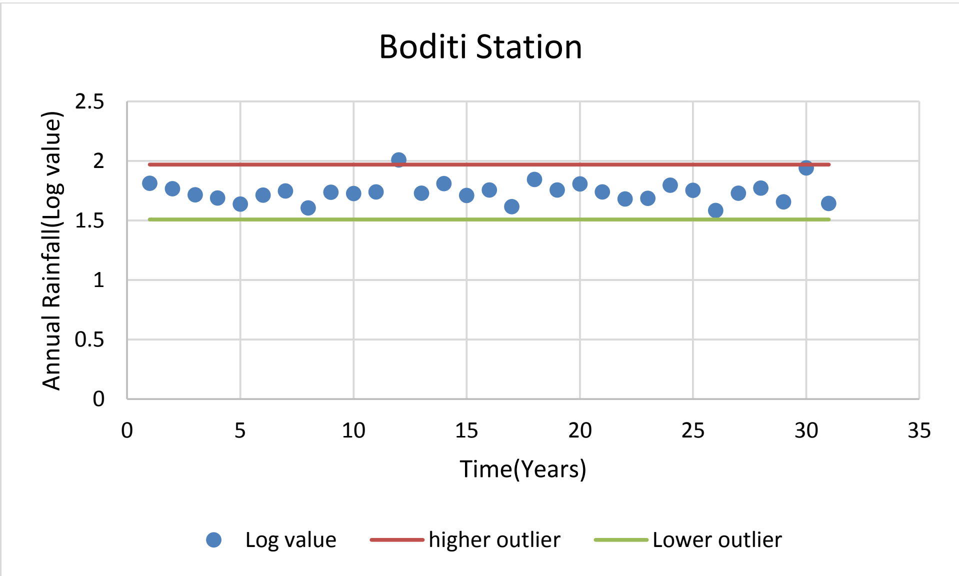
The table below contains one sided 10 percent significance level K_N alues for a normal distribution (38). Tests conducted to select the outier detection procedures used in this report indicate these K_N values are pplicable to log-Pearson Type III distributions over the tested range of kew values.

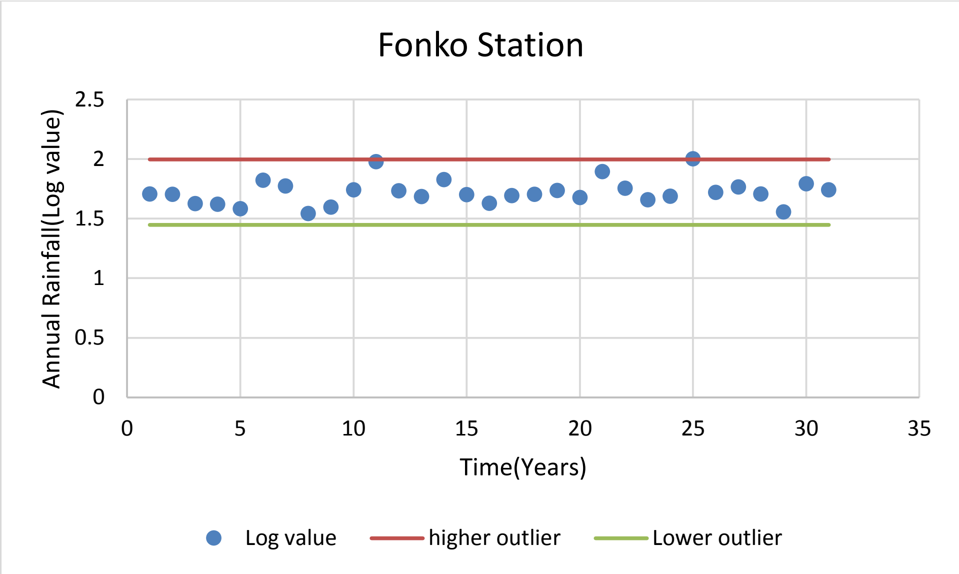
ample size	K_N value	Sample size	K_N value	Sample size	K_N value	Sample size	K_N value
10	2.036	45	2.727	80	2.940	115	3.064
11	2.088	46	2.736	81	2.945	116	3.067
12	2.134	47	2.744	82	2.949	117	3.070
13	2.175	48	2.753	83	2.953	118	3.073
14	2.213	49	2.760	84	2.957	119	3.075
15	2.247	50	2.768	85	2.961	120	3.078
16	2.279	51	2.775	86	2.966	121	3.081
17	2.309	52	2.783	87	2.970	122	3.083
18	2.335	53	2.790	88	2.973	123	3.086
19	2.361	54	2.798	89	2.977	124	3.089
20	2.385	55	2.804	90	2.981	125	3.092
21	2.408	56	2.811	91	2.984	126	3.095
22	2.429	57	2.818	92	2.989	127	3.097
23	2.448	58	2.824	93	2.993	128	3.100
24	2.467	59	2.831	94	2.996	129	3.102
25	2.486	60	2.837	95	3.000	130	3.104
26	2.502	61	2.842	96	3.003	131	3.107
27	2.519	62	2.849	97	3.006	132	3.109
28	2.534	63	2.854	98	3.011	133	3.112
29	2.549	64	2.860	99	3.014	134	3.114
30	2.563	65	2.866	100	3.017	135	3.116
31	2.577	66	2.871	101	3.021	136	3.119
32	2.591	67	2.877	102	3.024	137	3.122
33	2.604	68	2.883	103	3.027	138	3.124
34	2.616	69	2.888	104	3.030	139	3.126
35	2.628	70	2.893	105	3.033	140	3.129
36	2.639	71	2.897	106	3.037	141	3.131
37	2.650	72	2.903	107	3.040	142	3.133
38	2.661	73	2.908	108	3.043	143	3.135
39	2.671	74	2.912	109	3.046	144	3.138
40	2.682	75	2.917	110	3.049	145	3.140
41	2.692	76	2.922	111	3.052	146	3.142
42	2.700	77	2.927	112	3.055	147	3.144
43	2.710	78	2.931	113	3.058	148	3.146
44	2.719	79	2.935	114	3.061	149	3.148

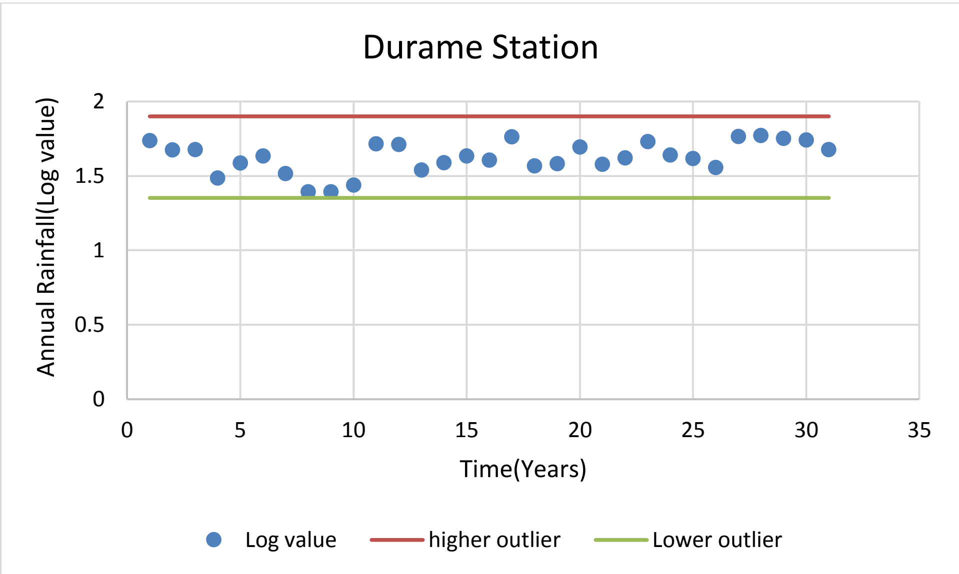
One-sided 10 percent significance outlier test KN values for a normal distribution (Interagency Advisory Committee on Water Data, 1982, after Grubbs and Beck, 1972).

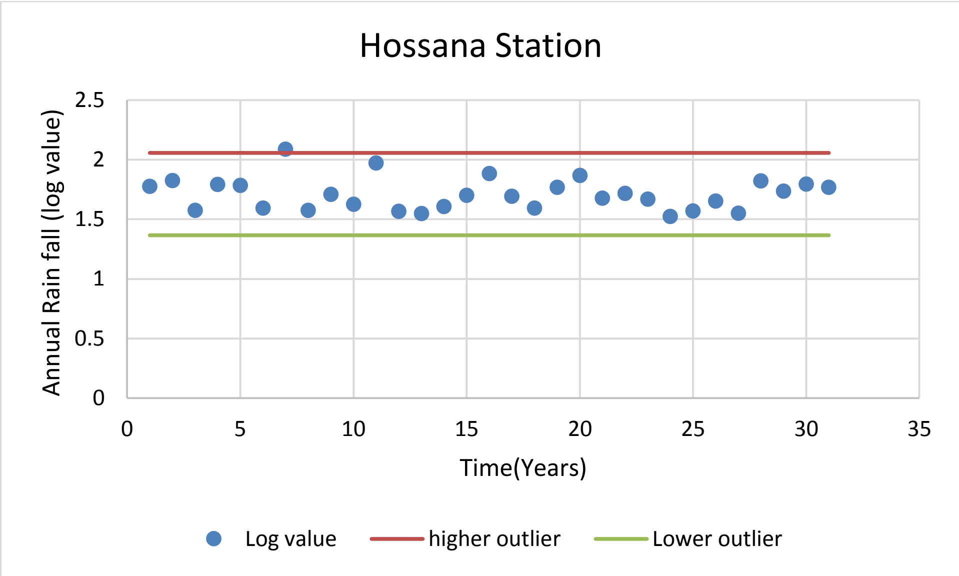
Appendix E: - Outlier test of Rainfall Stations for KN = 2.577

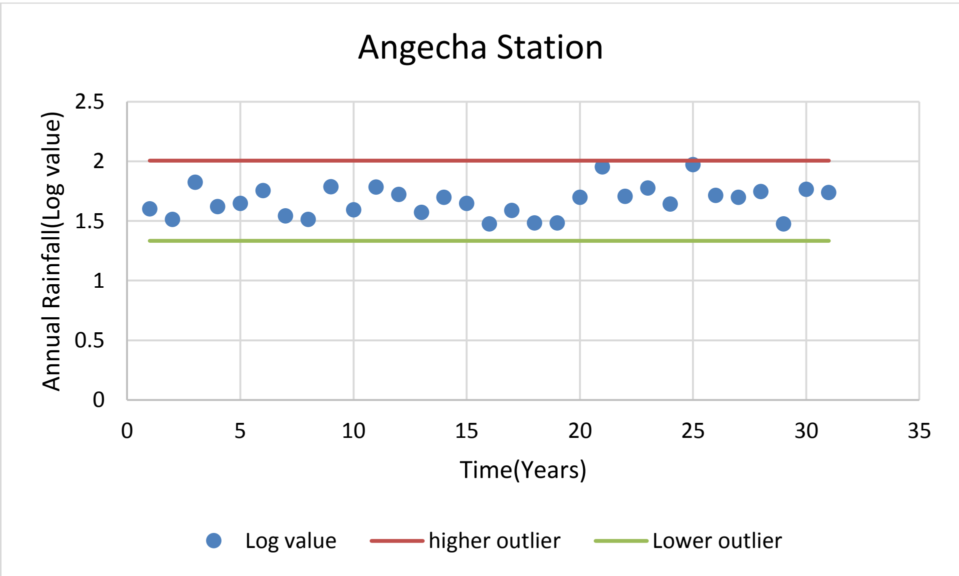


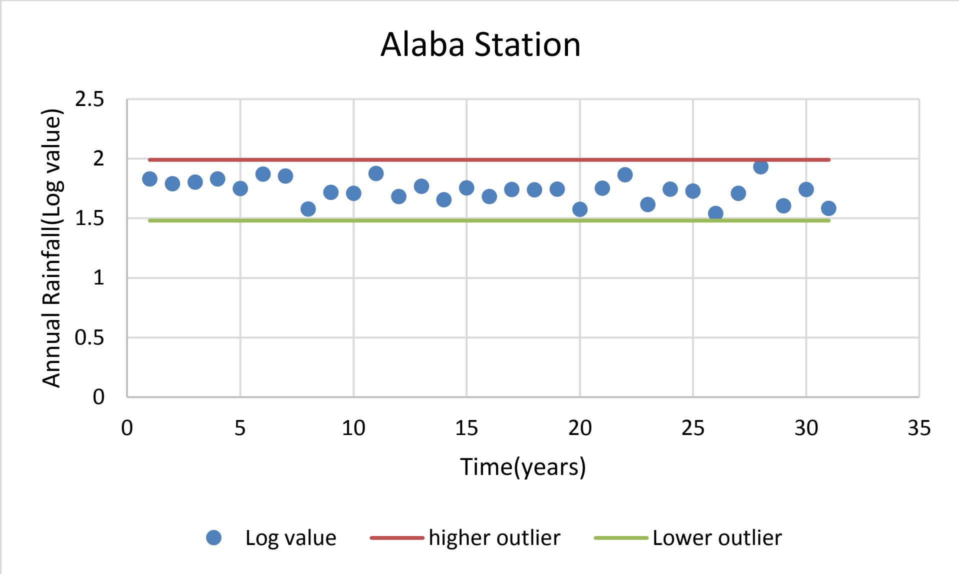



Fonko Station
Annual Rainfall(Log value)
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
35
Time(Years)
Log value
higher outlier
Lower outlier

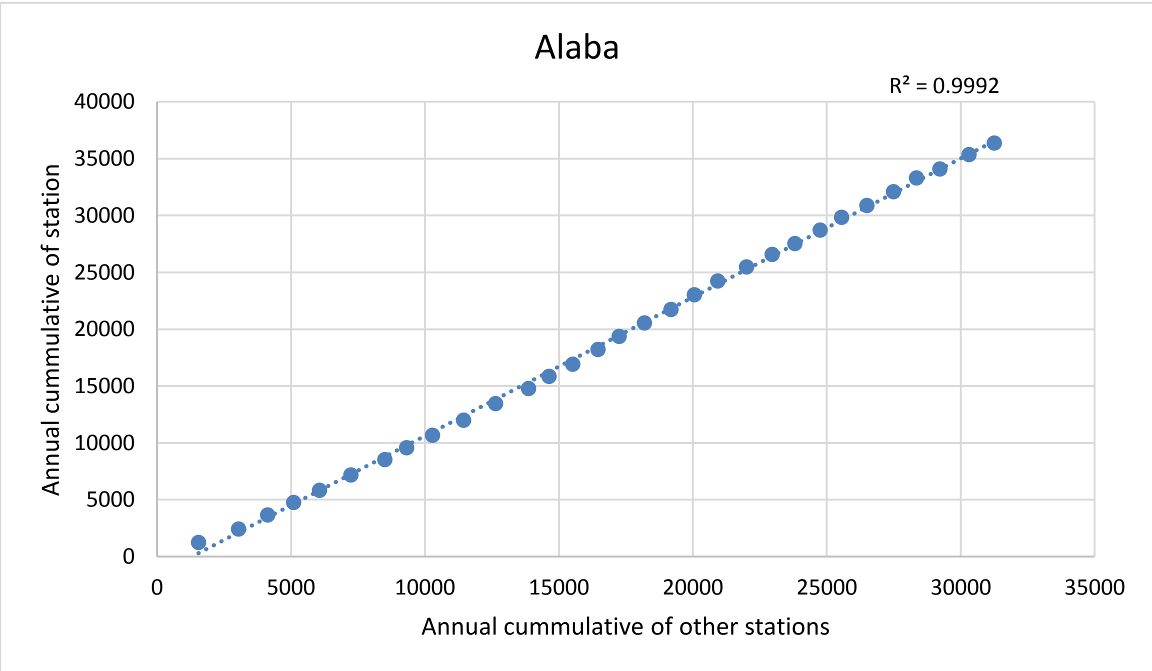

Durame Station
Annual Rainfall(Log value)
2
1.5
1
0.5
0
0
5
10
15
20
25
30
35
Time(Years)
Log value
higher outlier
Lower outlier

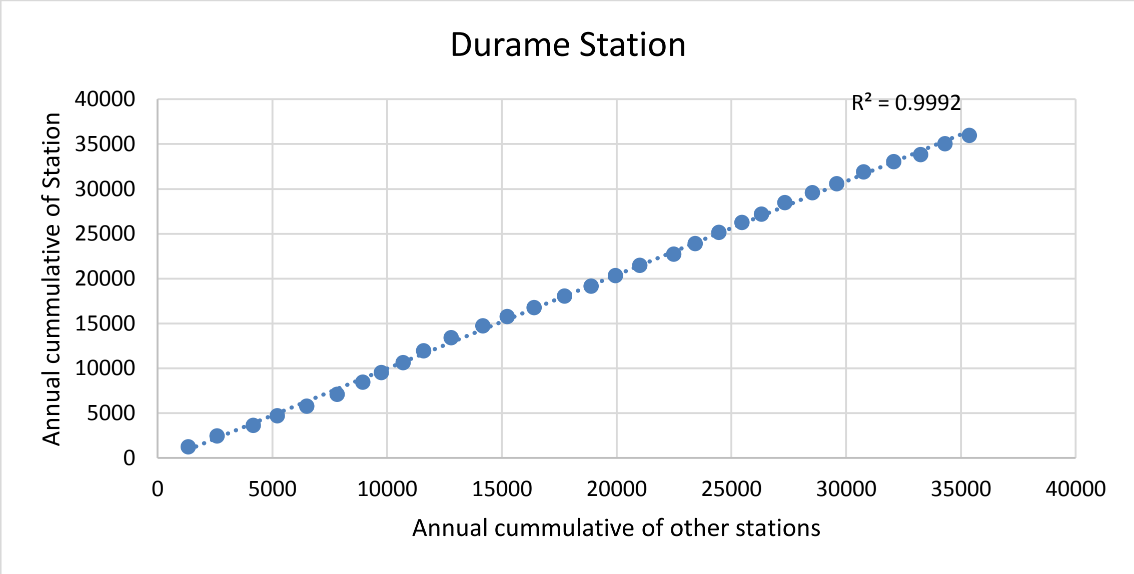

Hossana Station
Annual Rain fall (log value)
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
35
Time(Years)
Log value
higher outlier
Lower outlier

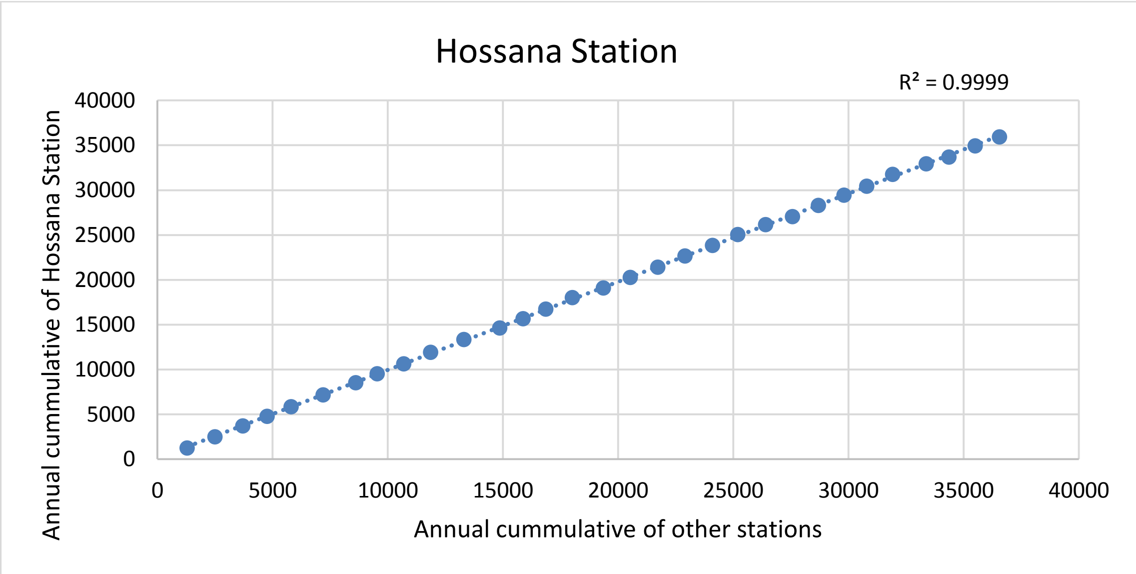

Angecha Station
Annual Rainfall(Log value)
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
35
Time(Years)
Log value
higher outlier
Lower outlier

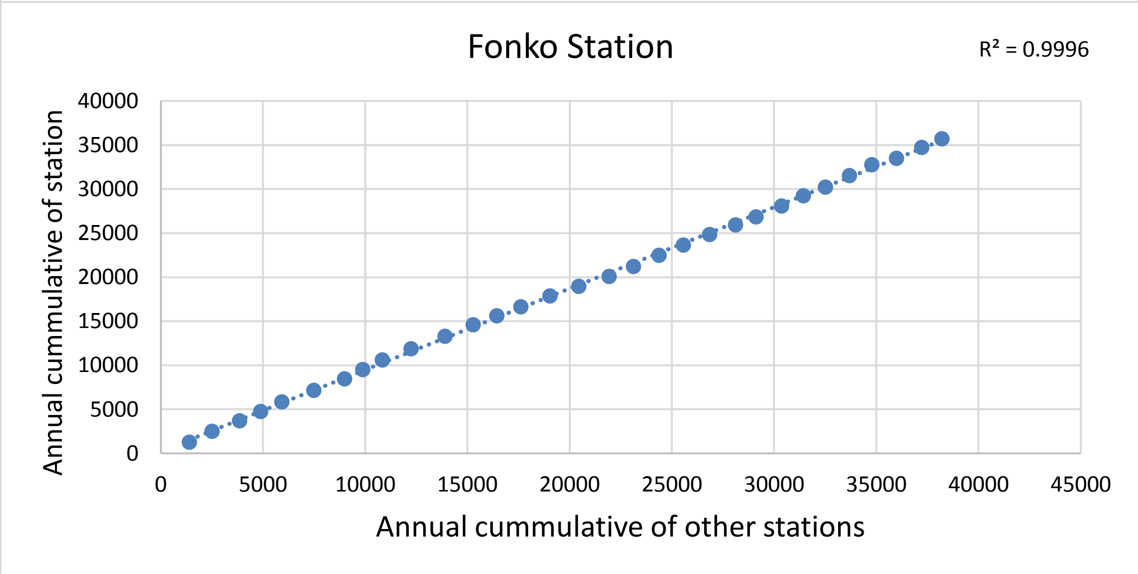


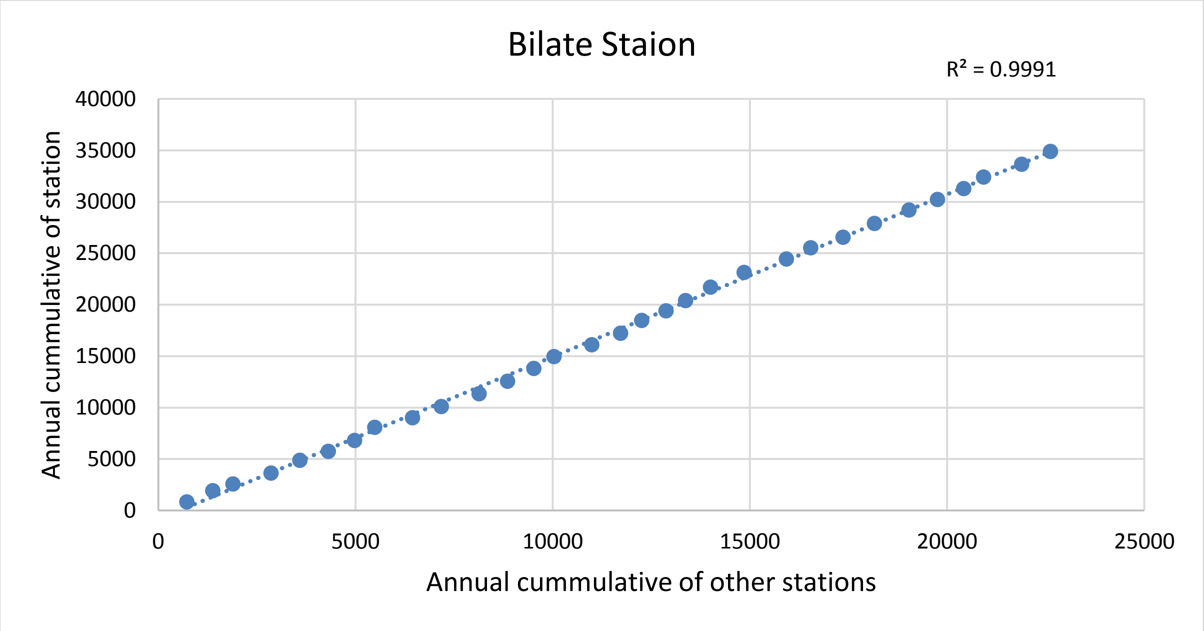
Appendix F:- Double mass curves of stations

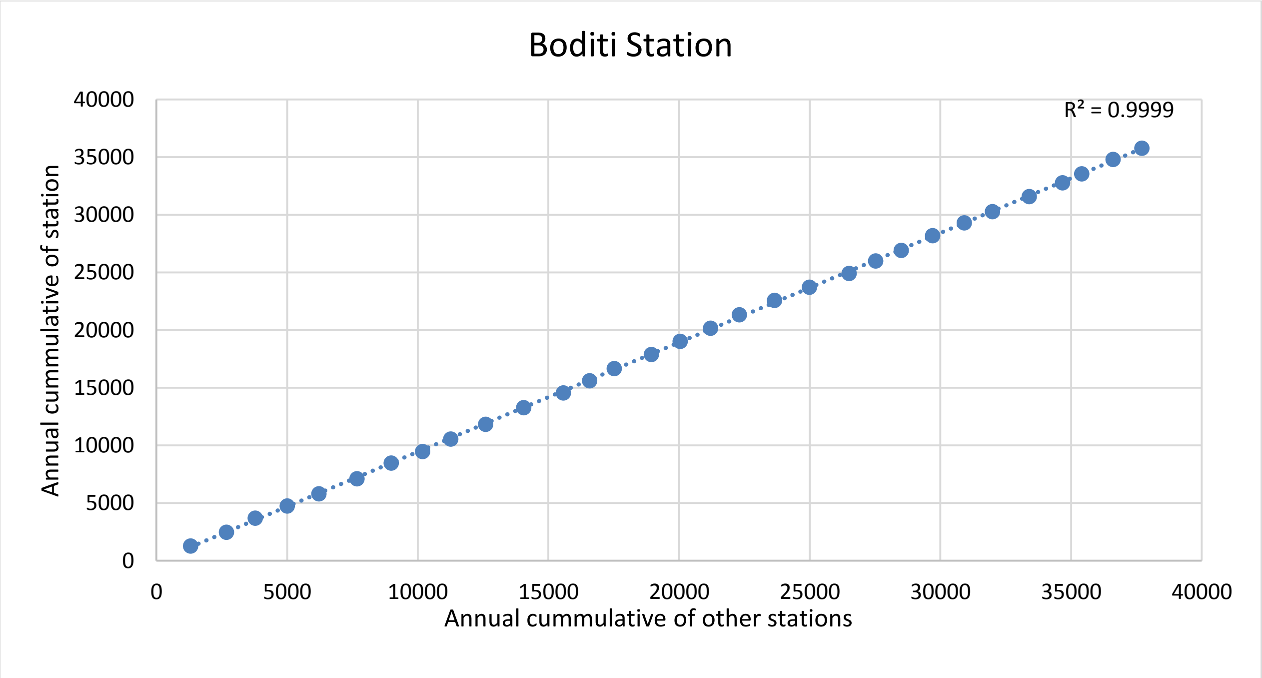



Durame Station
R² = 0.9992
Annual cummulative of Station
40000
35000
30000
25000
20000
15000
10000
5000
0
0
5000
10000
15000
20000
25000
30000
35000
40000
Annual cummulative of other stations


Hossana Station
R² = 0.9999
Annual cummulative of Hossana Station
40000
35000
30000
25000
20000
15000
10000
5000
0
0
5000
10000
15000
20000
25000
30000
35000
40000
Annual cummulative of other stations


Fonko Station
R² = 0.9996
Annual cummulative of station
40000
35000
30000
25000
20000
15000
10000
5000
0
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
Annual cummulative of other stations





Appendix G:- Average Kc values of different land uses/cover types of Bilate River

LULC	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Forest	0.65	0.66	0.77	0.77	0.78	0.78	0.78	0.78	0.77	0.78	0.77	0.7
Wood Land	0	0	0	0	0.35	0.64	1	1.06	1.04	0.52	0	0
Shrurb/Bush	0.65	0.66	0.77	0.77	0.78	0.78	0.78	0.78	0.77	0.78	0.77	0.7
Grass Land	0.00	0.00	0.00	0.00	0.35	0.64	1.00	1.06	1.04	0.52	0.00	0.00
Barren Land	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Water Body	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Crop Land	0.82	0.85	0.8	0.92	0.91	0.4	0.81	0.96	0.87	0.68	0.9	1.01