

**ADDIS ABABA UNIVERSITY**  
**ADDIS ABABA INSTITUTE OF TECHNOLOGY**  
**SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING**



**WATER RESOURCE DEVELOPMENTS AND FLOW ALTERATION: THE CASE  
OF DIDESSA RIVER BASIN**

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**A Thesis in Hydraulic Engineering Stream**

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Advisor: Fiseha Behulu (PhD)

A Thesis

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

October, 2021  
Addis Ababa, Ethiopia

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## DECLARATION

I confirm that the research work titled “**Water Resource Developments and Flow Alteration in Didessa River Basin**” is my own work. The work has not been presented elsewhere. Where material has been used from other sources it has been properly acknowledged.



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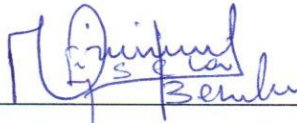
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## CERTIFICATION

I, the undersigned, certify that I read the thesis entitled “**Water Resource Developments and Flow Alteration in Didessa River Basin**” and hereby recommend for acceptance by the Addis Ababa University in partial fulfillment of the requirements for the degree of **Master of Science**.



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## **ABSTRACT**

*Water demand increases due to population growth and the associated economic growth and irrigation factors for food production. Water becomes scarce as the amount of demand exceeds the available supply. Didessa River is the largest tributary of the Abbay river basin in terms of discharge capacity per unit area and still susceptible to supply-demand misbalance issues. The study's main objective was to assess the impact of water resource development and flow alteration in the Didessa river basin.*

*The Water Evaluation And Planning (WEAP21) tool was used to simulate the catchments and integrate supply sources and demand sites. The hydrological model performances manually for calibrated (1990-2008) and Validated (2009-2017) of NSE and  $R^2$  are 0.89 and 0.68, and 0.9 and 0.73 respectively. The crops water requirement and degree of hydrologic alteration respectively CROPWAT 8.0 and Indicator of Hydrologic Alteration (IHA) programs were used to estimates.*

*Two different scenario development were built. The first scenario is based on increasing population growth rate divided into Reference (1990-2017), small population growth rate (2018-2035), and higher population growth rate (2036-2050). The results indicated the unmet water demand, 0.74, 297.87, and 784.46 in a million-meter cube. The second scenario was developed based on the expansion of irrigation activity, reference, short-term plan, and long-term plan remained the results indicate that the unmet water demand values: 0.195, 0.55, and 7.5-billion-meter cube in respectively.*

*The results of the first and second scenarios specify that the population growth rate and irrigation activities increased the unmet water demand also increased. It was shown that the degree of flow alteration was low in most months, and the Didessa near Dembi gauge station has high susceptibility to flow alteration than Didessa near Arjo gauge station. It was found that when the environmental flow has taken 20 up to 50 percent mean annual runoff, the unmet demand was reduced accordingly. Finally, it can be concluded that any future water development shall take into account all possible scenarios that can address environmental alteration and extra water requirements.*

**Keywords;** WEAP21, IHA, Didessa river basin, Flow Alteration, Scenarios, Unmet, Impact.

## ABBREVIATIONS

CSA	Census Statistical Agency
DEM	Digital Elevation Model
DMC	Double Mass Curve
DRB	Didessa River Basin
FAO	Food and Agricultural Organization
FDC	Flow Duration Curve
EFR	Environmental Flow Requirement
EFCs	Environmental Flow Components
GTP-II	Second Growth and Transformation Plan
IFR	Instream Flow Requirements
IHA	Indicators of Hydrologic Alteration
ITCZ	Inter-Tropical Convergence Zones
IWRM	Integrated Water Resource Management
MAR	Mean Annual Runoff
MoWIE	Ministry of Water, Irrigation, and Energy
NMA	National Meteorological Agency
PEST	Parameter Estimation Tool
RVA	Range of Variability Approach
SEI	Stockholm Environmental Institute
SRTM	Shuttle Radar Topography Mission
WEAP	Water Evaluation And Planning
WHO	World Health Organization

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# 1 INTRODUCTION

## 1.1 Background

The water demand is rising due to an increase in the population and related economic growth factors, and irrigation for food production (Sivapalan *et al.*, 2012). For most of the year, many watersheds undergo water shortages for agricultural and domestic use (Agarwal *et al.*, 2018). As the level of demand approaches the available supply, water becomes scarce. Ethiopia has initiated many water resource development projects in all the country's major river basins (Adgolign *et al.*, 2016). However, such developments may alter the hydrologic regimes of the basins. The most likely reasons for the streamflow decrease are human activities and climate change, primarily improvements in land usage, hydraulic development, and artificial water consumption.

Using water-based indexes, river flow regimes can be divided into five categories: magnitude, frequency, length, timing, and rate of change of flow. (Mathews *et al.*, 2007; Botter *et al.*, 2010; Worku *et al.*, 2014; Berhanu *et al.*, 2015). Water resources development that was carried out in the Didessa river basin, which is located in the southwest part of the Blue Nile River Basin, is very important due to its potential. Like other river basins in Ethiopia, the huge agricultural and hydroelectric power potentials in the Abbay basin have attracted considerable attention (Adgolign *et al.*, 2016). Hence, there are currently several water resources development projects under construction and planning phases in the Didessa river basin of the Abbay basin (Tena Bekele Adgolign† *et al.*, 2015). In this regard, it is also believed that the study and evaluation of water resources development effect and flow changes on environmental flow requirement and the downstream users are important.

Ethiopia has a complex topography and a diversified climate (Belete Berhanu, 2014), which are the factors of change of hydrologic system for the watershed/catchments. The hydrology of any catchments depends on the hydrologic cycle, especially in climatic conditions, especially rainfall. West flowing rivers in Ethiopia receives much rainfall that significantly responds to runoff. Didessa river sub-basin is one of the Abbay basin's major tributaries, which is Abbay basin's major tributaries, contributing the highest water volume in terms of discharge per unit area. Natural or anthropogenic influences can cause the variability of runoff in the basin; therefore, the problem becomes severe over time and reaches an irreversible condition in all riparian areas.

## 1.2 Problem Statement

Abbay Basin is the most important river basin in Ethiopia, where the Didessa sub-basin is situated. Because it accounts for twenty percent (20%) of the Ethiopian land area, for about fifty percent (50%) of total average annual runoff, for twenty-five percent (25%) of its population, and over forty percent (40%) of agricultural production.

Large-scale dam construction is currently undergoing in Didessa to develop a new large-scale irrigation project in the basin. The water demand is rising due to an increase in the population and related economic growth factors, and irrigation for food production. As the level of demand approaches the available supply, water becomes scarce. Natural or anthropogenic influences can cause the variability of runoff in river basins; therefore, the problem becomes severe over time and reaches an irreversible condition in all riparian areas. As a result, it is expected that the aforementioned (above) challenges and interactions in the Didessa river basin may cause several changes in hydrology, environment, and ecological conditions of the basin, including the livelihood and economy of the residing people (living) in the basin. Therefore, the study of flow alteration in the regime and the change in agricultural land coverage is needed to assess the impact of water resource development.

## 1.3 Research Questions

The study's main research question is where there is an impact of water resource development on natural flow (Environmental flow) of the basin hydrology and change in agricultural coverage. Accordingly, the following key questions were considered throughout the study.

- What are the influences of water resource development in the Didessa River Basin?
- Which area is more affected due to flow alteration in the Didessa River Basin?
- Is there a significant change in agricultural land coverage areas in the basin?

## 1.4 Objectives

### 1.4.1 Main Research Objective

The main objective (aim) of this study is to evaluate the possible impacts of water resource development on river flow regimes and the change in the agricultural land coverage in the whole Didessa river basin.

### **1.4.2 Specific Research Objectives**

Under the umbrella of the above general objective, the following specific objectives are expected to be undertaken in the present study:

- To assess the impact of water resource development (Large-scale Irrigation project) in the Didessa River basin;
- To identify the areas susceptible to flow alteration in the Didessa River basin;
- To assess the change in agricultural coverage as a result of Environmental Flow Requirements (EFR) in the Didessa River basin.

### **1.5 Significance of the Study**

The Didessa river basin is relatively in the Abbay basin. Water resource development activity was undergoing may cause a change in Hydrology, Environment, and Ecologies in a basin.

Indicators of Hydrologic Alteration software is not popular in the Ethiopian basin but Omo-Gibe.

Most studies focused on the lower Didessa sub-basin, but this study focuses on the whole Didessa river basin.

The study will provide basic input for future planning, implementation, and monitoring of water use schemes and further optimal use to meet the increasing demands for basic human needs and welfare.

### **1.6 Scope of study**

This thesis was carried out the impacts of water resources development and flow alteration in whole didessa sub-basin by WEAP and IHA tools, using the input data of streamflow record from 1990 to 2015 years, and meteorological variables such as rainfall, temperature, wind speed, and relative humidity their daily values used. The supply sources considered are river and precipitation, demand sites such as Domestic, Irrigation, Livestock, and Environmental flow requirements, to analyze their impact on water resources development by developing different scenarios.

### **1.7 Structure of the thesis**

This thesis deals with the impact of water resource development and flows alteration in the Didessa sub-basin case Didessa sub-basin case divided into five chapters.

Chapter one includes the study's brief introduction, problem statement, objectives of the research. Chapter two dealt with the literature review's brief clarification. Chapter three deals with the detailed description of the study area, the dataset and data sources used in the model, the topography, climate, soils, land use, land cover, and water resources system conditions, which were included in this chapter. It also deals with research methods and materials, which are used for the analysis of the supply and demands in the sub-basin. The fourth chapter explains the results and discussions of the study. It provides general hydrological analyses and water demands in the Didessa river basin, then discussion water demand and hydrological components in the study area and the interpretation of the main findings. Finally, the conclusions and recommendations of the study are points out in chapter five.

## 2 LITERATURE REVIEW

### 2.1 General Overview of Water Resources Development

The development of water resources mainly refers to the proper utilization of available resources either through the construction of hydraulic structures or natural resources protection.

To meet the demands of water for different sectors (e.g. Agriculture, Domestic Use, Industry, reservoir, etc.) water resource development increasing globally, nationally, and at local levels. Figure 2-1 shows the incremental water use of Agriculture, Domestic, Industry, etc.

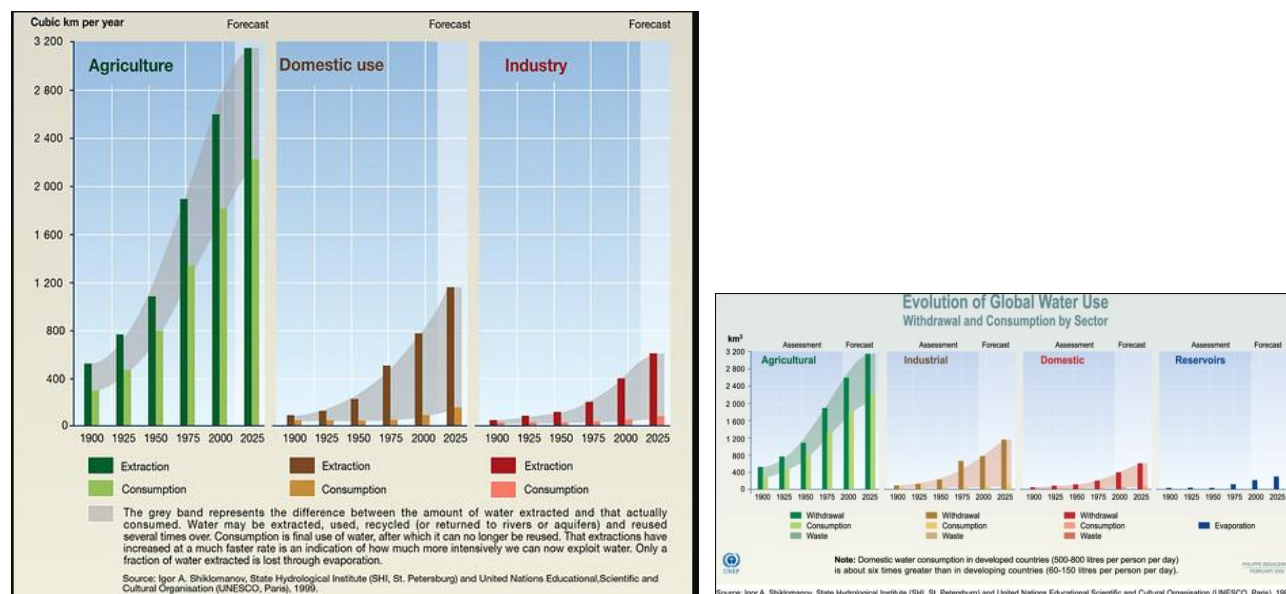


Figure 2-1 Globally water resources development (Asdrubali *et al.*, 2015)

### 2.2 Water Resources Potential in Ethiopia

As reviewed from Abbay basin IWRD plan the country, Ethiopia has 12 river basins: 8 river basin (Abbay, Awash, Baro Akobo, Genale Dewa, Mereb, Tekeze, Omo-Gibe, Webishebele), one lake basin (Rift valley lake basin), and three dry basins (Aysha, Dinakle, and Ogaden) that provide an estimated annual runoff of approximately 122 billion meter cubic (BMC) river water potential resources.

Abbay basin is one of the river basins from the 12-river basin of the country with a catchment area of 199,812 km<sup>2</sup>, covering three parts of Ethiopian regional states (Amhara, Oromia, and Benishangul Gumuz). It consists of the major sub-basins of Anger, Beles, Dabus, Debre Markos, Didessa, Dandir/Rahid, Fincha'a, Gudar, Jimma, Lake Tana, Mota, and Mugar. It accounts for twenty percent (20%) of the Ethiopian land area, for about fifty percent (50%) of total average annual runoff, for

twenty-five percent (25%) of its population, and over forty percent (40%) of agricultural production. Abbay river basin has 500m and 4261m the lowest and highest elevation respectively.

In terms of discharge per unit area, the surface water supply potential of the Didessa river basin, which is one of the sub-basins of the Abbay basin, was expected to have the highest water volume. The sub-basin consists of Anger, Dabena, Wama, Upper Didessa, and Lower Didessa main stem watersheds. Topographically, Didessa river basin has at an elevation range of 622m a.m.s.l and 3212m a.m.s.l.

## 2.3 Factors affecting water resource development

### 2.3.1 Climate change and human-induced abstraction

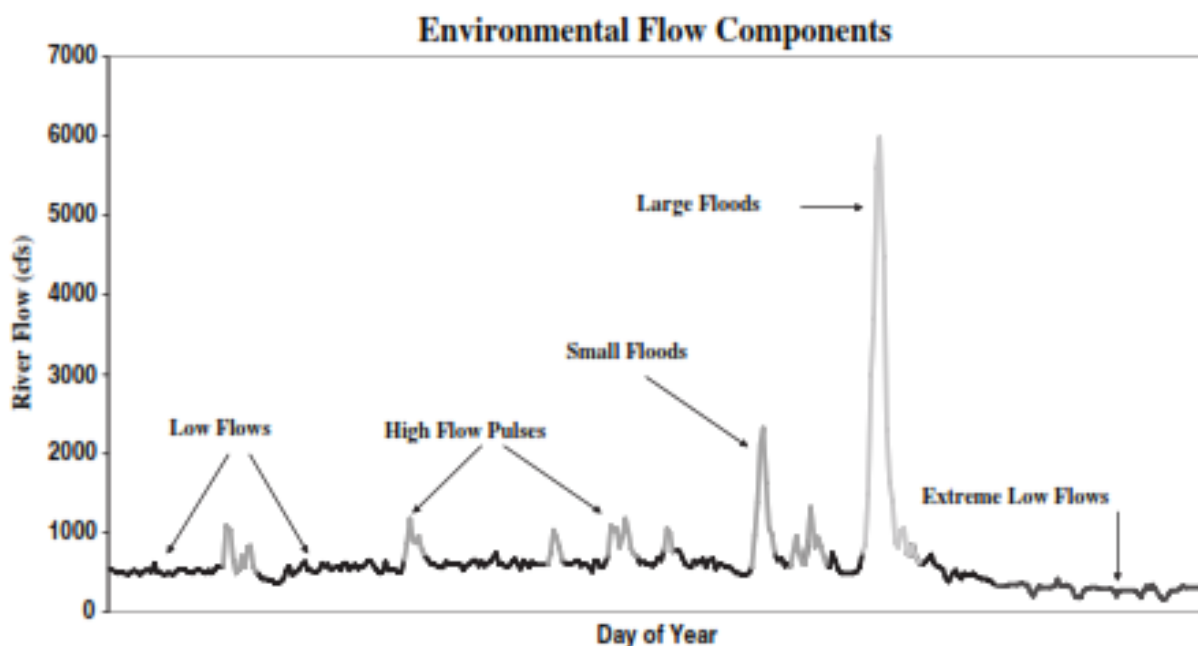
Climate change will affect the ecosystems and water resources developments of human systems like Agricultural, transportation, and healthy infrastructure. The climate variation change in the amount and pattern of precipitation may result in flooding and drought that brings a change in agricultural yield, reduced summer stream flows, species losses (extinctions) may cause an increase in the suicide rate of farmers. The couples' dynamics of six main variables (water storage capacity, capital, livestock, soil fertility, and fodder biomass) that are most relevant at the scale of smallholders bring risk in price and weather socks (den Besten *et al.*, 2016).

### 2.3.2 Environmental flow

At different times, environmental flows have been defined by different scientists. According to Poff *et al.* (2014) defined as ‘‘A flow regime (quantity, quality, and timing ) to sustain natural river functions and services while meeting human water demands.’’ The flow regime is a primary determinant of the structure and function of river ecosystems. Hydrologic alteration by human activities has impaired (reduced) river ecosystems on a global scale. There is some confusion between Environmental flows and Instream flow, a lot of people think about environmental flow as a flow that beneficial for the environment but also include human objectives. Instream flows are defined as flow regimes, associated physical habitat, connectivity, and water quality to sustain ecosystem functions for protecting or restoring freshwater and riparian ecosystems. To specify the group of things that relevant ecosystems of environmental flows are: Freshwater Ecosystems (what lives in the river), Riparian Ecosystems (what lives along the river) (both are the main objectives of Instream flow), and Terrestrial Ecosystems (what lives around the river). Freshwater Ecosystems include mammals (e.g.

Beavers), Aquatic flora, Fish communities, some Invertebrates, etc., and Riparian Ecosystems include Plant communities, Birds, some Invertebrates (Reptiles/ Amphibians). The terrestrial Ecosystem also includes mammals, Primary producers, Forest, etc.

The other part that relevant to Instream flow ecosystems are Quantity ( seasonal and inter-annual variability) how the flow change that the same river at the same location throughout different seasonal/years, which expressed by magnitude, timing, frequency, duration and rate of changes, Quality (Adequate along the river corridor) that include Temperature, PH, DO, BOD, Metals, Salinity. etc., the third one is Habitat (diverse throughout the networks) that also includes (channel forms, river types, and network Variability) (sediment transport and composition), and course woody habitats. And the fourth one is Connectivity (All directions) that assured that the river connected may be longitudinal, transversal (with surface water and groundwater). There are different methods for determining Instream flows, and those are Hydrology based that used Statistical methods to determine ecologically significant flow components, e.g. IHA, Function Flows, Tenant, etc., Hydraulic Rating based, Habitat Simulations and Holistic. In this paper, to determine Instream flow, use Hydrology-based methods by Indicators of Hydrologic Alteration (IHA) tools. According to 34 IHA parameters that apply to five flow components that have special ecological significance the ecological responses to river flow alteration illustrated in Figure 2-2 below.



Source: (Mathews *et al.*, 2007)

Figure 2-2 Special ecological significance of Environmental Flow Components

In fostering the chemical, physical and biological dignity of streams and rivers and the resources they offer, the natural flow regime of a water body, defined as the characteristic pattern of flow magnitude, timing, length, frequency, and rate of change, plays a critical role (Natural flow regime is the characteristic pattern of flow magnitude, timing, length, frequency, and rate of change).

## 2.4 Environmental Flow Requirements

To preserve the river ecology in a specified state, the environmental or in-stream flow requirement is also characterized as how much of a river's initial flow regime can continue to flow down it. The growing focus has been drawn to the environmental water demand or environmental flow requirement (EFR) of river basins. The most basic environmental water allocation activities rely on ensuring a minimum flow in a river downstream of the large abstractions. According to Tennant, the lowest feasible limit for EFR is 10% of MAR, as proposed in 1976. In the global situation, the moderately updated (Smakhtin et al., 2004) EFR figures obtained range from 20 to 50 percent of MAR.

## 2.5 Impacts of Water Resources Development

Water resources development is, (e.g. Dam, weir, barrage, etc.) one of human alteration of river flow patterns, which are the most obvious direct modifiers of river flow.

The impacts of water projects on the river flow regime and the Huai River Basin's surrounding environment were studied (Zhang *et al.*, 2010). Water resources development has positive impacts, negative impacts, social impacts, etc., which were discussed as follow:

### 2.5.1 Positive Impacts

Water resource development is one of the human activities used for a different purpose to increase productivity and upgrade the living standards of the population. The aim of improving water resource development is to increase agricultural production by implementing irrigated agriculture, thus achieving food self-sufficiency and food security and increasing the living standards for the area's population and nations.

### 2.5.2 Negative Impacts.

Human activities (Dam, Diversion, etc.) are the most driver of natural flow regimes that alter the river flow. The building of dams and reservoirs enables agricultural irrigation, flood management, power generation, and efficient water supplies as a widespread way of handling water resources, which decreases the river flow regime.

### **2.5.3 Socio-hydrology**

The development of water has its impacts on human water systems. The science that studies the relationship between humans and water and its impact is called socio hydrology. In 2012, the term socio-hydrology was coined by (Sivapalan *et al.*, 2012). It was defined as a “new science of people and water” that aims at “understanding the dynamics and co-evolution of the coupled human-water system”, and the competition for water between humans and ecosystems is set to become a flashpoint in the coming decades in many parts of the world. Socio-hydrology aims to cover the dynamic cross-scale interactions, and feedback between the natural and human processes that may give rise to water sustainability challenges that we face in the Anthropocene (Sivapalan *et al.*, 2014). Socio-hydrology treats society as an endogenous part of the water cycle and studies the impact of people on the water and water on people. This would result in a better understanding of long-term developments, better long-term predictions, and better water management support than approaches that treat society as exogenous, such as scenario-based approaches.

What are the difference and similarities between Socio-hydrology and Integrated Water Resources Management (IWRM)?

IWRM is a science which deals with also clearly and strongly about people and water. The main difference is that IWRM focuses on controlling or managing the water system to reach desired outcomes for society and the environment. In contrast, socio-hydrology focuses on observing, understanding, and predicting future trajectories of co-evolution coupled human water systems.

### **2.6 Indicators of Hydrological Alteration (IHA)**

The Indicators of Hydrologic Alteration software program was a suite of statistics developed by the US Nature of Conservancy (<http://www.nature.org/>) in the 1990s to assess the degree of hydrologic alteration caused by human activities, caused by various forms of river regulations (Gao *et al.*, 2009). The IHA consists of 67 parameters sub-divided into two groups; 33 IHA parameters and 34 EFCs parameters. The 33 IHA parameters lumped into five flow components: magnitude, frequency, duration, timing, and change rate of flows.

The Indicators of Hydrologic Alteration have been applied to several basins throughout the world to assess the impacts on streamflow caused by anthropogenic drivers (Conservancy, 2009a), Applications the Hydrologic Alteration (Taylor *et al.*, 2003; Mathews *et al.*, 2007), to evaluate the hydrologic

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variables and trends generated from daily streamflow data (Fentaw *et al.*, 2017). The scientific basis and some sample applications/computer programs of IHA were developed (Richter *et al.*, 1996; Richter *et al.*, 1997; Richter *et al.*, 1998). Together with ecological models, the IHA promotes the creation and testing of flow-ecology theories, the formulation of water and land conservation or restoration objectives, and the development of an oriented research and monitoring program, all of which are essential components of environmental flow setting processes (Mathews *et al.*, 2007).

The IHA uses daily data for its calculations (Conservancy, 2009b). The number of years of data needed for IHA is at least 20 years of data that was recommended by Fentaw *et al.* (2017). According to Taylor *et al.* (2003), 20 years of daily data was sufficient to characterize inter-annual variability for some parameters, but 35 or more years of daily data were needed for others. The general recommendation record lengths of data on IHA 20 years seems to be a good baseline requirement. The Range of Variability Approach (RVA)-based IHA technique is used to determine the degree of departure from the natural flow regime that has already occurred due to the building of dams. In order to set appropriate environmental flow goals, RVA is the most commonly used method for quantifying hydrological alterations with traditional and modified (scientific). The traditional RVA aims to detect the alteration of hydrologic flow regimes, and it is only considering the hydrologic parameters within a target range, even if, it is unable to reflect whether the frequency of hydrological parameters in the target range increases or decreases. The traditional range of variability approach was modified to consider the increase or decrease frequency of hydrologic parameters to solve this problem.

The IHA can compare two distinct periods in your Hydrologic record or analyze trends over a single period. Two-period analysis should be used when the hydrologic system you wish to study has experienced an abrupt change, such as constructing the dam. Single period analysis should be used for hydrologic systems that have experienced a long-term accumulation of human modifications. It can calculate statistics in Parametric or Non-Parametric Statistics. Parametric Statistics, in which the data are characterized by the mean and standard deviation. Non-Parametric Statistics, in which the data are represented by median and percentiles.

IHA parameters can be calculated as parametric (mean/standard deviation) or non-parametric (percentile) statistics. A key assumption of parametric statistics is that the data are normally distributed. Non-Parametric statistics are often useful because of the skewed (non-normal) nature of many hydrologic datasets.

The pre-impact streamflow data is classified into three distinct groups for RVA analysis; values up to 33 percentiles (lower category), 34 percentiles to 67 percentiles (middle category), and values greater than 67 percentiles (high category). For each of the three groups, a hydrological alteration component is determined as (observed frequency - expected frequency)/expected frequency.

## 2.7 General overview of the WEAP model

The **Water Evaluation And Planning**; abbreviated as WEAP, has been developed by Stockholm Environmental Institute (SEI) (Gaoa *et al.*; Sieber, 2006; Hoff *et al.*, 2007; Sieber *et al.*, 2007; Yates *et al.*, 2009; Mounir *et al.*, 2011; Gao *et al.*, 2017). The current version of the model is WEAP21. It is an integrated water resources planning tool used to represent current water conditions in a given area and explore the wide range of demand and supply options for balancing environment and development objectives. It is also an integrated hydrology/water allocation system and comprehensive planning framework; uses scenario analyses in understanding the effects of different development choices; demand management capability; Environmental assessment capability; and Ease of uses. The integration of WEAP is over several dimensions between water supply and demand, water quality and quantity and economic development, and environmental constraints. WEAP sets the demand and supply side of the equation in an organized way. Water use patterns, efficiencies, reuse, and allocation are placed on the demand side, while the supply side includes streamflow, groundwater, and water transfers. WEAP is a laboratory for examining alternative water development and management strategies. Furthermore, WEAP is the most commonly used tool for integrated water resource management (IWRM) worldwide.

WEAP consists of five main views: Schematic, Data, Results, Scenario explorer, and Notes. WEAP can address the broad range of “What if” questions by developing reference scenarios with various economic, demography, hydrological, and technological trend (Sieber *et al.*, 2007; Li *et al.*, 2015).

There are numerous applications of WEAP used as:

- **Integrated Approach:** Unique approach for conducting integrated water resources planning assessments,
- **Stakeholder Process:** Transparent structure facilitates engagement of diverse stakeholders in an open process,

- **Water Balance:** A database maintains water demand and supply information to drive mass balance model on a link node architecture,
- **Simulation-Based:** Calculates water demand, supply, runoff, infiltration, crop requirements, river flow, and storage, and pollution generation, treatment, and in-stream water quality under varying hydrologic and policy scenarios,
- **Policy Scenarios:** Evaluates a full range of water development and management options and takes account of multiple and competing uses of water systems,
- **User-friendly Interface:** Graphical drag and drop GIS-based interface with flexible model output as maps, charts, and tables.

## 2.8 Previous Study in Didessa Sub-basin

Different studies were conducted in Didessa Sub-basin considering different purposes. Different academic study and journal publications relevant for the study were reviewed and discussed as follows:

### 1. Morphometric Analysis of Didessa river catchment in Blue Nile Basin, Western Ethiopia

Tesfaye Muluneh and Wondimu Mamo, in 2014, are used GIS tools to evaluate the effect of morphometric parametric on hydrology and morphology of the basin, primarily used data was elevation model (DEM 30\*30) and the results are linear, areal, and relief aspects of the basin were computed use full for watershed-level planning and management.

### 2. Hydro-Geomorphological characterization of Didessa River Basin, Ethiopia

In 2018, as International Soil and Water Conservation Research, Gizachew Kabite and Berhan Gessesse, Characterized the hydro-geomorphology of the basin via basin morphometry analysis. The results, in the ArcGIS 10.3 environment, the analysis was done by SRTM DEM, Geological and hydrological maps of used data the stream length of all orders are found distributed within 28,637km<sup>2</sup> drainage area showed that 33468km.

### 3. Assessment of Spatio-Temporal Occurrence of Water Resources in Didessa Sub-basin, West Ethiopia

ADGOLIGN *et al.* (2015) study the assessment of spatial and temporary water resources in the Didessa Sub-basin West Ethiopia, using hydrological data set like: soil, land use and land cover, Digital

elevation model, flow, and metrological data by SWAT model they found that the monthly and annually flow in the sub-basin has a very good value for model performance evaluation parameters.

#### **4. Assessment of surface Irrigation potential of the Didessa River basin, Ethiopia**

Another study was done on the study area by Dawit *et al.* (2020) on the assessment of Surface Irrigation Potential of the Didessa River basin, using the input data set land use and land cover, stream flow data, and metrological data using the SWAT model, GIS application, and CROPWAT Model, they found that the model good performance for hydrology simulation and estimate the potential Irrigation based on the area to be irrigated and slopes requirements.

## 3 MATERIALS AND METHODS

### 3.1 Materials

#### 3.1.1 Study area description

##### 3.1.1.1 Location

Didessa Sub-basin is located in the southwestern portion of the Abbay Basin in West Ethiopia. Geographically, the study area is situated between 07°42'40''–09°58'17'' North latitude and 35°33'14''–37°07'52'' East longitude. Didessa Sub-basin is also expressed as topographically, at an elevation range of 622m a.m.s.l and 3212m a.m.s.l (from Didessa Sub-basin RawDEM). Physically, the Didessa basin drains four zones (Jima, Illubabor, East Wollega, and West Wollega) of the National Regional State of Oromia and Benishangul Regional State. Didessa River Basin (DRB) is one of the Abbay Basin's major tributaries (Blue Nile, Ethiopia) and provides the highest water volume in terms of discharge per unit area. Draining an area of nearly 34,000 square kilometers, the Didessa River originates in the Mountain Vennio and Mountain Wache ranges, flowing in an easterly direction for about 75 kilometers, and then turning rather sharply to the north until it reaches the Blue Nile River. They are three major tributaries of the Didessa River: the Wama, the Dabana, and Anger river that enter from the east, the west, and the east, respectively (Gebre *et al.*, 2015). Figure 3-1 shows the location of the Didessa River basin. As shown in the following Figure 3-1, the study area divided into five [5] catchments: Lower Didessa Catchment, Anger Catchment, Dabena Catchment, Wama Catchment, and Upper Didessa Catchment (Adgolign *et al.*, 2016).

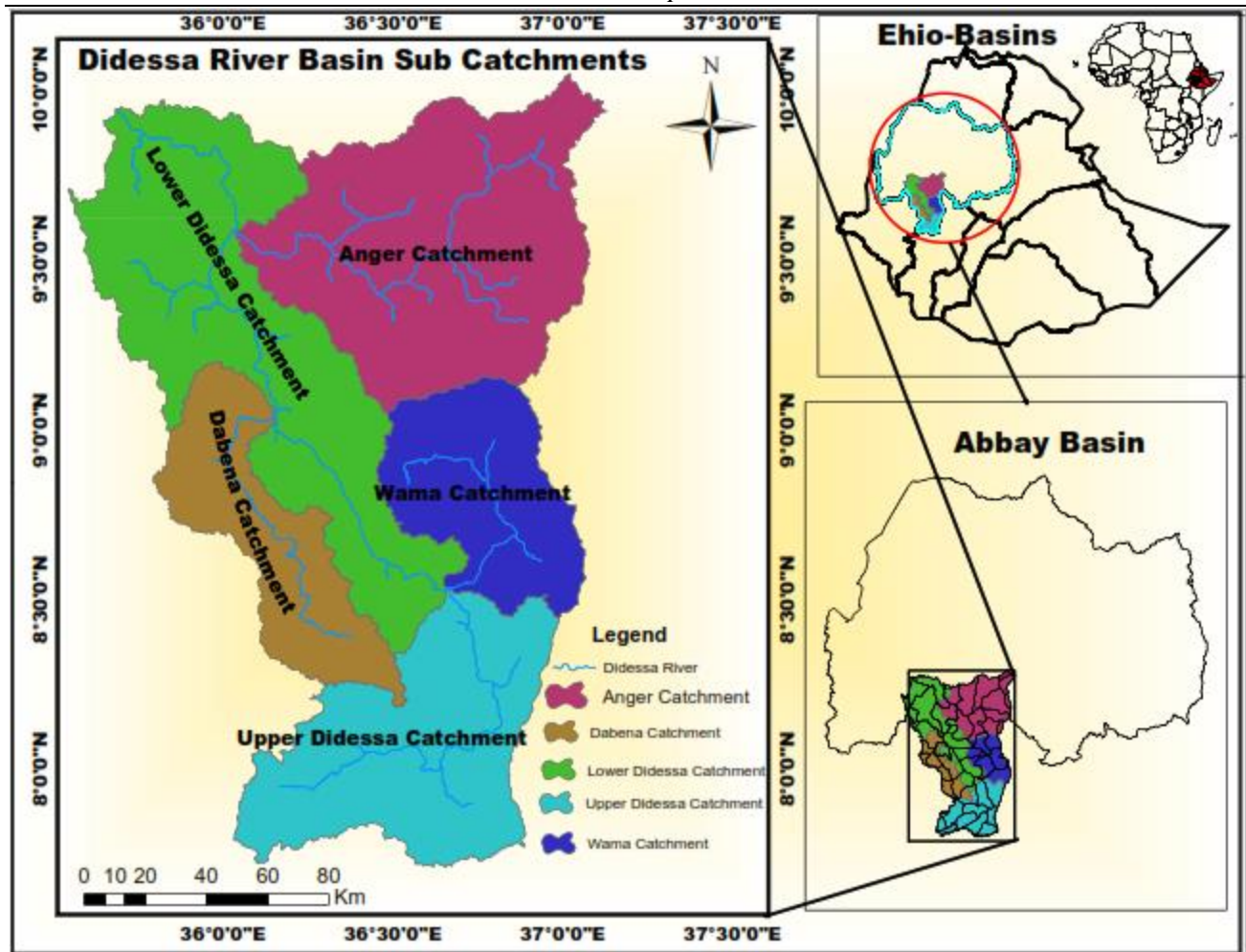


Figure 3-1: Location of the study area

### 3.1.1.2 Climate

The sub-basin climate is affected by the Inter-Tropical Convergence Zone movement (ITCZ) like many other river basins in Ethiopia.

The Didessa River is the largest tributary of the Abbay among the 16 sub-basins in terms of the amount of water contribution to the overall flow of the Abbay at the Sudanese border.

According to Hurni's (1986) classification, the country's traditional climate classification is based on altitude and temperature shows the presence of five climatic zones, namely, depicted in Table 3-1. From the traditional classifications of the country which are based on altitude and temperature, Didessa sub-basin is characterized by most in Woina Dega (Sub-tropical), partially Kola (Tropical) climate.

Table 3-1 Traditional climate classification in Ethiopia

Local class	Global definition	Description
Wurch	Alpine	The cold climate at more than 3000m altitude
Dega	Temperature	The highland climate within the range of 2500m-3000m
Woina Dega	Sub-Tropical	Warm between 1500m-2500m
Kola	Tropical	Hot and arid type, less than 1500m in altitude
Bereha	Desert	Hot and hyper-arid type climates, elevations generally below 500m

### 3.1.1.3 Topography

Physio-graphically, the Didessa river basin can be categorized into two broad units: the high land plateau and the associated low lands. The high land plateaus mainly embrace the Jimma- Ilu Abba Bora high lands, the Guduru highlands of Horo Guduru Wellega, while the associated low lands include the Didessa low lands. As illustrated in the following Figure 3-2, Didessa Sub-basin is also expressed as topographically, at an elevation range of 622m a.m.s.l and 3212m a.m.s.l

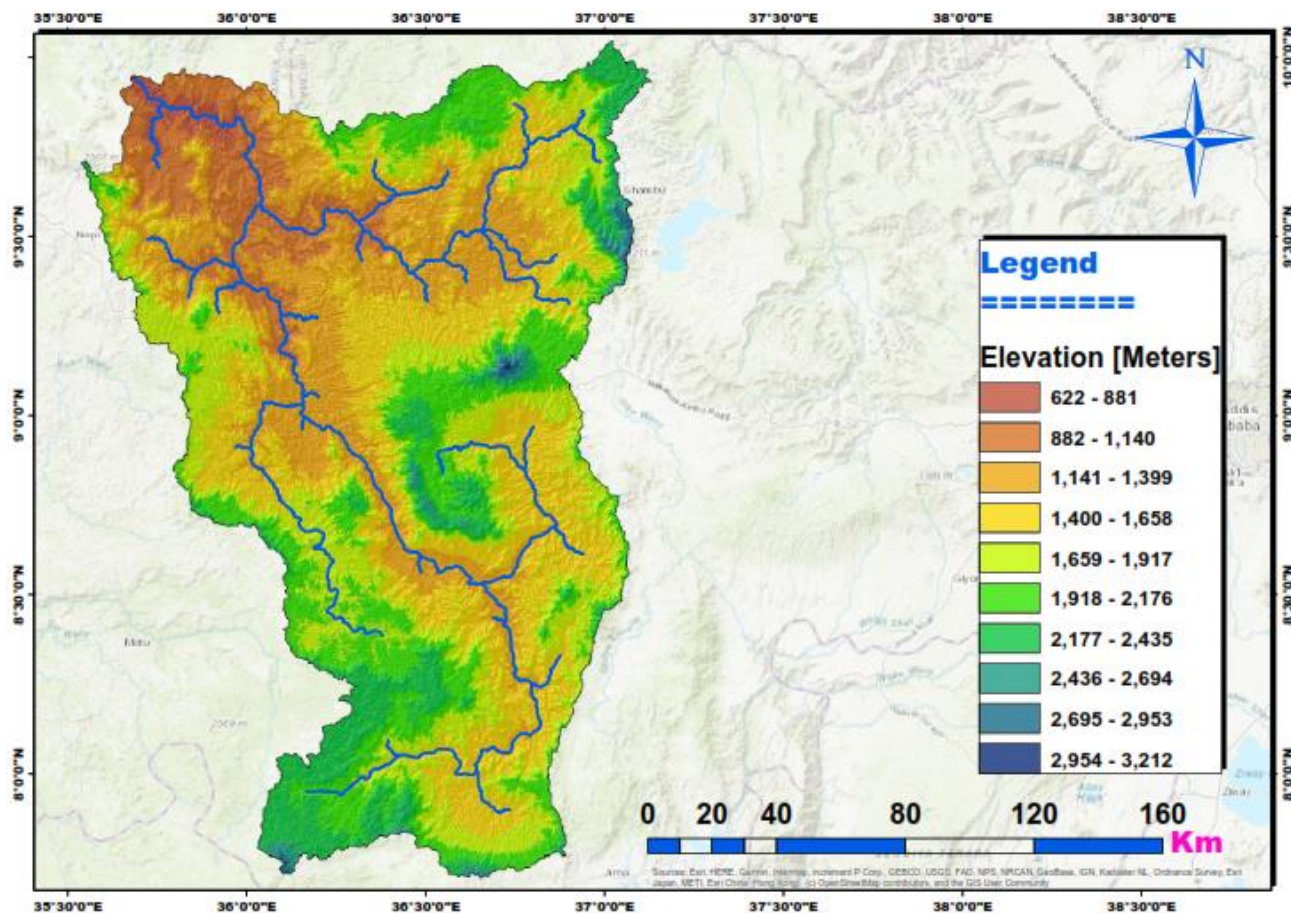


Figure 3-2 Didessa River Basin Elevation map

### **3.1.1.4 Soil types**

The majority of soil type found in the sub-basin area presented in Table 3-2 and Figure 3-3, the Haplic Alisols was the predominant Soil type in the study area, and the Haplic Arenosols was very low coverages soil type in the study area.

Table 3-2 Distribution of Soil type in Didessa Sub-basin

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<b>S. No</b>	<b>Soil Name</b>	<b>Area (Km<sup>2</sup>)</b>	<b>Percentage area coverage</b>
1	Dystric Cambisols	159.10	0.57
2	Dystric Leptosols	1202.26	4.30
3	Eutric Fluvisols	100.78	0.36
4	Eutric Leptosols	215.73	0.77
5	Eutric Regosols	8.5	0.03
6	Eutric Vertisols	1440.95	5.15
7	Haplic Acrisols	5316.05	19.01
8	Haplic Alisols	15692.03	56.12
9	Haplic Arenosols	0.03	0.00
10	Haplic Nitisols	1747.81	6.25
11	Rhodic Nitisols	2077.57	7.43

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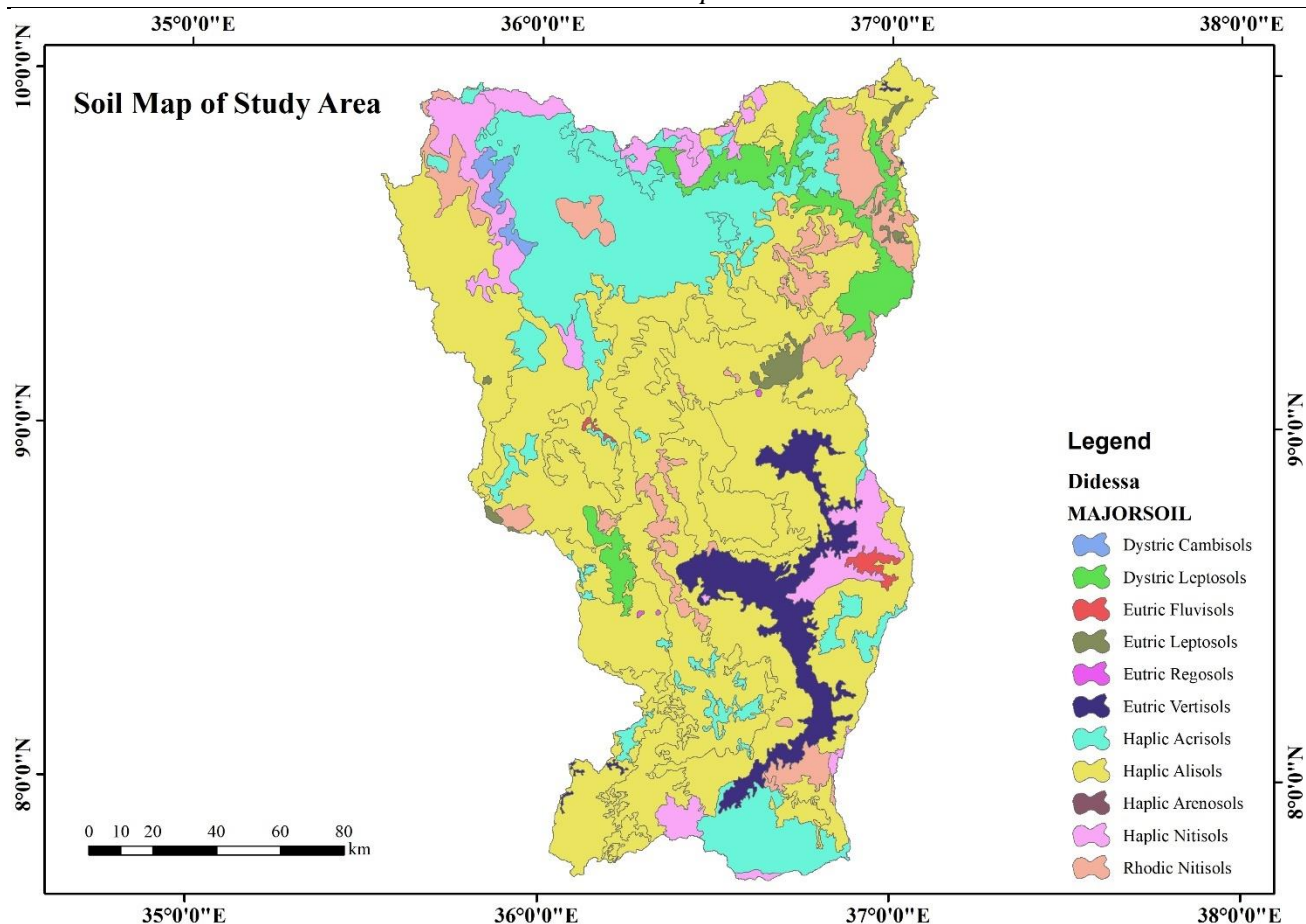


Figure 3-3 Soil map of the Study Area (MoWIE, 2006)

### 3.1.1.5 Land Use and Land Cover

The land use and land cover identified in the Didessa Sub-basin was depicted in Figure 3-4 below. The Traditional one was the major land use in the study area.

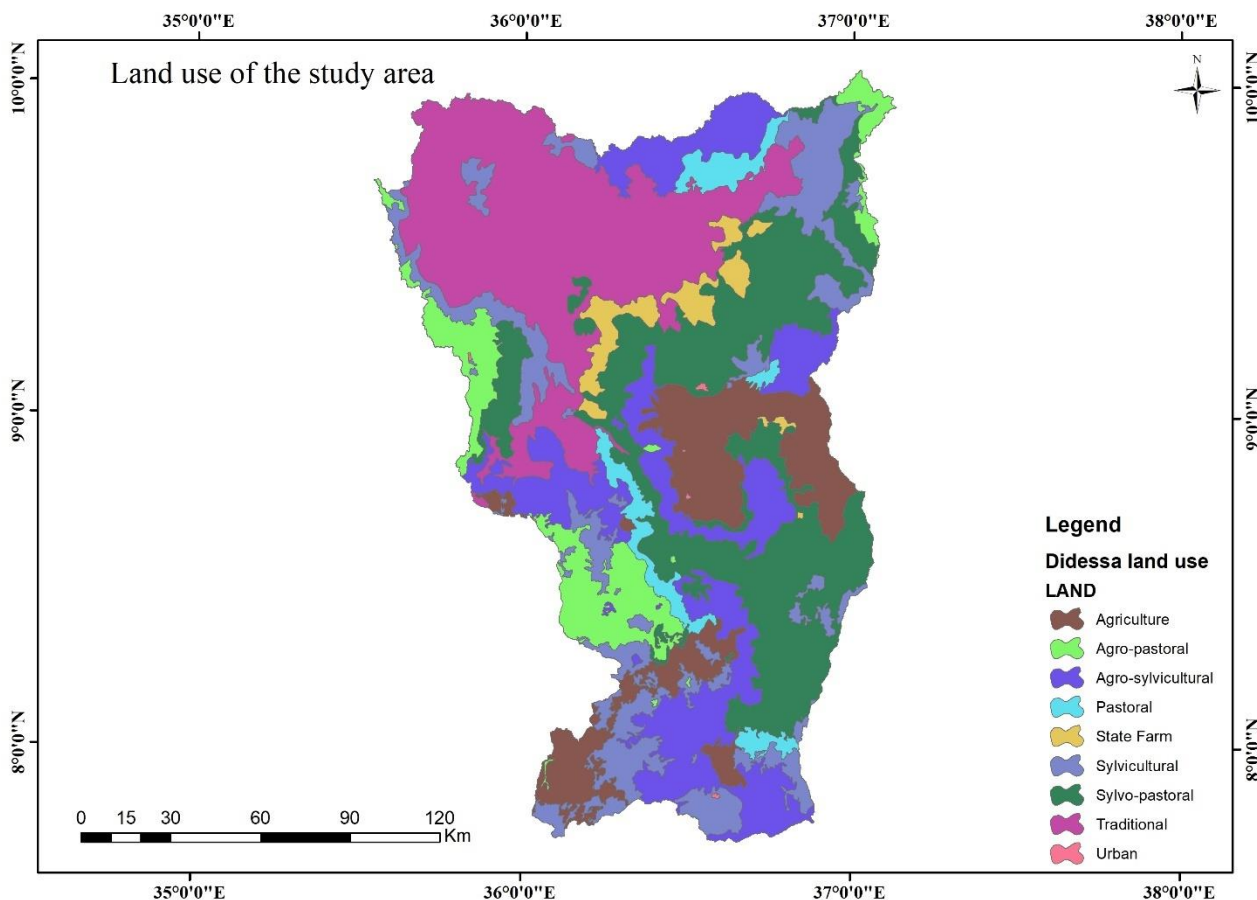


Figure 3-4 Land use and Land cover Map of the study area (MoWIE, 2006)

Didessa River Basin subtends six administrative zones which are depicted in the following in Table 3-3 and it covers around fifty woredas which shown in Figure 3-5.

Table 3-3 Regions and zones of the study area

S. No	Zones	Nº of Woredas	Woreda areas in the Basin (km <sup>2</sup> )	% share	Region
1	East Wellega	16	10381.64	37.03	Oromia
2	Horo Guduru	5	1681.98	6.00	Oromia
3	Ilubabor	9	5130.57	18.30	Oromia
4	Jimma	10	4651.21	16.60	Oromia
5	Kamashi	4	4280.50	15.27	B/Gumuz
6	West Wellega	6	1912.10	6.80	Oromia
Total Area coverage		<b>50</b>	<b>28038</b>	<b>100</b>	

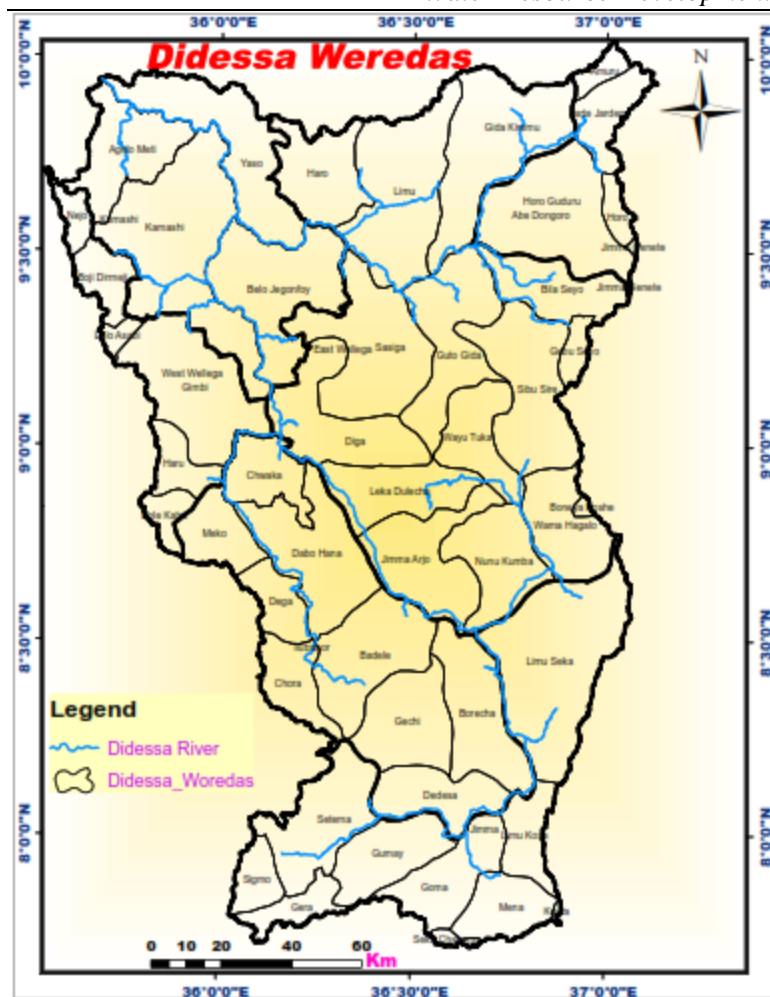


Figure 3-5 Weredas of the Didessa River Basin

The study area was divided into five catchments, and automatic delineation was done with the help of WEAP software, depicted in the following *Table 3-4* and *Figure 3-6*.

Table 3-4 Five catchments in Didessa sub-basin with coverage area in square kilometers

Name of the catchments	Areas (Km <sup>2</sup> )
Lower Didessa Catchment	8175
Anger Catchment	7865
Dabena Catchment	3272
Wama Catchment	3407
Upper Didessa Catchment	5586
Total of the whole catchments	<b>28305</b>

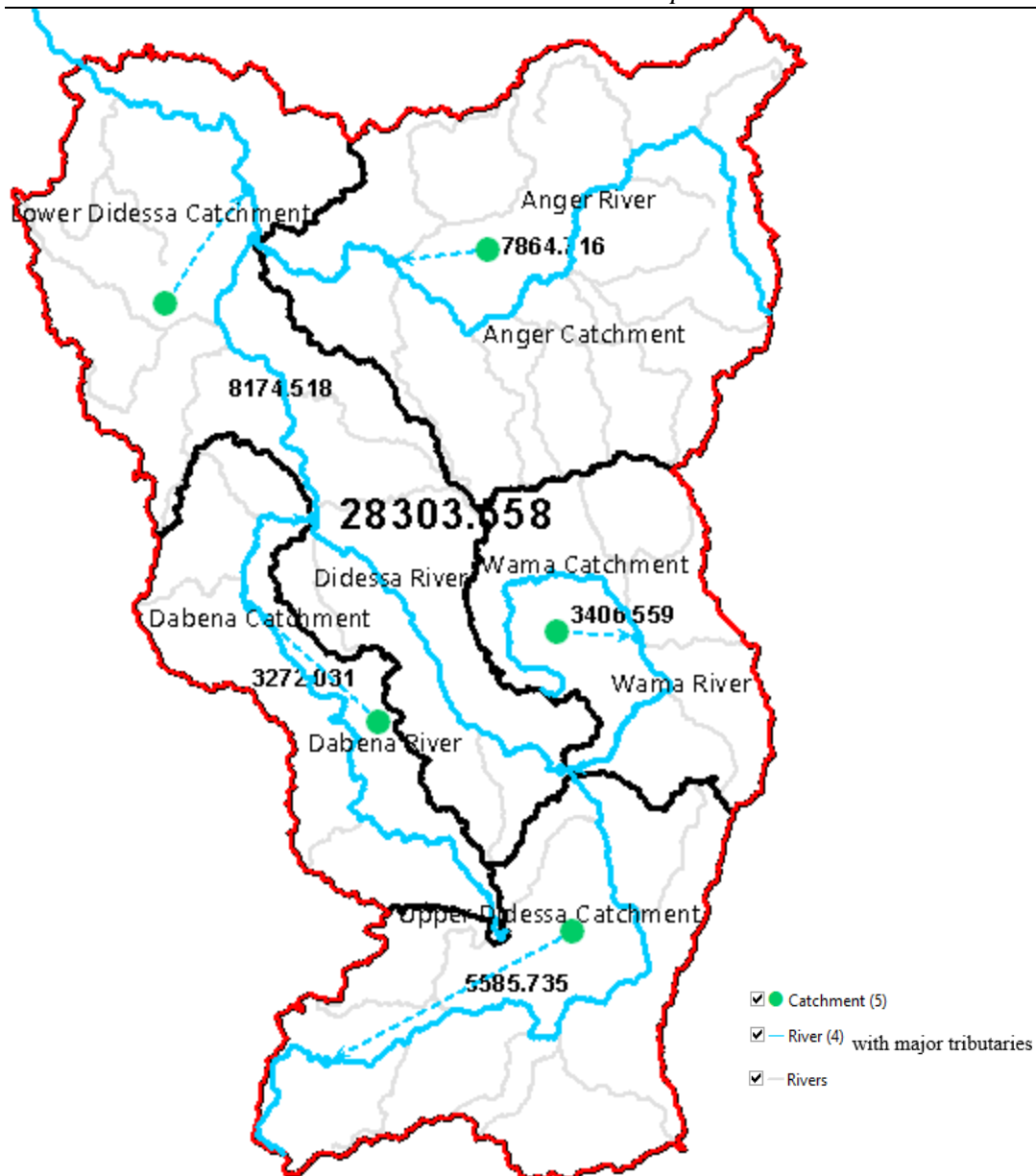


Figure 3-6 Didessa sub-basin catchments with the help of automatic delineation in WEAP

### 3.1.1.6 Demography

There are around more than 40 Woredas identified for analysis in the study areas. According to Ethiopia's Central Statistical Agency's (CSA) census data in 2014, 2015, 2016, 2017 at Woreda level and towns, its population number is projected. The exponential method of population projection was used to estimate the future population in the basin. From the year 2014 up to 2017, and 2020 the Didessa River basin's major towns projected population is presented in Appendix A and B, respectively.

### 3.1.2 Used software (Model), its purposes and sources)

For conducting any research tool is the basic, to conducting this study the following materials or model are used for analysis the research which is illustrated in *Table 3-5*.

Table 3-5 Summaries of Software used, purposes, and their sources

Name of Software	Purposes	Sources
ArcGIS 10.4.1	<ul style="list-style-type: none"> <li>• Locating the Study area</li> <li>• Study area delineation</li> <li>• Preparing Various thematic maps of the study area (e.g. Catchment, topography, drainage, etc.)</li> </ul>	Student trial licenses, From AAU FTP portal
WEAP21	<ul style="list-style-type: none"> <li>• Determining supply requirement, unmet demand, Scenario development</li> <li>• Physical Simulation of Demands and supplies</li> <li>• Simulation of catchments</li> <li>• Model Calibration (PEST Calibration)</li> </ul>	<a href="https://www.weap21.org/">https://www.weap21.org/</a>
IHA	<ul style="list-style-type: none"> <li>• To assess the hydrological regime alteration, to create Environmental Flow Components (EFCs), to draw Flow Duration Curves (FDC)</li> </ul>	<a href="http://www.nature.org/">http://www.nature.org/</a>
CROPWAT 8.0	<ul style="list-style-type: none"> <li>• To estimate Crop Water Requirement (CWR) and Irrigation Water Requirement (IWR), especially for Sugarcane</li> </ul>	<a href="http://www.fao.org/land-water/databases-and-software/cropwat/en/">(http://www.fao.org/land-water/databases-and-software/cropwat/en/</a>
ClimWAT 2.0 for CROPWAT 8.0	<ul style="list-style-type: none"> <li>• Derived Climate Data for CropWAT 8.0</li> </ul>	<a href="https://climwat-for-cropwat.software.informer.com/">https://climwat-for-cropwat.software.informer.com/</a>
EndNote	<ul style="list-style-type: none"> <li>• To organize all journals and insert citation</li> </ul>	

### 3.2 Methodology

The Figure 3-7 illustrates the WEAP model framework for the simulation of water supply and uses in the Didessa River Basin.



Figure 3-7 Conceptual flow chart of WEAP model

#### 3.2.1 Meteorological and Hydrological Data collection and its sources

Data used in this study were collected from different sources by visiting responsible government institutions and analyzed using different software. Meteorological, Hydrological, Topography data and data layers that used to conduct this research depicted in *Table 3-6* and *Table 3-7*.

Table 3-6 Data Requirements collection and Sources of data

Data types		Sources	Purposes
Hydrological data (Gauged Flow)	River flows	<ul style="list-style-type: none"> <li>MoWIE</li> </ul>	For IHA input and PEST Calibration in WEAP
	<ul style="list-style-type: none"> <li>Rainfall(mm)</li> <li>Temperature(°C) (Max. and Min.)</li> </ul>		WEAP inputs
Weather Data (Climate Data)	<ul style="list-style-type: none"> <li>Relative Humidity (%)</li> <li>Windspeed (m/s)</li> <li>Sunshine hours (hrs.)</li> </ul>	<ul style="list-style-type: none"> <li>NMA</li> </ul>	
Topography data	<ul style="list-style-type: none"> <li>Digital Elevation Model (DEM)</li> </ul>	<ul style="list-style-type: none"> <li>MoWIE</li> <li>SRTM</li> </ul>	Delineation of the Study area
Population	<ul style="list-style-type: none"> <li>Number of populations</li> </ul>	<ul style="list-style-type: none"> <li>Projected population of Ethiopia) (CSA, 2014,2015,2016 and 2017</li> </ul>	For WEAP input

Table 3-7 Short Summary of data layers and sources

Data types	Sources	GIS data types with cell sizes
STRM DEM	<a href="https://earthexplorer.usgs.gov/">https://earthexplorer.usgs.gov/</a>	Grid (30m)
Land use land cover	MoWIE	Grid (30m)
Soil types	MoWIE	Grid (30m)
Slope	Derived from DEM	Grid (30m)

Different criteria are used to selected meteorological and hydrological data. In this study, the requirements that are concerned to choose the weather and gauging stations area: (1) based on data classes, (2) long-term data availability, (3) percentage of missing, and (4) representativeness of the study area. Depends on the above criteria, around seven [7] weather stations and four [4] gauging stations are selected for this study, as shown in *Table 3-8* and *Figure 3-9*.

Table 3-8 Selected Meteorological station data with Scale/Period

S. No	Station Name	Rainfall [mm]	Scale/Period	Temperature [oC]		Scale/Period	Relative Humidity [%]	Windspeed [m/s]	Scale/Period
				Max	Min				
1	Anger	✓		✓	✓		✓	✓	
2	Arjo	✓		✓	✓		✓	✓	
3	Bedele	✓		✓	✓		✓	✓	
4	Didessa	✓	1986-	✓	✓	1986-	✓	✓	1986-
5	Gimbi	✓	2017	✓	✓	2018	✓	✓	2013
6	Nekemte	✓		✓	✓		✓	✓	
7	Shambu	✓		✓	✓				

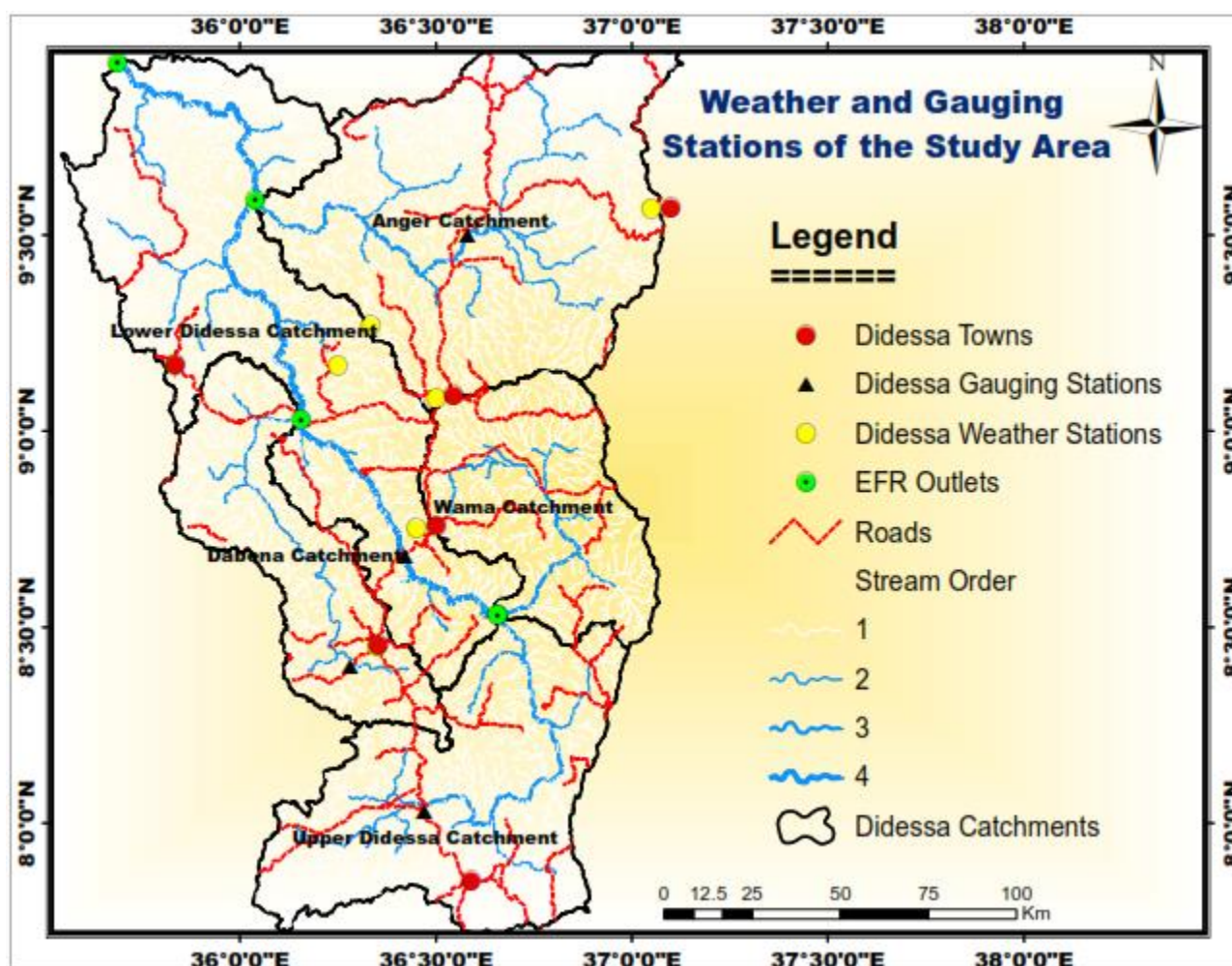


Figure 3-8 Selected weather and River flow gauging stations of Didessa sub-basin

### 3.2.2 Data Analysis, Quality control, and Processing

#### Rainfall data

Currently, seven [7] daily rainfall gauging stations used in this analysis have been selected in the Didessa River Basin based on long-term data availability, percentage of missing data, and basin representativeness which illustrated in Table 3-1.

Table 3-9 Selected Rainfall station in the study area

S. No	Station Name	Year	Elevation	Latitude	Longitude	% Missing
1	Anger	1986-2017	1350	9.267	9.267	17.88
2	Arjo	1986-2017	2565	8.75	36.5	14.46
3	Bedele	1986-2017	2011	8.45	36.33	8.74
4	Didessa	1986-2017	1310	9.383	36.1	9.18
5	Gimbi	1986-2017	1970	9.167	35.783	13.35
6	Nekemte	1986-2017	2080	9.083	36.463	10.12
7	Shambu	1986-2017	2460	9.571	37.121	7.75

For seven stations, the mean monthly precipitation of the Didessa River basin ranged from 3 mm (January) to 402 mm (June) in the period from 1986 to 2017. *Table 3-10* shows the characteristics of the Monthly Rainfall of selected stations.

Table 3-10 Mean Monthly rainfall the stations

Month	Anger	Arjo	Bedele	Didessa	Gimbi	Nekemte	Shambu
<b>Jan</b>	4.34	15.82	15.91	4.14	2.88	9.37	9.70
<b>Feb</b>	4.78	20.96	21.74	6.24	7.96	14.47	20.89
<b>Mar</b>	31.67	98.10	73.84	30.35	23.84	53.48	48.13
<b>Apr</b>	59.13	120.03	97.95	49.09	58.45	90.63	75.03
<b>May</b>	160.05	242.24	231.66	160.74	214.83	256.01	188.08
<b>Jun</b>	267.83	334.49	322.40	289.08	337.26	401.13	247.26
<b>Jul</b>	325.66	332.10	299.95	293.78	356.54	400.02	324.08
<b>Aug</b>	312.86	347.77	297.01	268.03	342.84	383.08	312.93
<b>Sep</b>	284.20	278.83	286.81	242.23	316.55	280.20	234.63
<b>Oct</b>	132.17	132.92	144.12	118.56	144.10	147.67	81.30
<b>Nov</b>	25.76	58.62	33.29	30.04	20.73	49.62	30.17
<b>Dec</b>	8.53	28.12	23.26	8.59	22.37	17.87	18.87

The mean annual distribution of rainfall across the seven Didessa River Basin stations ranges from 1500 mm to 2104 mm at the Didessa and Nekemte stations, respectively. The characteristics of the Mean Annual rainfall at the selected stations are shown in Figure 3-9 and tabular annual rainfall for the stations depicted in Appendix E.

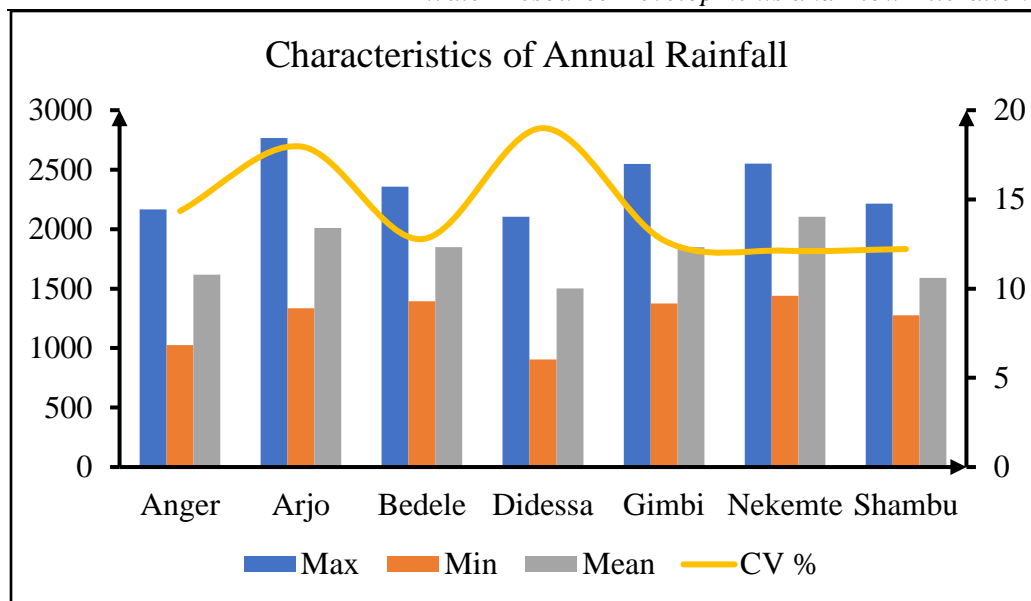


Figure 3-9 Characteristics of Annual Rainfall of Selected Stations

In order to identify the degree of variability of rainfall events as less ( $CV < 20$ ), moderate ( $20 < CV < 30$ ), high ( $CV > 30$ ), very high  $CV > 40$  and  $CV > 70$  percent, the coefficient of variation (CV %) is used. The coefficient of variability (CV) of rainfall in Ethiopia varies from 10 percent to 70 percent, of which areas with CV above 30 percent are vulnerable to drought (Gebremicheal *et al.*, 2014).

As shown in Table 3-11 below CV, all selected stations are categorized under less rainfall variability, varying from 12.13 percent to 18.99 percent, respectively, for Nekemte and Didessa station.

Table 3-11 Coefficient of Variation and Standard deviation of selected rainfall stations

S No	Station Name	SD	CV %
1	Anger	231.97	14.35
2	Arjo	361.05	17.96
3	Bedele	236.09	12.78
4	Didessa	285.08	18.99
5	Gimbi	234.68	12.70
6	Nekemte	255.08	12.13
7	Shambu	194.40	12.22

### Temperature

One of the necessary data for the soil moisture method in the WEAP model is the weighted mean temperature. NMA, which is the daily minimum and maximum temperature measured at selected stations from 1986 to 2018, was used to obtain the temperature data used in this analysis.

**Reference Evapotranspiration (ET<sub>o</sub>)**

As explained under Irrigation Water Demand, Reference Evapotranspiration (ET<sub>o</sub>) was calculated by the Hargreaves method depending on the maximum and minimum temperature of the selected station, maximum in March and minimum in July. The characteristics of mean Monthly ET<sub>o</sub>, that is, maximum in March and minimum in July of the selected stations, are shown in Table 3-12 below.

Table 3-12 Mean Monthly, Maximum, and Minimum ET<sub>o</sub> of the study area

<b>Month</b>	<b>Anger</b>	<b>Bedele</b>	<b>Didessa</b>	<b>Gimbi</b>	<b>Nekemte</b>	<b>Shambu</b>
<b>Jan</b>	154.69	137.79	173.79	138.60	129.45	119.29
<b>Feb</b>	156.36	140.11	176.38	141.88	133.28	120.03
<b>Mar</b>	178.44	158.79	203.38	166.97	153.40	141.02
<b>Apr</b>	174.25	151.14	190.84	159.69	144.90	136.94
<b>May</b>	161.61	141.87	172.47	145.95	132.84	132.25
<b>Jun</b>	137.73	120.65	146.79	123.13	112.17	113.58
<b>Jul</b>	132.14	114.83	134.92	117.75	106.44	105.62
<b>Aug</b>	135.41	119.31	141.63	119.20	108.23	106.95
<b>Sep</b>	138.42	126.46	147.73	124.93	115.19	111.35
<b>Oct</b>	141.26	132.94	158.55	128.57	122.85	115.67
<b>Nov</b>	140.14	125.17	153.58	121.55	114.89	110.83
<b>Dec</b>	143.83	130.34	161.27	125.35	119.73	112.65
<b>Max</b>	178.44	158.79	203.38	166.97	153.40	141.02
<b>Min</b>	132.14	114.83	134.92	117.75	106.44	105.62

**Data Quality control**

Before using any data, quality control is the most important for the results. The basic idea of data quality control is detecting gaps in the data, detecting physically impossible values, and controlling spatial consistency.

**Filling Missing Data**

In meteorological and hydrologic observational datasets, missing data is a common issue.

Instruments may split, or they may interrupt the transmission of data. Hence, filling in missing data is very important to perform hydrological analysis and simulation using long-time series data. There are several methods have been proposed to estimate missing rainfall and river flow data. The long-term year method was used in this study to fill missing rainfall data, and the Normal Ratio method was used to filling river flow data.

$$P_x = \frac{N_x}{N} \left( \frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} \dots + \frac{P_n}{N_n} \right) \tag{3-1}$$

where,  $P_x$  = missing values of precipitation to be computed,

$N_x$  = Average values of rainfall for the station in question for recording period,

$N_1, N_2, N_3, \dots, N_n$  = Average values of rainfall for the neighboring station,

$P_1, P_2, P_3, \dots, P_n$  = Rainfall of neighboring station during missing period,

$N$  = Number of stations used in the computation

### Homogeneity Test of rainfall time series in RStudio

The homogeneity of the time series is the other criteria used to assess the quality control of data. Using RStudio, RStudio-1.3.1093.0, based on four homogeneity test methods: Pettitt 's test, Regular normal homogeneity test (SNHT), Buishand 's test (BRT), and Von Neumann's ratio (VNR) test, the homogeneity of the annual total rainfall was examined. The result summary of those four tests is shown in the following Table 3-13. Based on an alpha value of 0.05 (95 percent significance level), the series is thus homogeneous if the p-value is greater than the alpha value.

Table 3-13 Summary of Homogeneity test results

S. No	Station Name	Methods				Result
		Pettitt's	Bushland's	SNHT	Von Neumann's	
1	Anger	0.5545	0.1852	0.5004	0.0255	Useful
2	Arjo	<0.001	<0.001	<0.001	<0.001	Suspect
3	Bedele	0.6604	0.4415	0.4517	0.1731	Useful
4	Didessa	0.8379	0.518	0.5761	0.2809	Useful
5	Gimbi	0.9446	0.9261	0.3061	0.4616	Useful
6	Nekemte	0.4597	0.4667	0.08975	0.08621	Useful
7	Shambu	0.0995	0.06845	0.0103	0.3574	Useful

### Test for Outliers

Because outliers affect statistics, especially higher-order statistics, it is recommended that outliers are checked and higher and lower data removed before use. The outlier test is one of the data qualities measures that influence the statistics. Before using it, it is recommended to test outliers and exclude the higher and lower ones. The Water Resources Council's approach advises that the outliers rely on the values of skewness to make changes for Outliers if the station skew is greater than 0.4 and less than -0.4, extreme events that might be high and low outliers are first evaluated, respectively. If the station skew is between -0.4 and 0.4, before removing any outliers from the sequence, tests should be performed with both the high and low outliers.

$$Kn = -3.62201 + (6.28446 * (N^{0.25})) - (2.49835 * (N^{0.5})) + (0.491436 * (N^{0.75})) - (0.03791 * N) \quad (3-2)$$

$$HL = e^{(mean + Kn * SD)}, \quad LL = e^{(mean - Kn * SD)} \quad (3-3)$$

where,  $N$  = Number of data,  $SD$  = Standard deviation,  $HL$  = Higher limit time series,  
 $LL$  = lower limit of time series

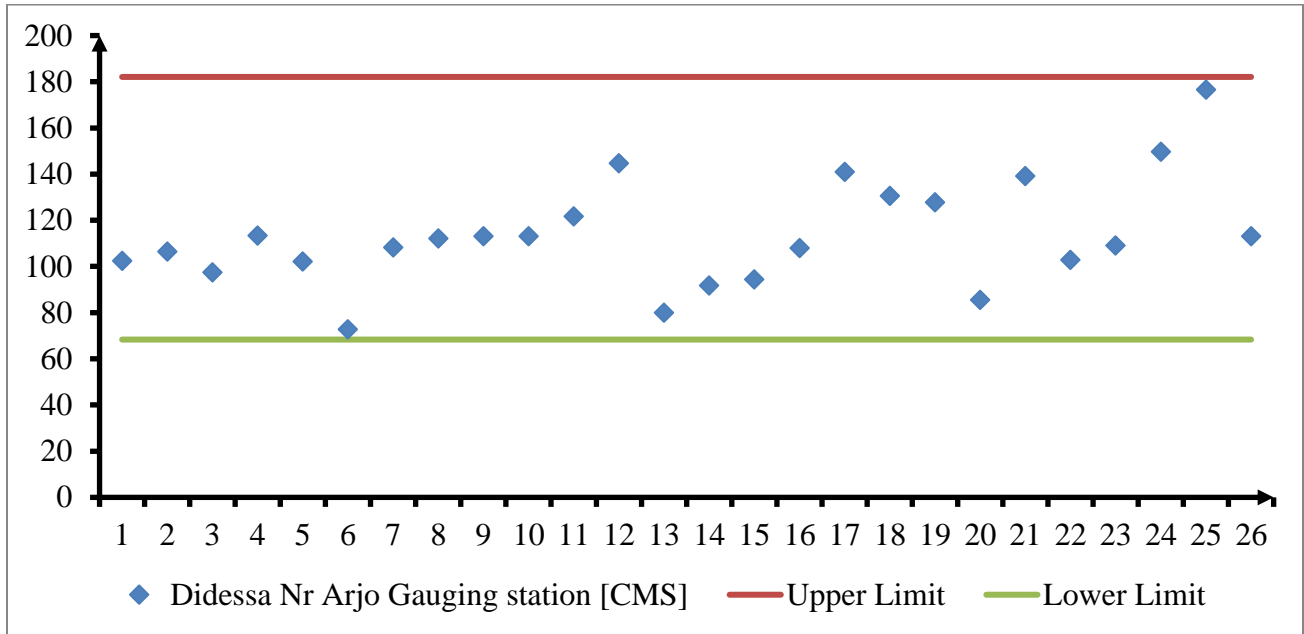


Figure 3-10 Testing Outlier for Didessa Nr Arjo gauging Station [CMS]

Not only Hydrological data but an Outlier test also mandatory for rainfall data before input into the software. The following Figure 3-11 display the outlier graph of the Didessa station.

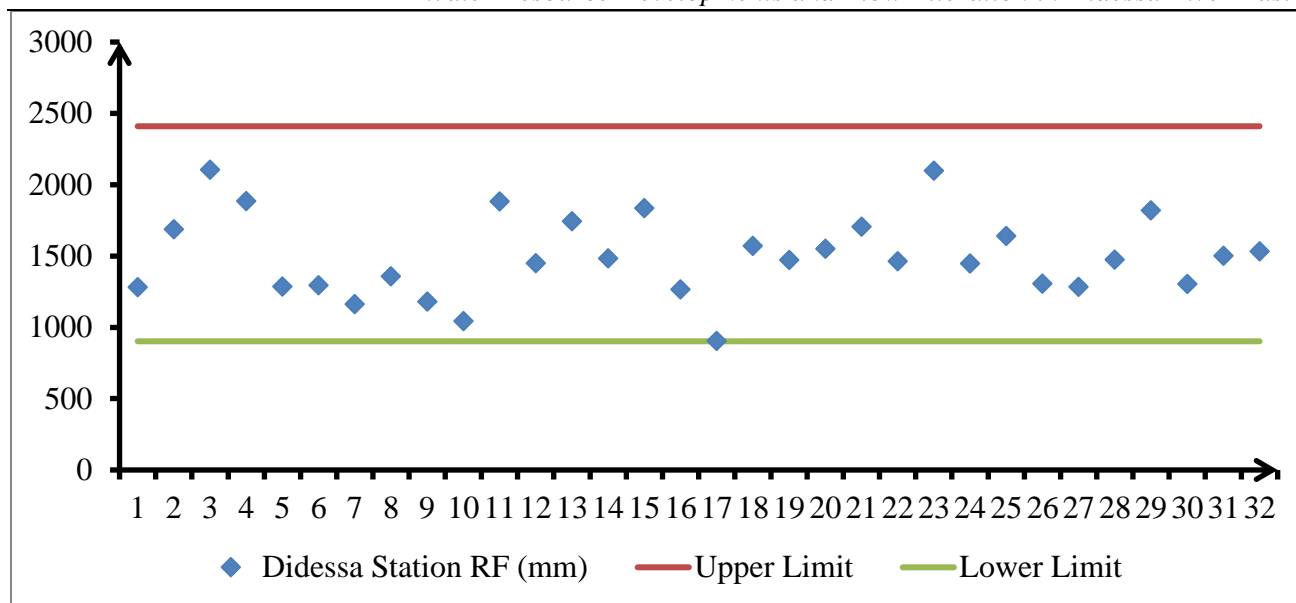


Figure 3-11 Outlier test Didessa Station Rainfall [mm]

The Remaining station of the outlier graph test was attached in Appendix-G.

### Double Mass Curves (DMC)

Filled data must also be tested for patterns that may suffer from irregular trend data. During the recording period, the rainfall recording of the rain gauge stations has experienced a major change for different reasons; there will be uncertainty in that station's rainfall data. A record is tested for inconsistencies by a double mass curve technique.

$$Ma = \frac{Sa}{So} * Mo \tag{3-4}$$

where,  $Ma$  = adjusted Precipitation(mm),  $Sa$  = slope of graph at time  $Po$  was observed

$Mo$  = observed precipitation(mm),  $So$  = slope of a graph to which records were adjusted

The double Mass Curve is one of the most popular techniques used by comparing data for a single station with a pattern composed of the data from many other stations to verify the accuracy of several kinds of hydrological data.

For a representative group of neighboring gauges, the cumulative sum of the individual gauge is compared with the corresponding totals. If a determined shift in the curve regime is detected, corrections should be made. There is no need for further modification, however, as all the selected stations in this study were consistent. Two stations (Anger and Bedele) are shown as a sample in Figure 3-12, and the other selected stations are shown in Appendix H.

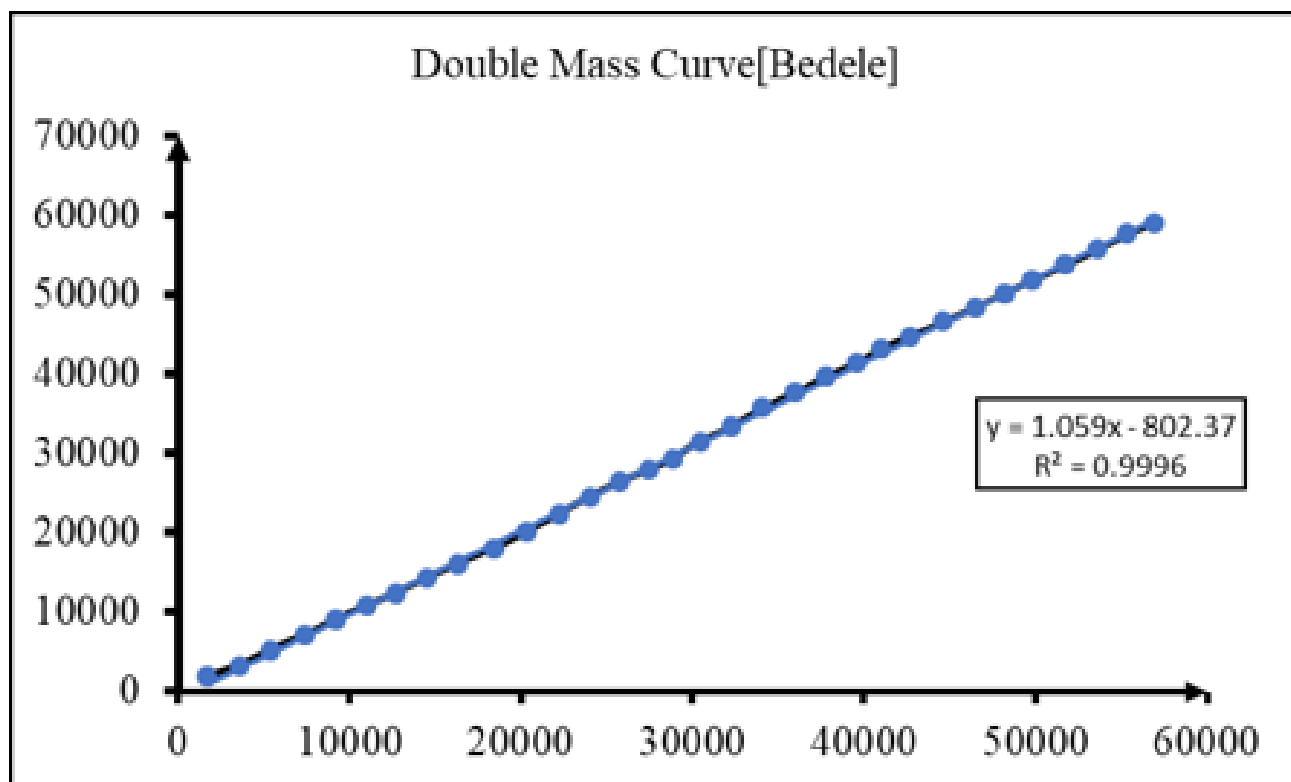
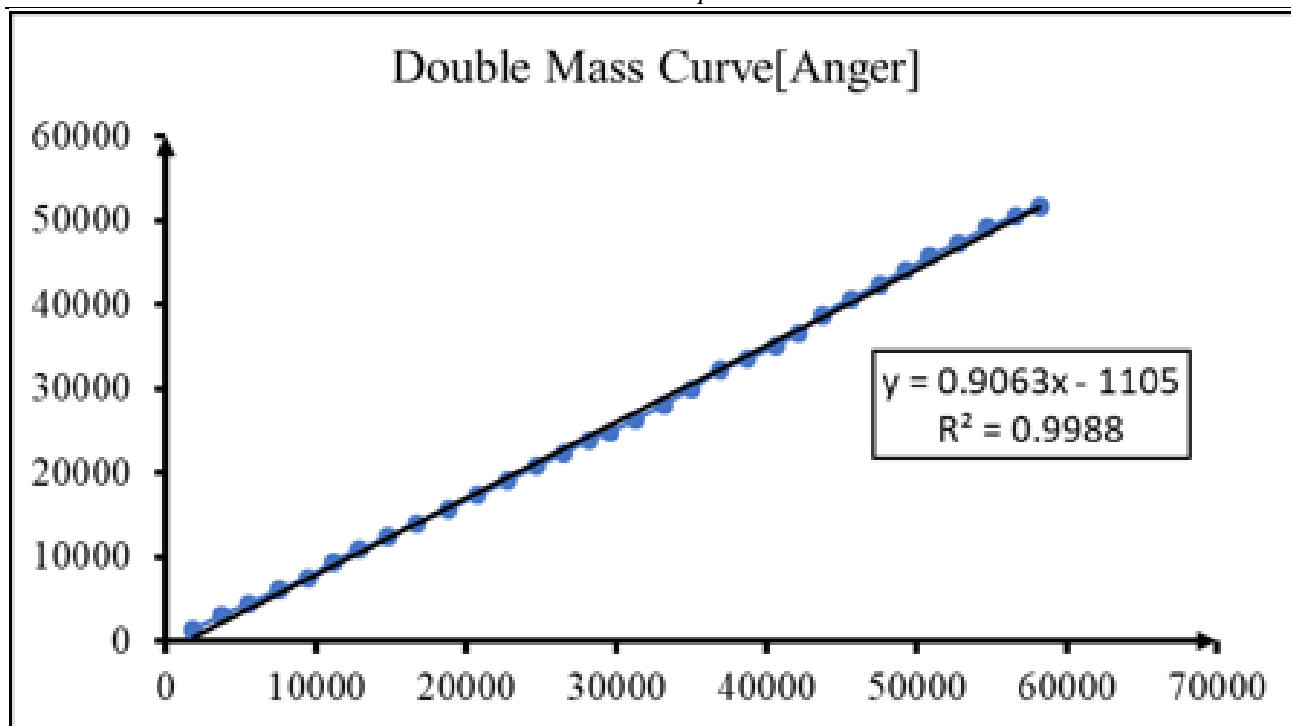


Figure 3-12 Sample Double Mass Curves of two Stations [Anger and Bedele] to check data trend

### **3.2.3 Methodology to determine the surface water potential**

#### **3.2.3.1 WEAP Model setup**

Schematic, Data, Results, Overviews, and Notes are the five key views in WEAP. The schematic view is a collection of GIS-based methods for quickly arranging the system's components, such as demand nodes, rivers, and reservoirs. The data view helps you to create variables and relationships, as well as enter expectations and predictions, as well as dynamically connect to Excel. In charts and tables, as well as on the Diagram, the resulting view allows for a detailed and versatile display of all model outputs. The summary, on the other hand, highlights the main device metrics for easy viewing. Finally, the notes view helps you to keep track of your details and assumptions. To build WEAP for an area, a typical stepwise approach was used:

- Create a geographic representation of the area,
- Enter the data for the different supply and demand sites,
- Compare results with observations and simulated model data,
- Define scenarios, and
- Compare the results of the scenarios.

#### **3.2.3.2 WEAP simulation Methods**

The WEAP model was used to simulate both the hydrological behavior and anthropogenic activities of water resources to analyze the water availability in the basin. To simulate the catchments of rainfall-runoff, the WEAP model uses five [5] methods: [1] Rainfall-Runoff (simplified Coefficient method), [2] Irrigation demand only (simplified Coefficient method), [3] Rainfall-Runoff (Soil Moisture methods), [4] MABIA (FAO 56, dual KC, daily), and [5] Plant growth (daily; Co<sub>2</sub>, water, and temperature stress effects) based on a daily or monthly basis. For this analysis, the soil moisture method was selected for catchments because it allows for the characterization of the impacts of land use and soil types on these processes.

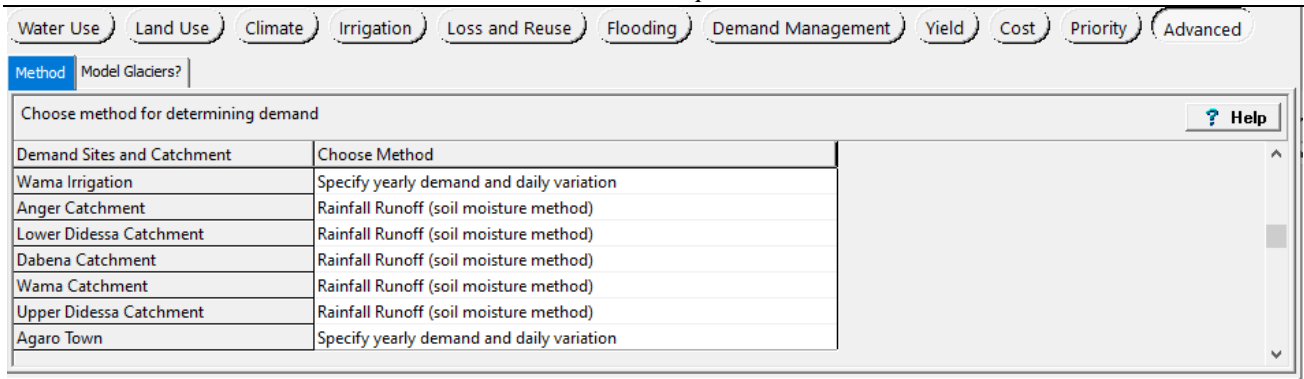


Figure 3-13 Rainfall-Runoff (Soil Moisture Method) simulation methods for the catchments

This method divided soil into two layers. It is a 1-D, 2-bucket water accounting method based on empirical functions used to explain the deep percolation, evapotranspiration, surface runoff, and interflow for the basin.

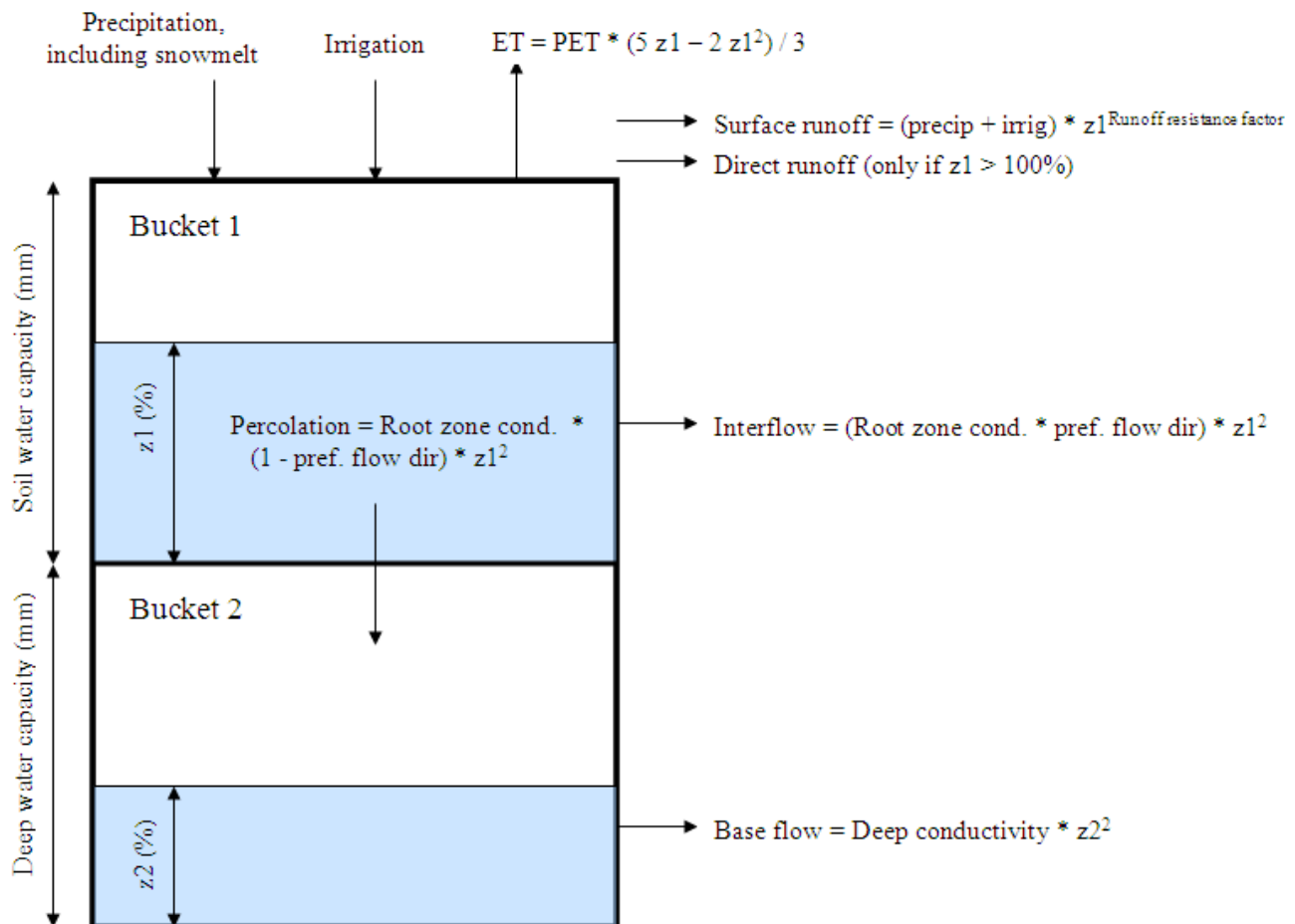


Figure 3-14 Conceptual Diagram of Soil Moisture Method (sources: WEAP User Manual)

Soil Moisture Method in WEAP simulation model converses the climate in each catchment to flow to the river or groundwater nodes. The initial  $Z_1$  and  $Z_2$  are the relative storage, expressed as a percentage

of the total water capacity of root zone and deep zone respectively. The mathematical (soil moisture calculation algorithms) for both root and deep zones are illustrated in the following equations 3-5 and 3-6 respectively:

$$Sw_{,j} \frac{dZ_{1,j}}{dt} = P_e(t) - PET(t)k_{c,j}(t) \left( \frac{5Z_{1,j} - 2Z_{1,j}^2}{3} \right) - P_e(t) Z_{1,j}^{\frac{RRF_{,j}}{2}} - f_j k_s Z_{1,j}^2 - (1 - f_j) k_s Z_{1,j}^2 \quad (3-5)$$

$$Dw_{,j} \frac{dz_{2,j}}{dt} = (1 - f_j) k_s Z_{1,j}^2 - k_d Z_{2,j}^2 \quad (3-6)$$

### 3.2.3.3 Sensitivity Parameters

The sensitivity parameters identified in the WEAP software are listed in the following Table 3-14.

Table 3-14 Identified sensitive parameters

S. No	Variables/Parameters	Ranges	Default	Units
1	Crop coefficient, <b>Kc</b>	0-∞	1	
2	Soil Water Capacity, <b>Sw</b>	0-∞	1000	mm
3	Deep Water Capacity, <b>DW</b>	0-∞	1000	mm
4	Runoff Resistance Factor, <b>RRF</b>	0-∞	2	
5	Root Zone Conductivity, <b>Ks</b>	0-∞	20	mm/month
6	Deep Conductivity, <b>Kd</b>	0-∞	0	mm/month
7	Preferred Flow Direction, <b>f</b>	0-1	0.15	
8	Initial Z, <b>Z1</b>	0-100	30	%
9	Initial Z, <b>Z2</b>	0-100	30	%

### 3.2.4 Model Efficiency

Indicators for model performance measurement are used to verify how well the model works. Correlation coefficient ( $R^2$ ) and Nash-Sutcliffe efficiency (NSE) are often used to assess hydrological model performance evaluations in this study. They are calculated manually using observed and simulated flow data. The Didessa River Basin WEAP model was calibrated and validated at the Near Arjo gauging station in CMS using daily streamflow recorded from 1990 to 2008 and 2009 to 2017. As an objective function, the determination coefficient ( $R^2$ ) and Nash-Sutcliffe Efficiency (NSE) were used to calibrate and validate the model using the flow-sensitive parameters. For both calibration and

validation, model performance was assessed in various ways, including the coefficient of determination and efficiency of Nash-Sutcliffe. The following Equations 3-7 and 3-8 are shown statistically computed formulas used to determine the model efficiency,  $R^2$  and NSE, respectively:

$$R^2 = \frac{(\sum [Q_{si} - Q_{si_{avg}}][Q_{ob} - Q_{ob_{avg}}])^2}{\sum [Q_{si} - Q_{si_{avg}}]^2 \sum [Q_{ob} - Q_{ob_{avg}}]^2} \quad (3-7)$$

$$NSE = 1 - \frac{\sum (Q_{ob} - Q_{si})^2}{\sum (Q_{ob} - Q_{ob_{avg}})^2} \quad (3-8)$$

### 3.2.5 Model Calibration and Validation

WEAP provides a link to a parameter estimation tool (PEST) that enables the user to automate the process of comparing WEAP outputs with historical observations and to improve its accuracy by changing model parameters. It is a software computer for model-independent parameter estimation and analysis of uncertainty. In the weighted least squares context, PEST can "take control" of a model, run it as many times as it needs to while changing its parameters until the differences between selected model outputs and a supplementary collection of field or laboratory measurements are reduced to a minimum (Agarwal *et al.*, 2018).

### 3.2.6 Methodology to determine water demands

#### 3.2.6.1 Assessment of Demand Sites

The major demand sites in the Didessa river basin, Adgolign *et al.* (2016) argued, are Irrigation, Domestic water, and hydroelectric power demand sites. This paper's demand site is Agricultural water demands, Domestic water demands and Livestock water demand, and Environmental water demand (Instream Flow Requirements, which is abbreviated as IFR). These demand sites are identified from the data taken from MoWIE and Oromia Irrigation Development Authority (OIDA). Industrial water demands are not considered in this paper because it is significant in the whole basin's perspectives and reuse water. The demand sites are distributed almost all over the Woredas of sub-basin, especially small-scale irrigation (SSI), which are often managed at household levels. No document shows the final and accurate location of SSI schemes at the Woreda level in the study area. Hence, for this study, the planned SSI schemes are located approximately WEAP integrated with the Google Earth Pro as shown in Figure 3-15.

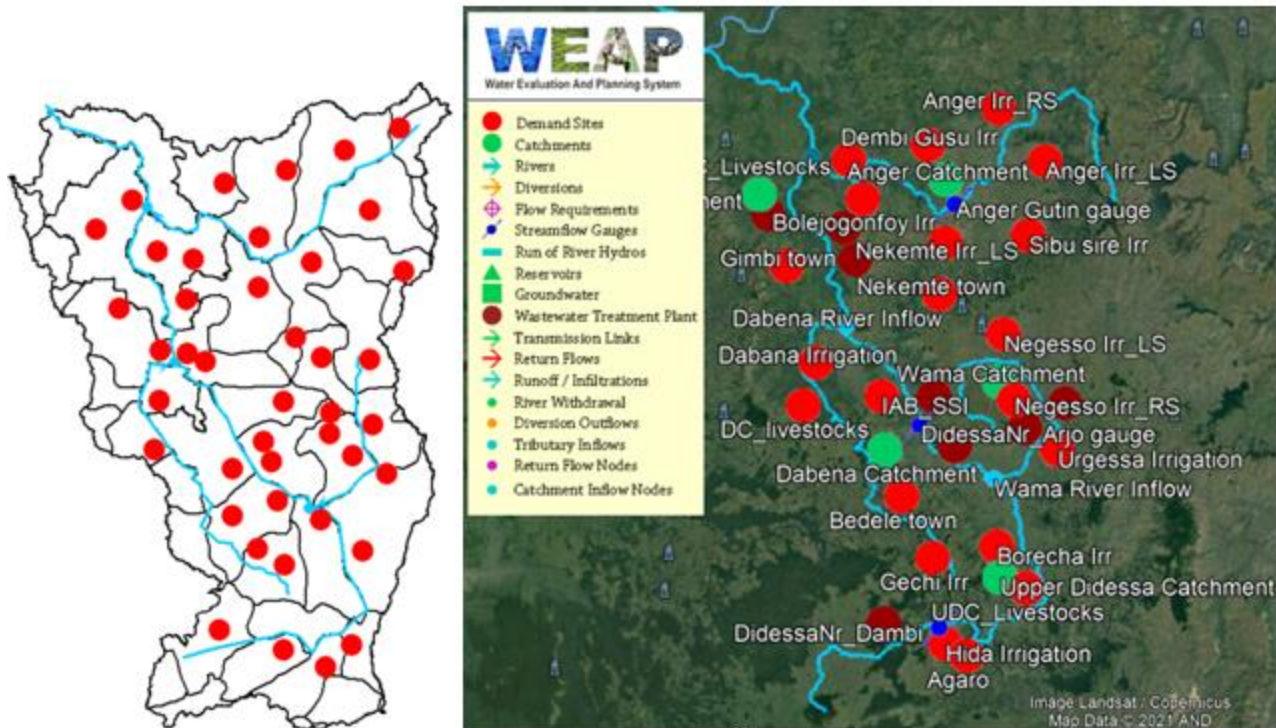


Figure 3-15 Distribution of demand site in Didessa sub-basin

**i. Agricultural and Domestic**

In agricultural demand sites, irrigation demand (existing irrigation demand and planned/ potential irrigation) and livestock are considered.

**Irrigation Water Demands:** There are numerous existing irrigation sites and planned irrigation demand. The irrigation water demand and their corresponding annual activity levels data have been identified from Adgolign *et al.* (2016); those are cross-checked with the Abbay basin Integrated development master plan project document and Oromia Irrigation Development Authority’s data. The data taken from those documents are portrayed in Appendix E, the water demand side: Domestic water demand, Agricultural (Irrigation) water demand, and Environmental flow requirements). Big projects with a command area of more than 3,000 ha, medium projects with a command area of 200 to 3,000 ha, and small projects with a command area of less than 200 ha are the three types of irrigation projects. The total area of existing irrigation site (Anger, Dembi Gusu, Nekemte, Nekemnte1, Didiga, Dimtu, Negesso, Dabana, Didessa, Wama, Arjo-Didessa, Urgesa, Upper Dabana and Hida) are 2,364km<sup>2</sup> as illustrated in the following Figure 3-16. The demand site is one of the key assumptions in scenario development when evaluating the impact of future water use in the study area. The existing irrigation water demand in the study area shapefile was taken from the ministry of water, Irrigation, and Energy, which is edited for the present thesis depicted in Figure 3-16 below.

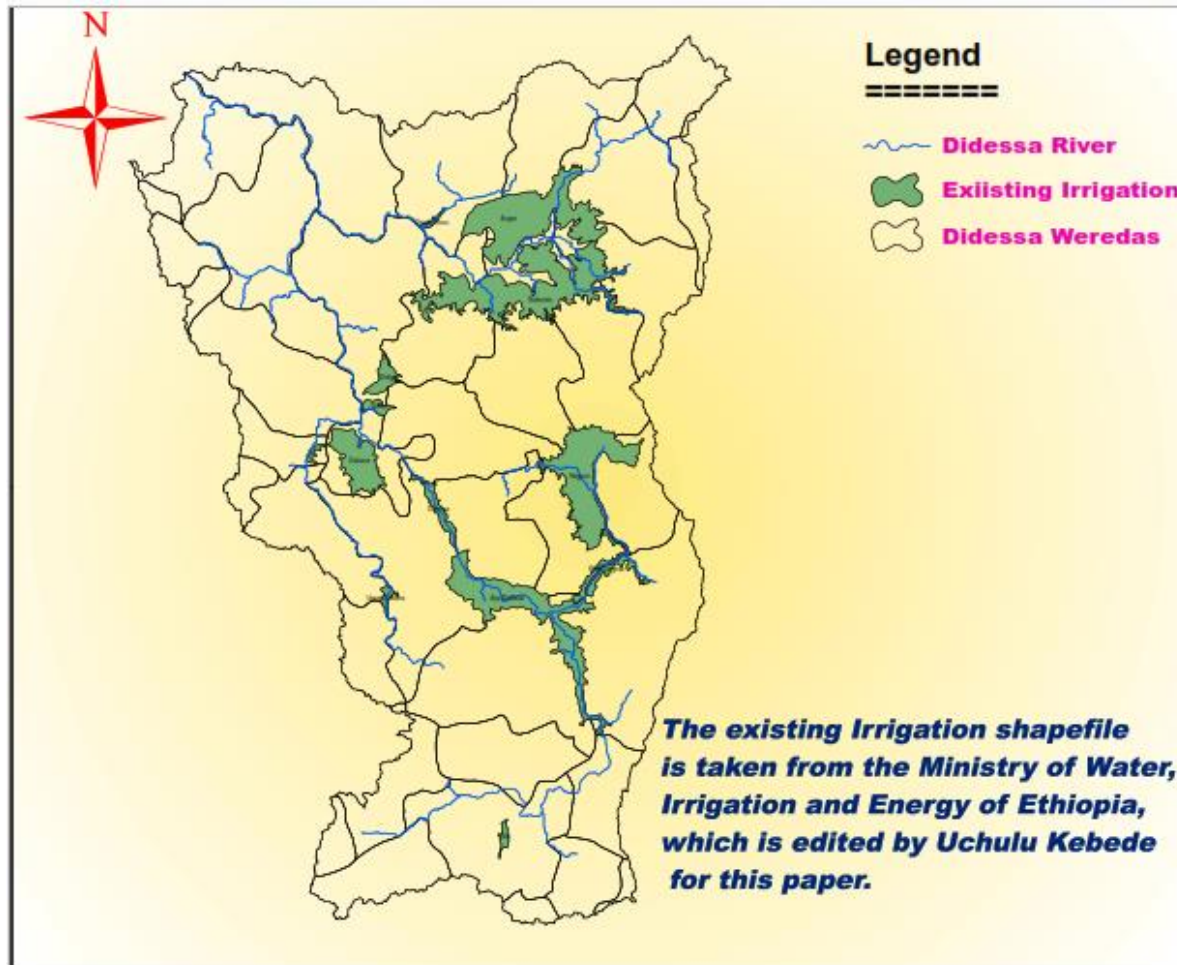


Figure 3-16 Existing Irrigation site of the study area

In many of the current stations, the lack of weather monitoring stations and short records challenges the use of site-specific estimation of crop water requirements. Hence, the Didessa River basin, based on proximity and agro-ecological similarity, was categorized into two clusters. Depending on these clusters, Bedele, Nekemte, and Anger stations were selected. They have relatively better data availability and fairly represent the Didessa river basin agro-ecological zoning of the existing and planned water resource development projects. Also, the concept of proximity was considered as the criteria for clustering of the areas to one another or adjacency of one site to the others. The irrigation demand water requirement has been estimated for Sugarcane, which requires the highest amount of water, including the other crop water requirement. The main objective of the Arjo Didessa Irrigation Development Project is to develop sugarcane on 80,000 hectares of land.

Table 3-15 Irrigation Schemes

S. No	Irrigation Schemes	Sub-Catchments	Station Name
-------	--------------------	----------------	--------------

1	Negesso Irrigation, Small and medium scale Irrigation	Wama Catchment	Nekemte Station
2	Arjo Didessa irrigation, Small and medium irrigation including the main stem of Didessa river, Dabena Irrigation, Upper Dabena Irrigation	Upper Didessa Catchment and Dabena Catchment	B. Bedele Station
3	Anger irrigation, SSI in Anger sub-catchment, and SSI in the lower reach of the main Didessa River	Anger Catchment and Lower Didessa Catchment	Anger Station

CROPWAT software is used to estimate irrigation water requirements. CROPWAT 8.0 is a program that is developed by FAO of the United Nations which is used to estimate the crop water requirement of this thesis using the three selected stations. Monthly Irrigation requirements output for sugarcane is depicted in Table 3-7 is also used as input for WEAP software.

Table 3-16 Irrigation Water Requirement summary of the Nekemte Station

Month	Station Nekemte		Monthly Variation
	mm	m <sup>3</sup> /Month	%
Jan	124.8	1248	23.77
Feb	129	1290	24.57
Mar	113.7	1137	21.65
Apr	90.9	909	17.29
May	5.8	58	1.1
Jun	0	0	0
Jul	0	0	0
Aug	0	0	0
Sept	0	0	0
Oct	0	0	0
Nov	2.2	22	0.42
Dec	58.8	588	11.2

For Sugarcane crop type

The total water demand for irrigation was estimated by multiplying the total area under irrigation with irrigation water requirements for cropping patterns. The crop water requirement for different crops was calculated using  $ET_c$ ,  $K_c$ , and  $P_{eff}$ , based on the following Equations:

$$ET_c = k_c * ET_o \tag{3-9}$$

$$IWR = ET_c - P_{eff} \tag{3-10}$$

where,  $ET_c$  = crop evapotranspiration ( $\frac{mm}{period}$ ),  $kc$  = crop coefficient,

$ET_o$  = Reference evapotranspiration ( $\frac{mm}{day}$ ),  $IWR$  = irrigation water requirement,

$P_{eff}$  = effective rainfall ( $mm$ )

Reference Evapotranspiration ( $ET_o$ ) was calculated by the Hargreaves method; the available data was maximum and minimum temperature used the following equation that passes different steps, but the other methods require additional data. The procedure to calculate  $ET_o$  was as follows:

Step 1: calculate the day of the year (Julian day)

Step 2: calculate declination ( $\delta$ ) =  $0.4102 * \sin\left(\frac{2\pi}{365}(J - 80)\right)$  where  $\delta$  is in radians

Step 3: convert Latitude of the station to radians ( $\Phi$ )

$$\phi = \left( \text{latitude} * \frac{\pi}{180} \right)$$

Step 4: Estimate potential Extraterrestrial Radiation ( $R_a$ ):

$$R_a = \frac{118}{\pi} \left\{ \cos^{-1}(-\tan \delta \tan \phi) \sin \phi \sin \delta + \cos \phi \cos \delta \sin \left[ \cos^{-1}(-\tan \delta \tan \phi) \right] \right\}$$

Step 5: Calculate the reference evapotranspiration ( $ET_o$ )

$$ET_o = 0.408 * 0.0023 * R_a * (T_{mean} + 17.8) * \sqrt{T_{max} - T_{min}} \tag{3-11}$$

The potential area for irrigation in the study at the end 2050 will be around 18.75km<sup>2</sup>.

## ii. Domestic water demand

To quantifies domestic water demands in the watershed, how many people are living in the watershed, and how much water does an individual need are determined based on information obtained from relevant sources. As peoples' need is unlimited, it isn't easy to fix the amount of water used for each

individual. However, there is a standard guideline that has been established in different kinds of literature like WHO and GTP.

According to Ethiopia’s second growth and transformation plan (GTP-2) to meet the water demand, which supplied 25 liters per capita per day and 40-100 liter per capita per day for Rural and Urban (there are five categories of towns/cities), respectively based on the number of populations as depicted in the following *Table 3-17*. WHO is also recommends about 100 liters per capita per day.

Table 3-17 The GTP-2 water supply service level standard for Urban and Rural areas

As per GTP-2 water supply service level standard, it is required to provide safe water in minimum for Urban and Rural within a distance of 250m and 1km respectively.				
	Urban Areas			Remarks
	Towns/Cities Category	Population No.	water Demand	
	1	>1Million	100 l/c/d	within a distance of 250m
	2	100,000-1Million	80 l/c/d	
	3	50,000-100,000	60 l/c/d	
	4	20,000-50,000	50 l/c/d	
	5	<20,000	40 l/c/d	
	Rural Areas		25 l/c/d	within a distance of 1km
	GTP-2	Second Growth and Transformation Plan (GTP-II)		

The water demand was calculated by multiplying the projected population number under Zones/Woreda (Urban and Rural) administrative of the basin by appropriate per capita demand. The population projection methods for the future period were selected based on the values of percentage error for 2017. According to our projection, the exponential method is more reliable than the other forecasting population methods because it has small values of percentage error which are given in Appendix B.

To estimate the population projection, two methods were population projection: the exponential method proposed by Central Statistical Agency (CSA) and expression builder methods in the WEAP model was used. The equation of the exponential method proposed by the Central Statistical Agency (CSA) is given as follows:

$$P_n = P_o * e^{n*r\%} \tag{3-12}$$

Where,  $P_n$  = population at n decades or years,  $P_o$  = initial population,  $n$  = decades or years,  $r\%$  = growth development rate,  $e$  = exponential

$$\text{Per capita water demand } (l/c/d) = (((l/c/d)/1000) * 365 * P_n) m^3 / \text{year} \quad (3-13)$$

In this study area, there are five major cities [Agaro, Arjo, Bedele, Gimbi, and Nekemte] considered that are presented in Appendix C with projected population from 2020 to 2050, which are used as input for WEAP following Table 3-18.

Table 3-18 Recommended water use rate based on the Population number of Major towns

Towns Name	Population Numbers		Water Use Rate		
	Year		2017		
	2007	2017	l/c/d	m <sup>3</sup> /c/d	m <sup>3</sup> /c/Year
Agaro	25719	41085	50	0.05	18.25
Arjo	10363	14806	40	0.04	14.60
Bedele	19504	31500	50	0.05	18.25
Gimbi	31311	49999	60	0.06	21.90
Nekemte	76817	121385	80	0.08	29.20
<b>Total Domestic water Demands (in MCM)</b>					<b>102.2</b>

The Expression Builder is a "GrowthFrom" function built into the WEAP model, which helps project the reference time population (2020-2050). "GrowthFrom" is a general-purpose method for constructing WEAP expressions by dragging and dropping the WEAP branches and functions into the edit box. Input data in the WEAP "GrowthFrom" sector for population estimates for the reference period is the year of the last census (2007), the population in 2007, and the projected growth rate in 2007. This result built-in WEAP, in the following format for the expression:

$$\text{GrowthFrom}(r\%, 2007, P_0) \quad (3-14)$$

Where, r%-Estimated population growth rate, 2007-Year of the last census, Population number at 2007.

### iii. Livestock water demands

Ethiopia's livestock population is one of Africa's largest and puts increased pressure on water and land resources. The type of livestock population is expressed by using the conversion factor in the tropical livestock unit (TLU). By multiplying the livestock population by TLU and unit water requirements for each livestock, water demand for livestock was estimated. Within the woredas, the proportion of livestock species varies depending on the type of vegetation and geography. The Tropical Livestock

Unit (TLU) is a simple tool for standardizing the estimation of a wide variety of livestock types and sizes. As reviewed from the water sector development program document, Ethiopia has about 35 million tropical livestock units (TLU), each of which needs about 25 liters of water per day on average that are illustrated in Table 3-19.

Table 3-19 Summary of Livestock population of Didessa River Basin

S. No	Types of Livestock	TLU conversion factors	Total livestock Population	Water Consumption (in l/d)	Livestock Demand (in m <sup>3</sup> /year)
1	Cattle	0.7	<b>1,054,651</b>	25	6736583
2	Equines	0.7	<b>236,775</b>	25	1512400
3	Sheep	0.1	<b>1,222,380</b>	25	1115422
4	Goat	0.1	<b>461,514</b>	25	421132
5	Poultry	0.01	<b>1,102,822</b>	25	100633
<b>Total Livestock water Demands (in MCM)</b>					<b>10</b>

The Livestock water demand for this study was calculated as equation 3-15.

$$\text{Livestock Water Demand} = \text{Per capita water consumption (l / d)} * \text{Livestock Population} * \text{TLU} \quad (3-15)$$

In other side, Arranz and McCartney (2007) recommended that the daily water use rate for livestock is 42 l/c/d. Therefore, the annual water use rate is the products of the daily water use rate and the number of days in a year that is calculated as follow:

$$\text{Annual Water Use Rate} = (0.042m^3 \text{ pcpd}) * 365 = 15.33m^3 \text{ pcp year}. \quad (3-16)$$

The population of the livestock of the study area is presented under the Appendix for five catchments.

#### **iv. Environmental flow requirements**

Environmental flows are flows that are left in a river system or released into it for the particular intention of managing some aspect of its state. To safeguard natural reserves and sustain habitats, environmental flows are needed. Environmental flow is the quantity or volume of water flow left in or released into a river system that is required over time in some conditions for the maintenance of river-healthy riverine ecosystems. It is impossible to fix the quantity or volume of water released downstream in the modification of natural flow systems. However, there is a guideline of ten to fifty (10%-50%) percent of the river flow's overall amount. In practice, environmental flow requirements shall be set by the appropriate authority. In the Ethiopian context, there are no defined thresholds. However, different threshold values are used in the present study while developing different scenarios.

### 3.2.6.2 Assessment of Supply Sources

The supply source for all demand sites was considered in the Didessa River basin, including its major tributaries: Anger River, Dabena River, and Wama River. As the reservoir is still under construction, it was not considered a supply source. Both demand sites and supply sources are depicted in Figure 3-17 below.

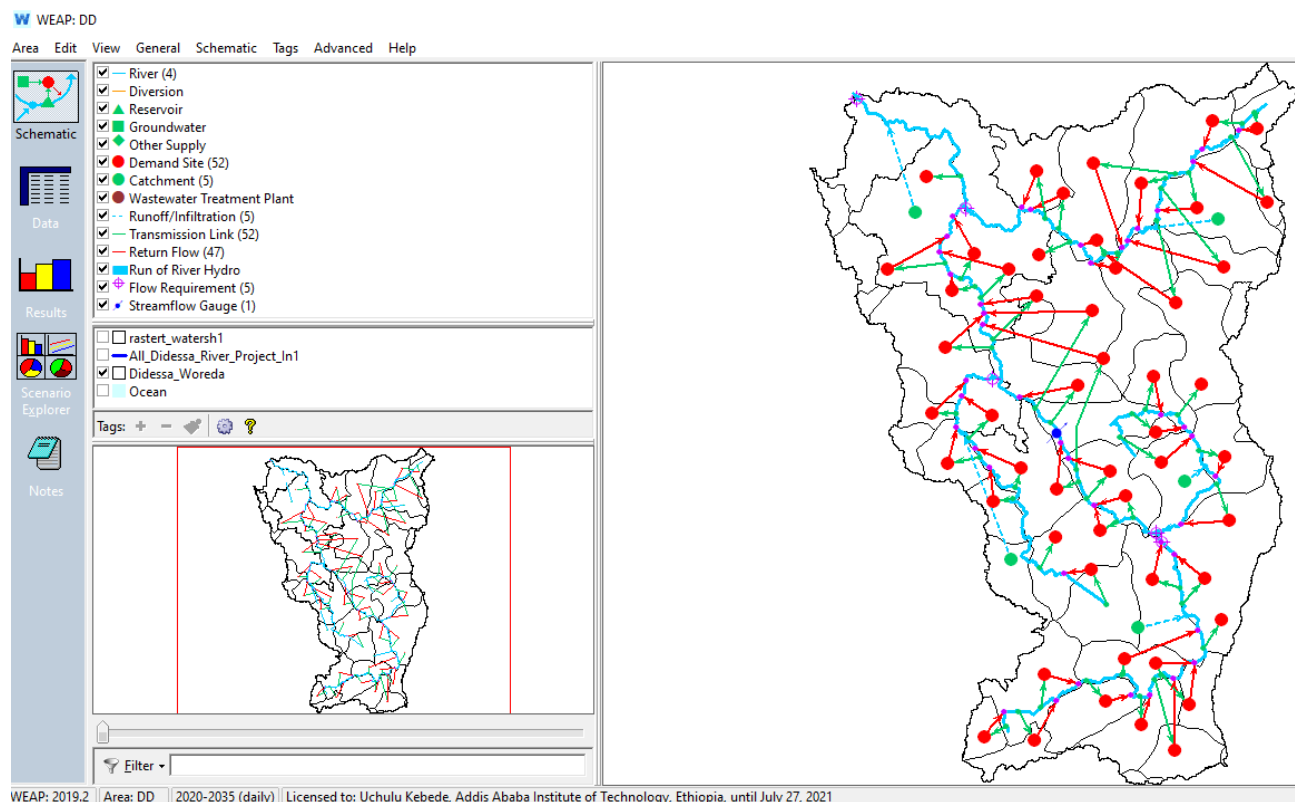


Figure 3-17 Study area Schematic View of WEAP Model

### 3.2.7 Indicators of Hydrologic Alteration method

The IHA approach was used to determine the hydrological system's alteration, including 33 ecologically important hydrological parameters, and to analyze the hydrological regime's alteration using the parameters of the five main categories. The set of hydrologic alteration indicators are used in this study to assess the impact of water resource development on the flow regime of the Didessa river. To classify the flow regime, the IHAs are classified into five categories in terms of the magnitude of monthly flow, the magnitude and duration of annual extreme flows and baseline flow state, the timing of annual extreme flow conditions, the frequency and duration of high and low pulses, and the rate and frequency change inflows which are depicted in Table 3-20.

Table 3-20 Five flow components of 33 IHAs parameters

Groups	Group description	Hydrological Indicators (33 IHAs)
1(12 IHAs)	The magnitude of monthly flow	The average flow of each calendar month
2(12 IHAs)	Magnitude and duration of extreme annual flows, base flow conditions, and zero flow days	Annual minimum 1-, 3-, 7-, 30-, 90-day, annual maximum 1-, 3-, 7-, 30-, 90-day, Baseflow index, and zero flow days
3(2 IHAs)	Timing of annual extreme flow conditions	Julian date of annual 1-day minimum and maximum
4(4 IHAs)	Frequency and duration of high and low flow pulses	A number of low and high pulses, mean duration of low and high pulses, each year.
5(3 IHAs)	Rate and frequency flow changes	Rise rate, fall rate, and number of flow reversals

To quantitatively compare the effects of human activities on IHAs, IHA is calculated by computing the pre-and post-impact intervals in terms of median values, degree of deviation, and degree hydrological alterations. The deviation degree for IHA is calculated with the following equations;

$$P_i = \frac{M_e - M_o}{M_o} * 100\% \tag{3-17}$$

where,  $P_i$  – deviation degree,  $M_o$  and  $M_e$  are median values of pre – and post impact period

A positive  $P_i$  indicates an increased median value and decreased negative median value in the post-impact period compared with the pre-impact period. For each predictor, the degree of hydrological alteration of the flow regime can be further determined according to the following equation.

$$D_R = \left| \frac{N_o - N_e}{N_e} \right| * 100\% \quad \text{Traditional} \tag{3-18}$$

where,  $D_R$  – degree hydrologic alteration,  $N_o$  and  $N_e$  are observed and expected number of year post and pre – impact years for which the values of the indicator falls within the RVA target ranges

$$D_R = \left( \frac{N_o - N_e}{N_e} \right) * 100\% \quad \text{Modified} \tag{3-19}$$

The RVA approach can be used, based on the IHA, to measure the effect of human actions on the river flow regime. Richter *et al.* (1998) break the levels of hydrologic alteration into three groups of equal

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size to measure the hydrologic alteration: 0-33 percent (L) represents little, or no alteration, 34-67 percent (M) represents mild alteration, and 68-100 percent (H) represents a high degree of alteration.

### **3.2.8 Scenario Developments**

Scenarios are self-consistent storylines about how a potential system might evolve in a particular socio-economic context and under a specific set of policy and technological circumstances. It is a method of analyzing possible future events, sometimes called alternative worlds, by considering possible alternative outcomes. As a consequence of socio-economic growth, how future processes will be altered over time and other considerations are considered in constructing a scenario. Based on assumptions that would impact the water balance of the catchment, this study generates scenarios.

Two scenarios are generated, and their potential impacts on the water balance are analyzed to answer a wide variety of “what if” questions.

**Scenario 1:** - Increase in Population Growth rate

**Scenario 2:** -Expansion of Irrigation Activities

## 4 RESULTS AND DISCUSSION

The WEAP model was developed for water requirements and runs until 2050, with the baseline year of 2020. For the estimated period from 2020 to 2050, the scenario analysis approach was used to assess the impacts of water resources development and the flow alteration situation based on EFR's.

### 4.1 Availability of Water Resources in Didessa River Basin

The total annual flow of the Didessa River Basin amounts to a quarter of the total Abbay River as quantified on the Sudan border. Almost similar values are quantified as around 10.71 BCM and 10.63 BCM using the SWAT and WEAP model by different authors (ADGOLIGN *et al.*, 2015; Adgolign *et al.*, 2016) respectively. In the present analysis, it was estimated that the available volume of water is around 10 BCM. Such differences are expected as the method of model conceptualization are different. Moreover, the water development in the basin is still growing and some amount might have been utilized.

### 4.2 WEAP Model Calibration and Validation

The calibration and validation are calculated manually using observed and simulated flow data. The Didessa River Basin WEAP model was calibrated and validated at the Near Arjo gauging station in CMS using daily streamflow recorded from 1990 to 2008 and 2009 to 2017. Figure 4-1 shows the full hydrograph of the Didessa near Arjo gauging stations from the year of 1990 to 2017.

Using the WEAP-accessible PEST system, the model was calibrated. The output graph results using the PEST system in WEAP of the calibration and Validation were in the following Figure 4-2 and Figure 4-3, respectively. The graph shows simulated vs observed data for the precipitation parameter between the selected nodes/reaches of upper Didessa catchment runoff and Didessa river flow near Arjo gauging station. The model performance values depicted in Table 4-1.

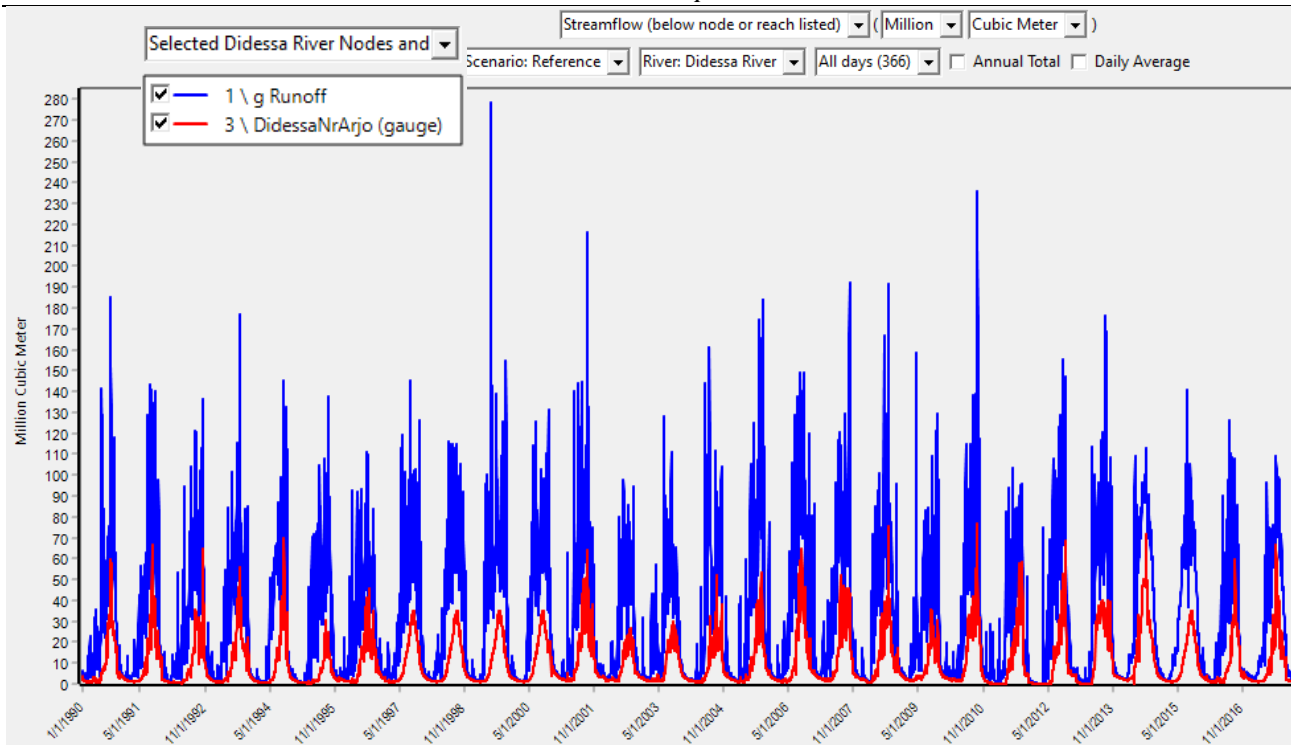


Figure 4-1 Overviews of Didessa flow near Arjo station vs Arjo Didessa in return

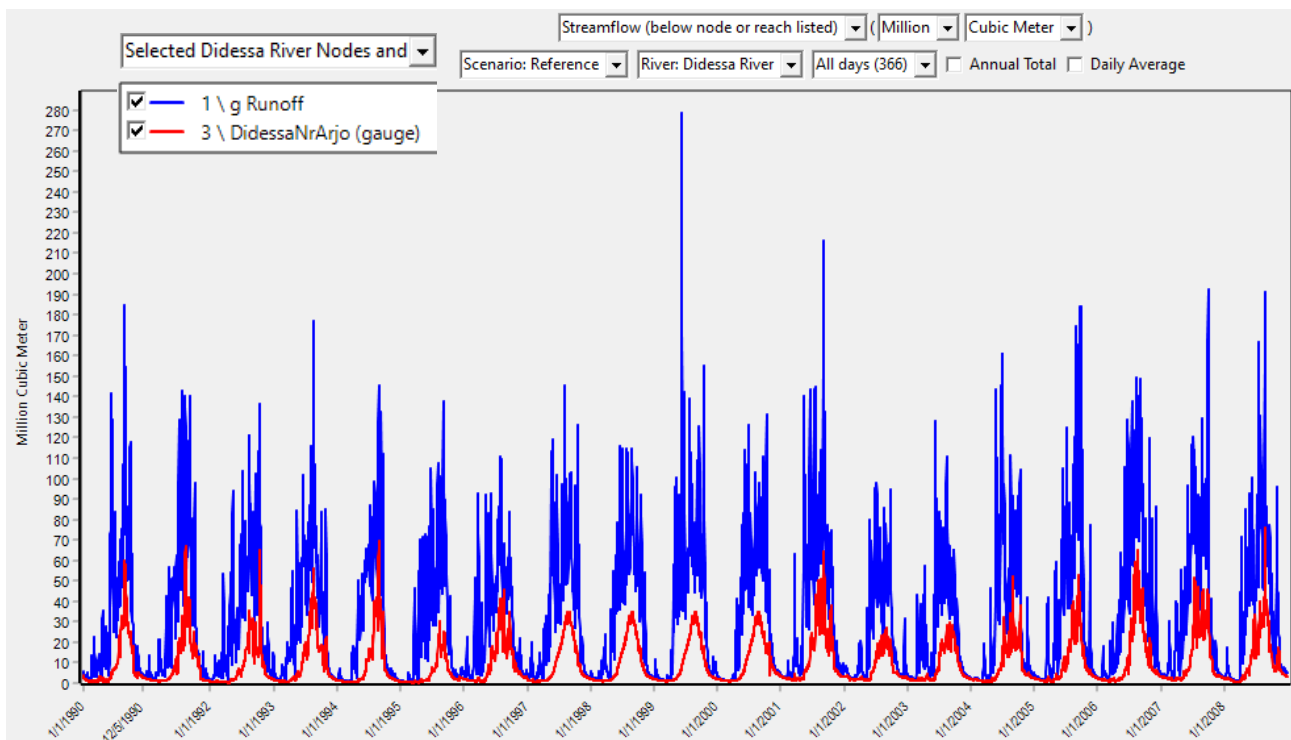


Figure 4-2 Calibrated daily flow data [1990-2008]

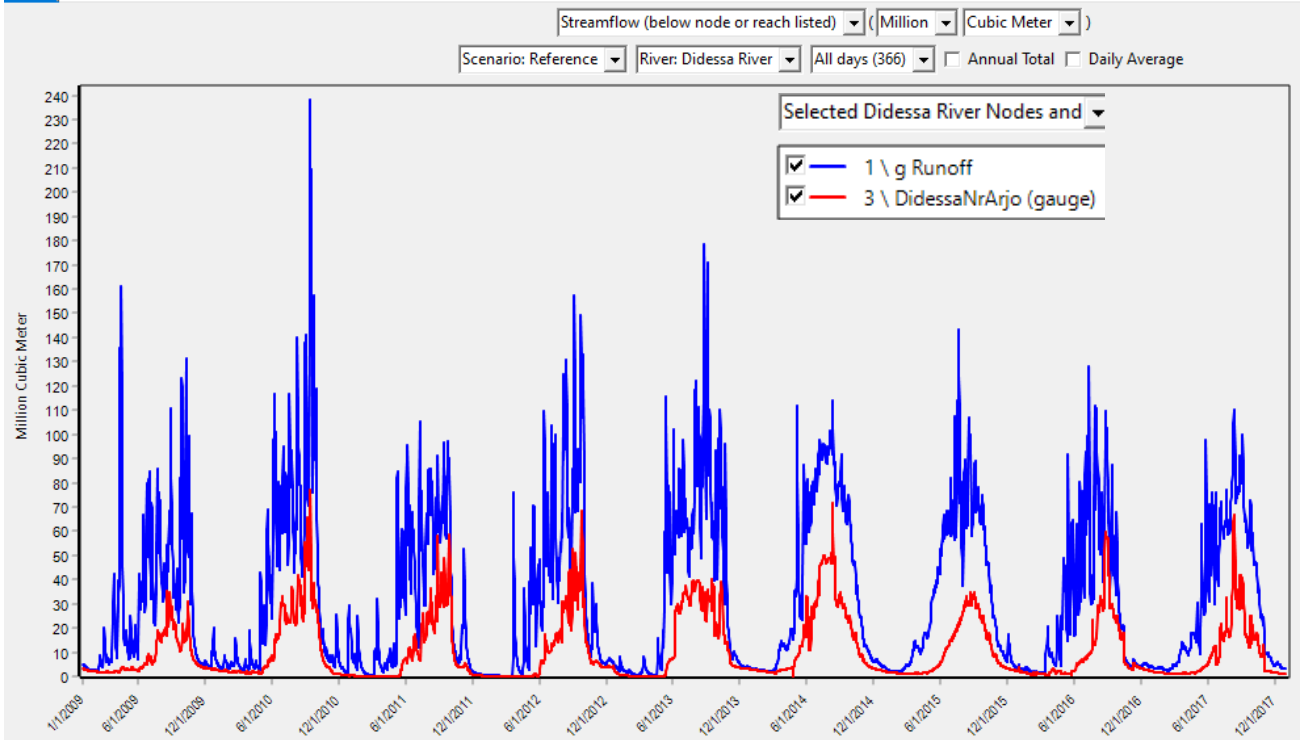


Figure 4-3 Validation of Daily flow [2009-2017]

The following Table 4-1 shows statistically computed values of  $R^2$  and NSE.

Table 4-1 Model performance Values

The results of Statistical Analysis		
Parameters	Calibration [1990-2008]	Validation [2009-2017]
Nash-Sutcliffe Efficiency (NSE)	0.89	0.68
Correlation Coefficient ( $R^2$ )	0.9	0.73

### 4.3 Reference Scenarios

A reference scenario prediction is built based on various economic, demographic, hydrological, and technical patterns. The reference scenario is constructed from the current account to simulate the possible evolution of the mechanism without interference. This scenario acts as a guide to the other scenarios that have been built to demonstrate numerous developments. Therefore, as there are interventions in the reference scenario rather than projecting the current account year to the future year, any scenario created to display the model outcome trend is compared to the reference scenario.

**4.3.1 Water Demands in Didessa River Basin**

The outcome of the WEAP model includes the annual summation demand for all locations, both separately, and the overview of all these demands. The water demand of the three sectors without the Basin's Environmental Flow Requirement is presented and discussed below under different scenarios.

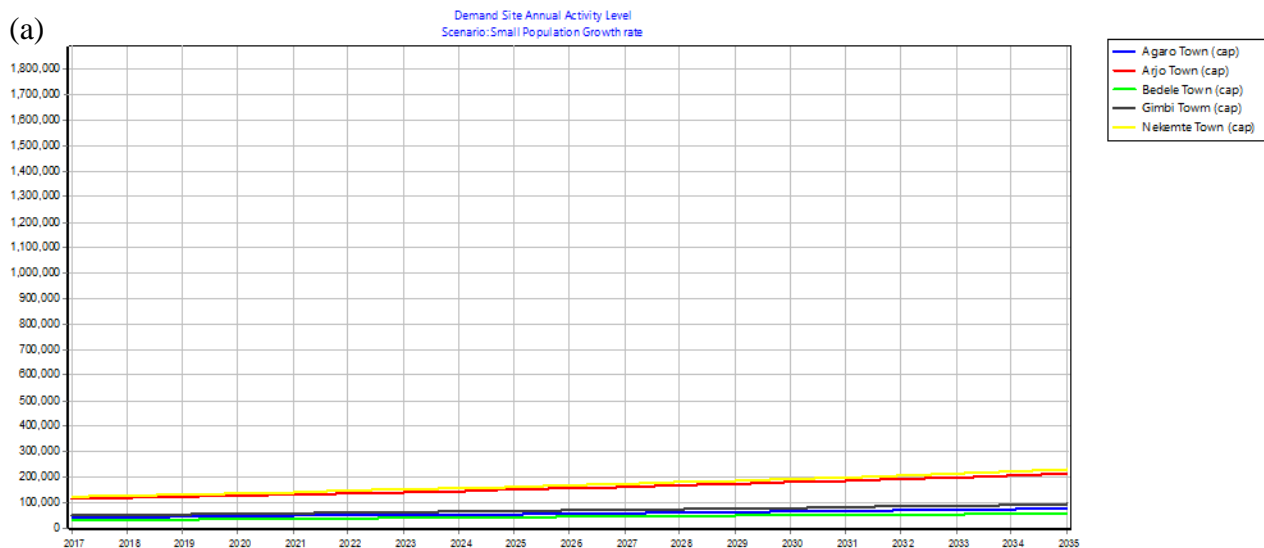
**i. Domestic Water Demand**

This study's domestic water demand was considered five major towns/cities whose population forecast based on CSA data for the last projection study for 2017.

Using the WEAP Expression Builder, the future population prediction (scenario) was carried out using the model project, including population growth rate at different time schedules up to 2050 are depicted in Table 4-2.

Table 4-2 WEAP results of Domestic water demand of major towns from year by year

Periods	Total Population in Million	Water requirements (Mm <sup>3</sup> /year)
Reference (1990-2020)	0.36	151.1
Small growth rate (2021-2035)	0.67	375.06
Higher growth rate (2036-2050)	1.81	954.46



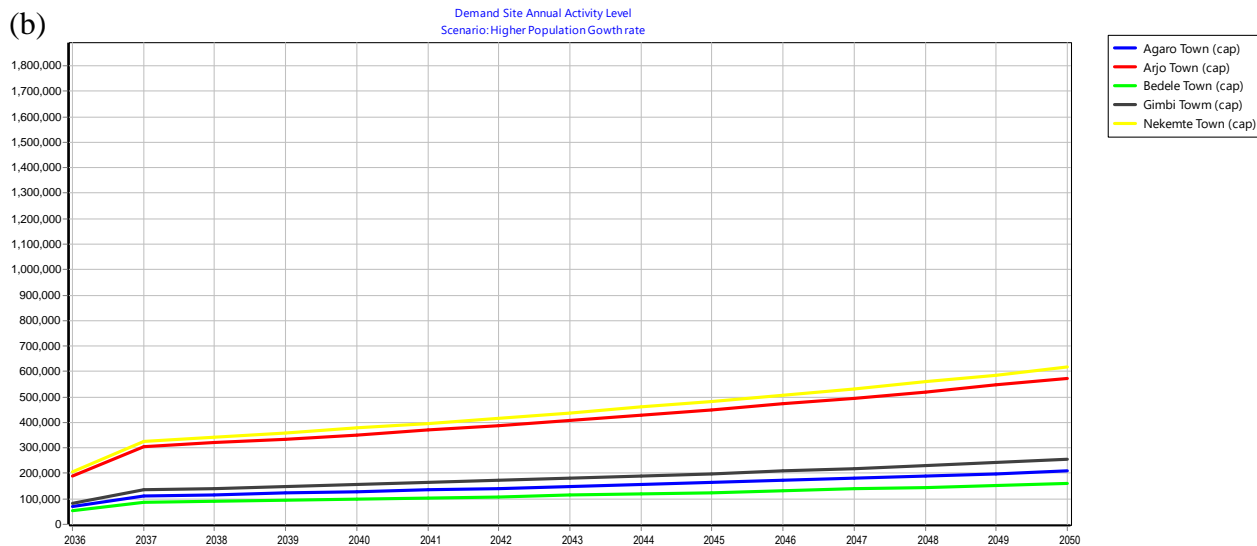


Figure 4-4 Incremental town’s population number as population growth rate increase from year by year (a) 2021-2035, and (b) 2036-2050

### 4.3.2 WEAP results for Developed Scenarios

A strong future priority is recommended for all water resource management. It is important to base such a future emphasis on scenario analysis. Scenarios are alternatives or a series of hypotheses that can answer a wide range of "what if" questions about the quantity of demand, water coverage for each demand location, and overall water balance in the study area.

#### Scenario 1: - Increase in Population Growth Rate

Scenario 1 was grouped into three parts based on the population growth rate values, Reference scenario ( $r=3.1\%$ ), Small Population Growth rate ( $r=3.5\%$ ), and Higher Population Growth rate ( $r=5\%$ ). The annual summation results of domestic water demand in a Million-meter cube for each scenario, based on increasing population growth rate and time increment, were illustrated in Table 4-3. The figural representation of domestic water demand with each scenario showed (see Figure 4-6 a, b, c, and Figure 4-7 a, b, c). The scenario prediction is built based on various economic, demographic, hydrological, and technological trends. To simulate the system's possible evolution without interference, the reference scenario is constructed from the current account (1990). From 1990 to 2020, It established the reference scenario in the study area, and population projections were carried out accordingly.

Table 4-3 Domestic water demand in the development scenarios with increasing population growth rate

S. No	Scenarios	Water demands (Mm <sup>3</sup> )	Supply delivered (Mm <sup>3</sup> )	Unmet (Mm <sup>3</sup> )
1	Reference (1990-2020)	151.19	150.45	0.74
2	Small Population Growth Rate (2021-2035)	375.06	77.19	297.87
3	Higher Population Growth Rate (2036-2050)	954.46	107.28	784.18

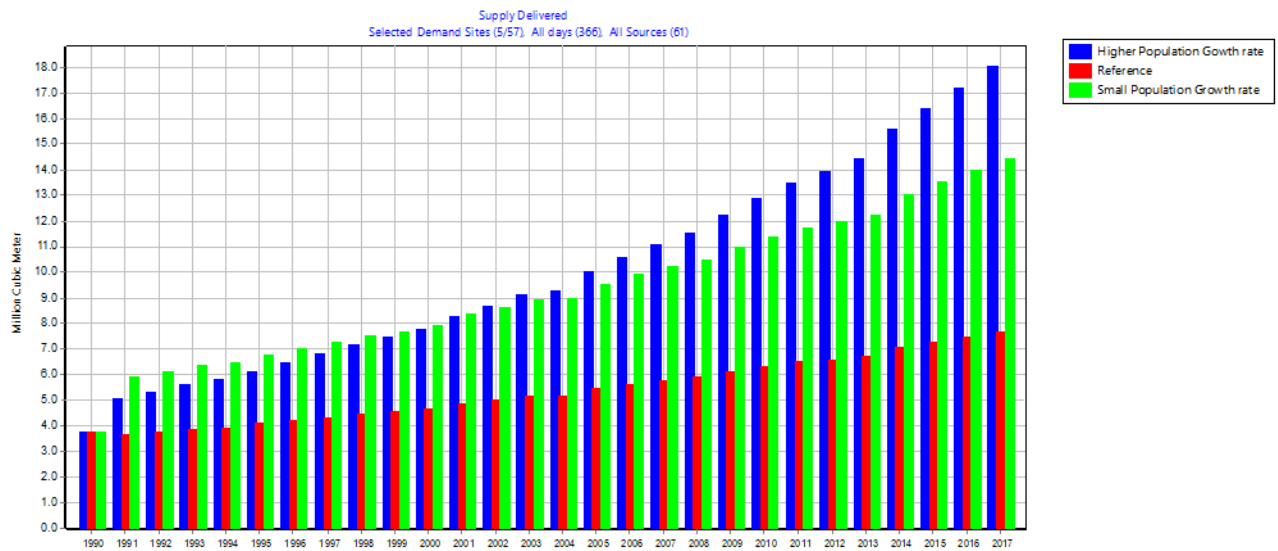
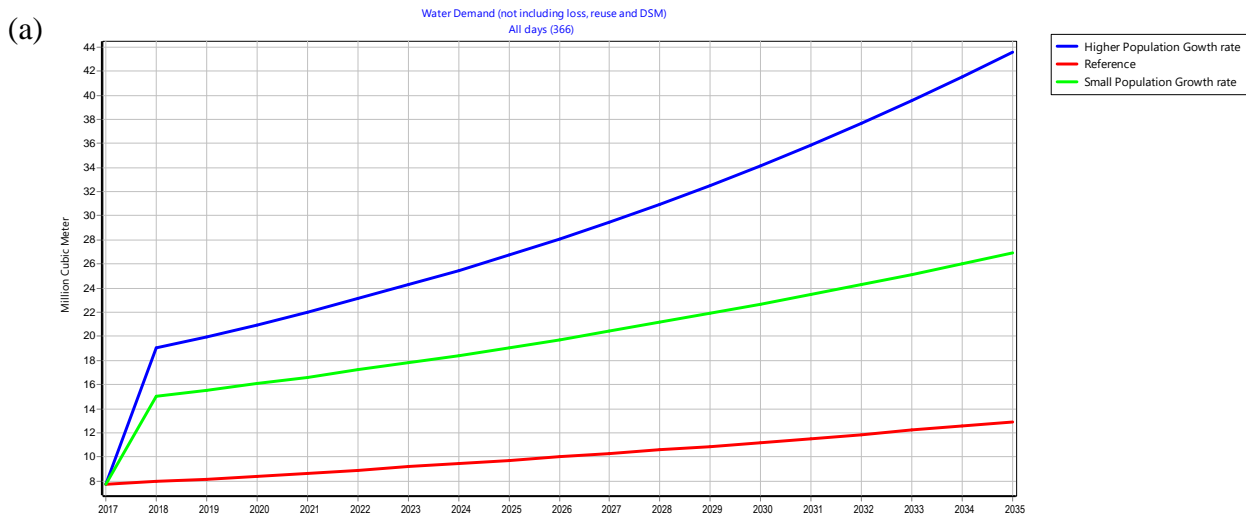


Figure 4-5 Histogram representation Supply delivered for Domestic



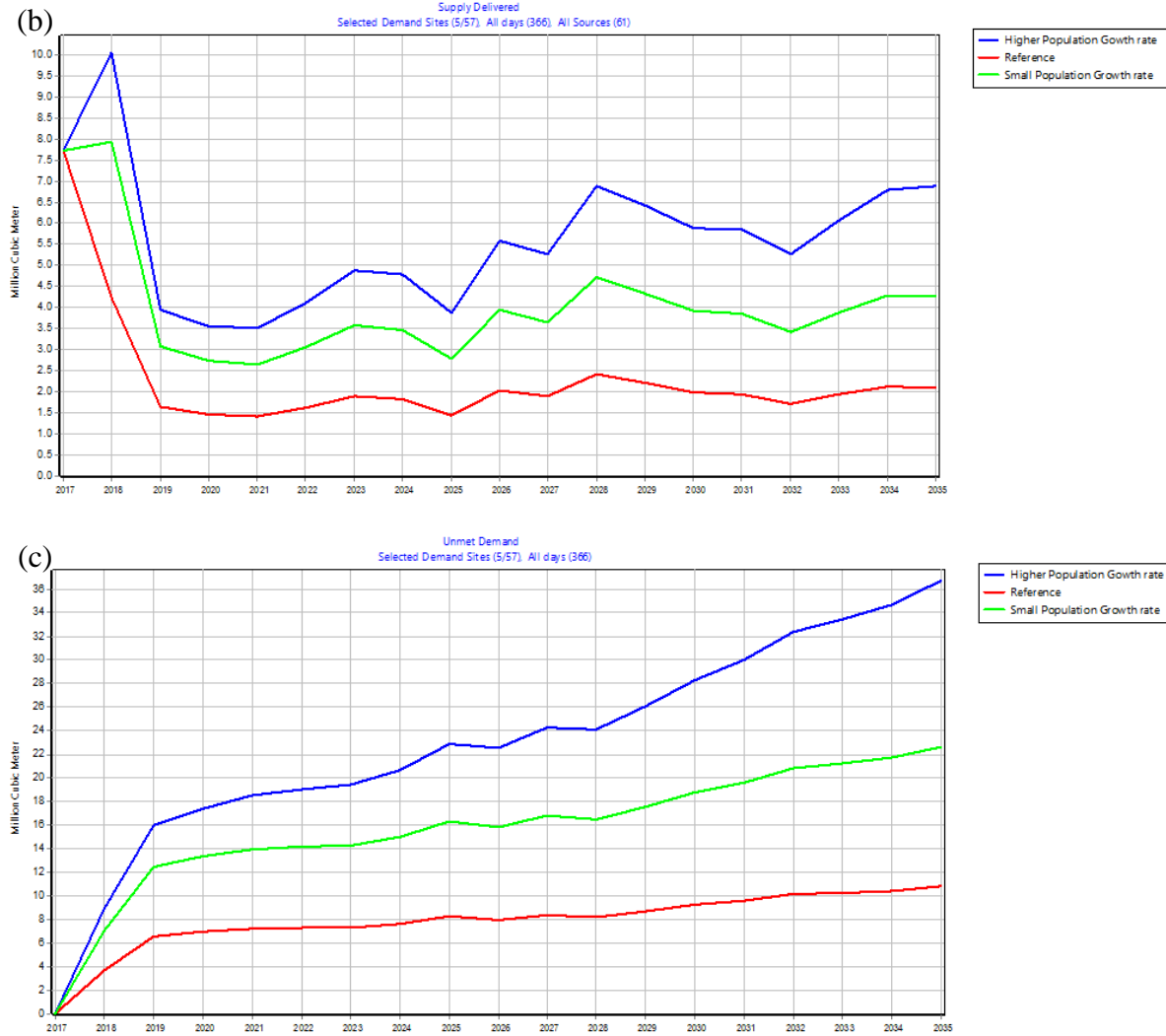
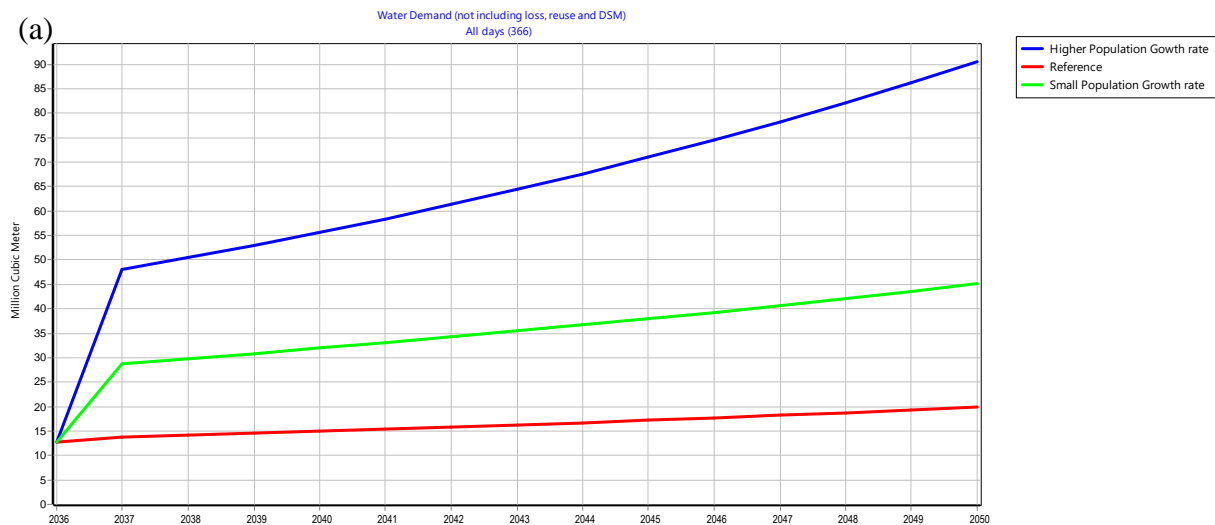


Figure 4-6 Small population growth rate: (a) water demand, (b) supply delivered, and (c) unmet



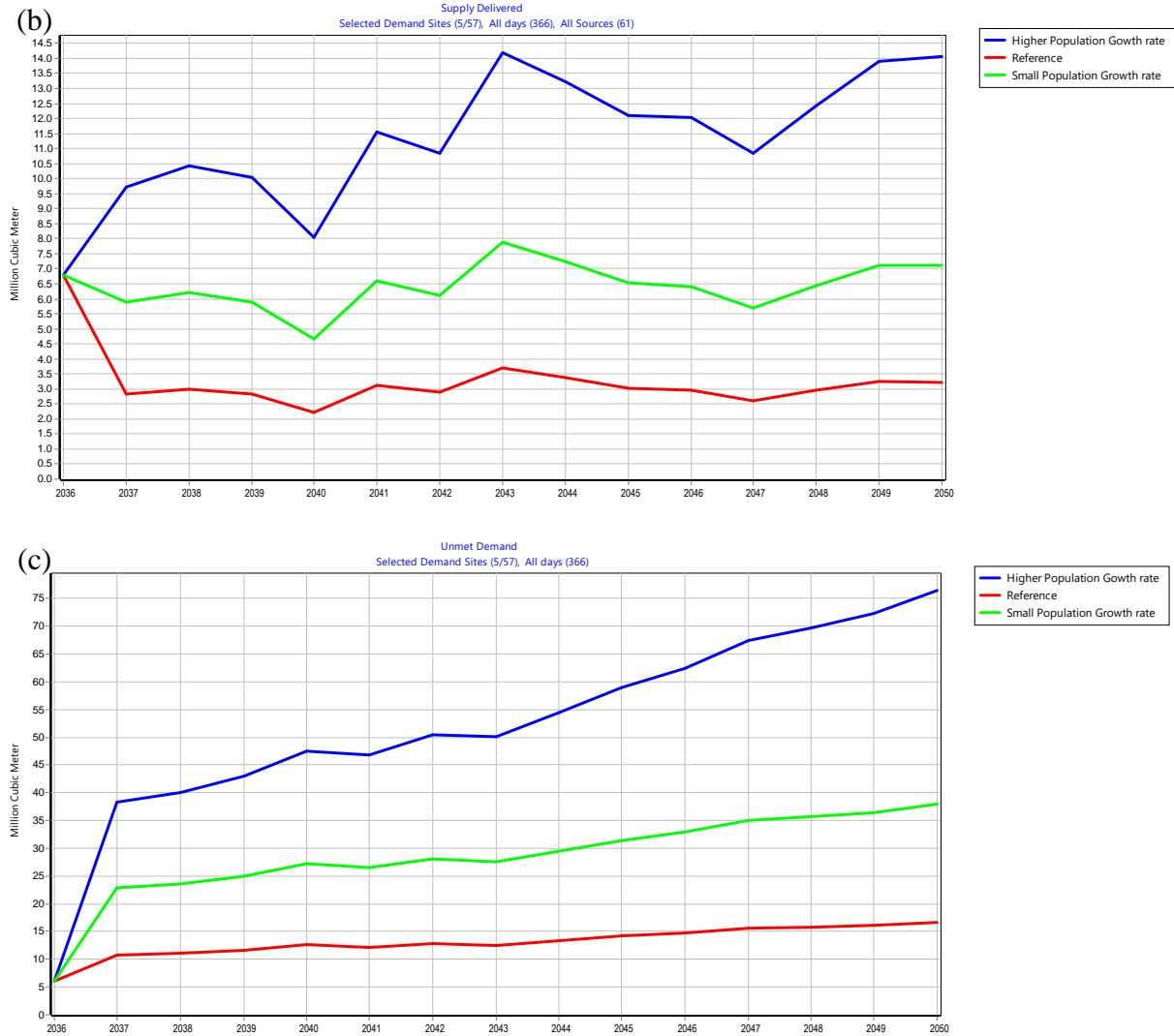


Figure 4-7 Higher population growth rate: (a) water demand, (b) supply delivered, and (c) unmet

**Scenario 2: - Expansion of Irrigation Activities**

Irrigation expansion scenarios that define the potential future irrigation situation in the entire sub-basin of Didessa prioritized irrigation areas' development up to future long-term future development (2050).

Table 4-4 Expansion of irrigation activities within different scenarios

Scenarios	Water Demands (BCM)	Supply Delivered (BCM)	Unmet Demands (BCM)
References (1990-2020)	1.65	1.45	0.195
Short term future expansion (2021-2035)	1.68	1.31	0.55
Long term future expansion (2036-2050)	11.45	3.95	7.5

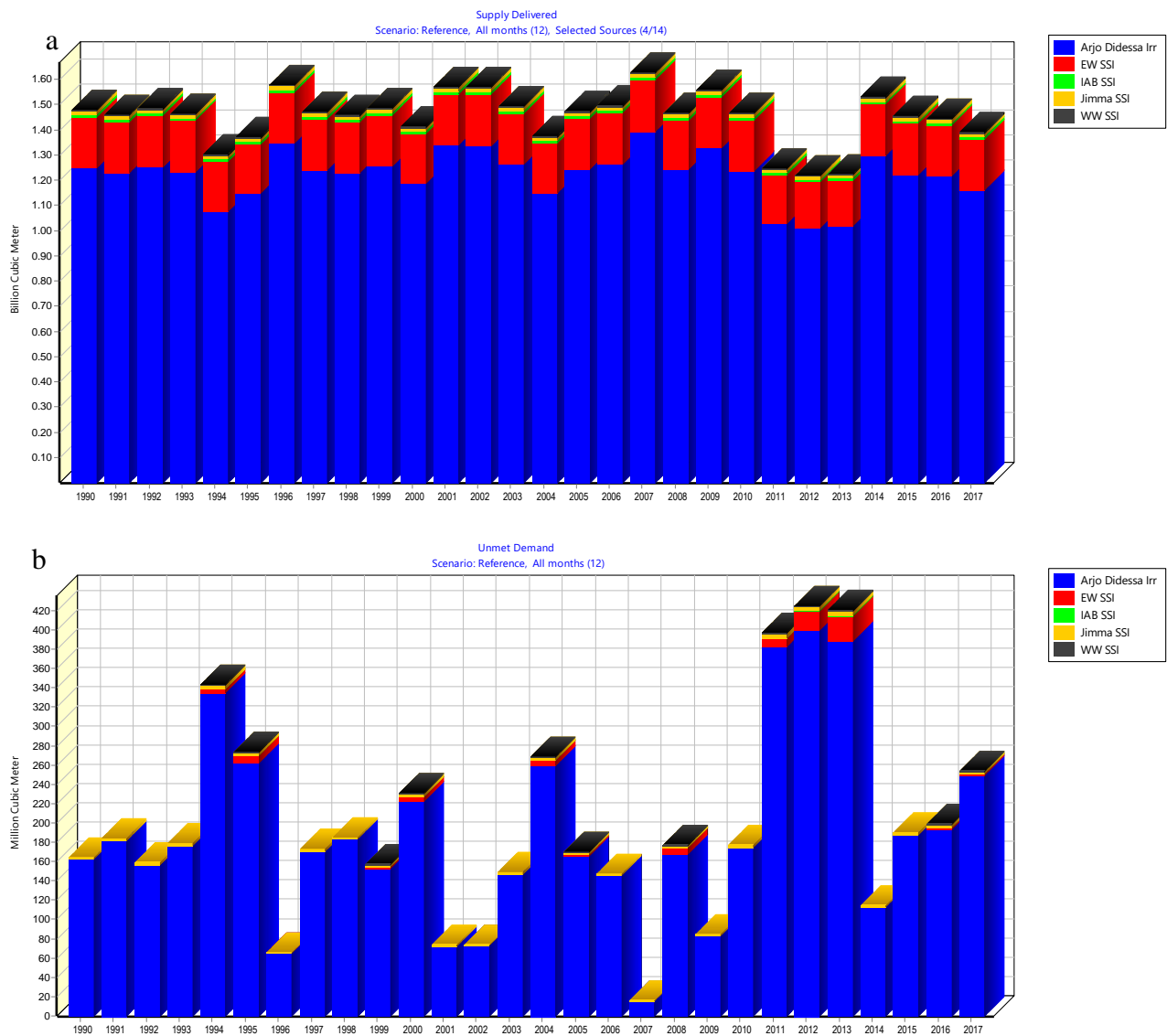


Figure 4-8 Expansion of irrigation for reference: Supply delivered (a) and unmet demand (b)

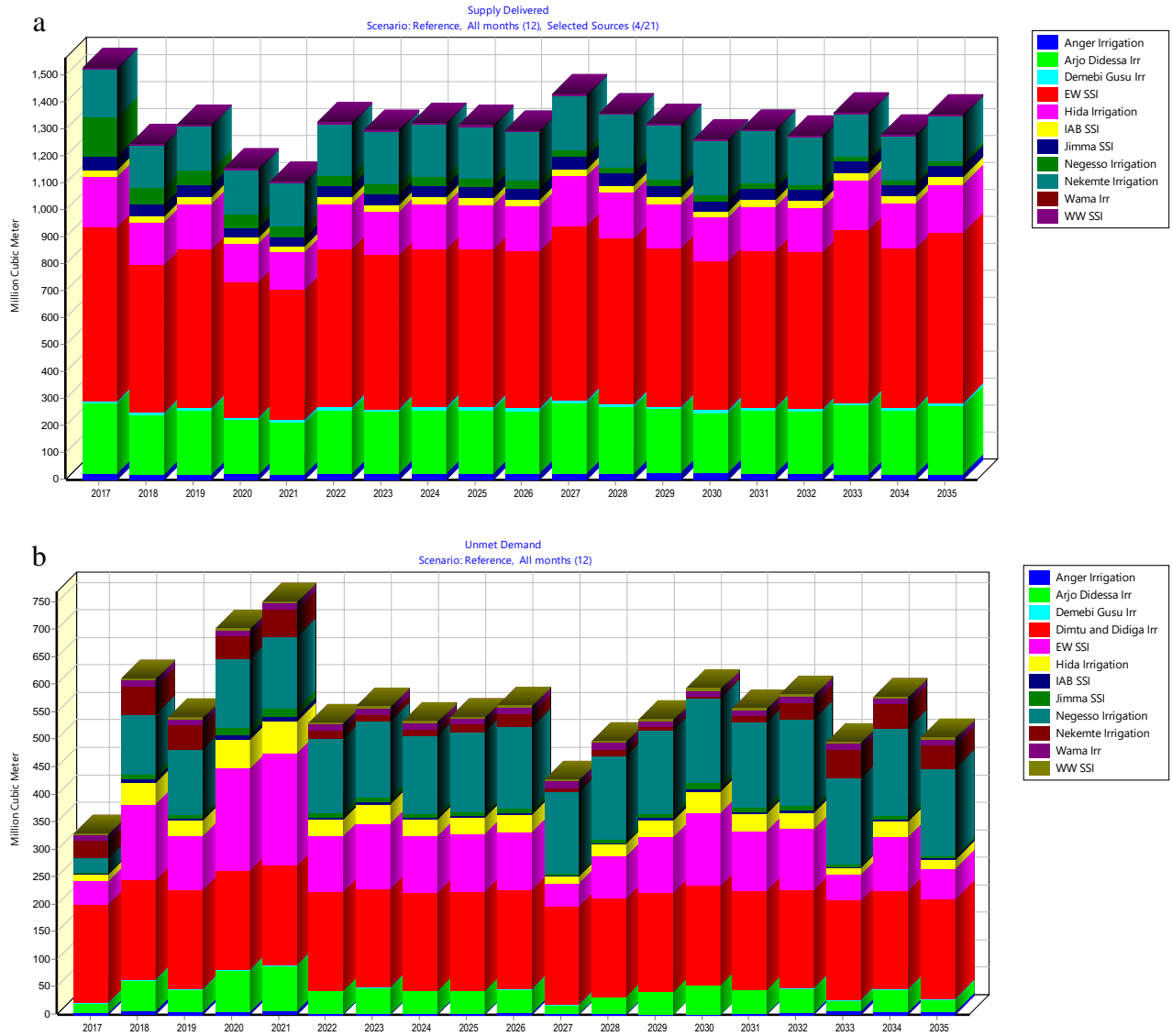


Figure 4-9 Expansion of irrigation for small future development: Supply delivered (a) and unmet demand (b)

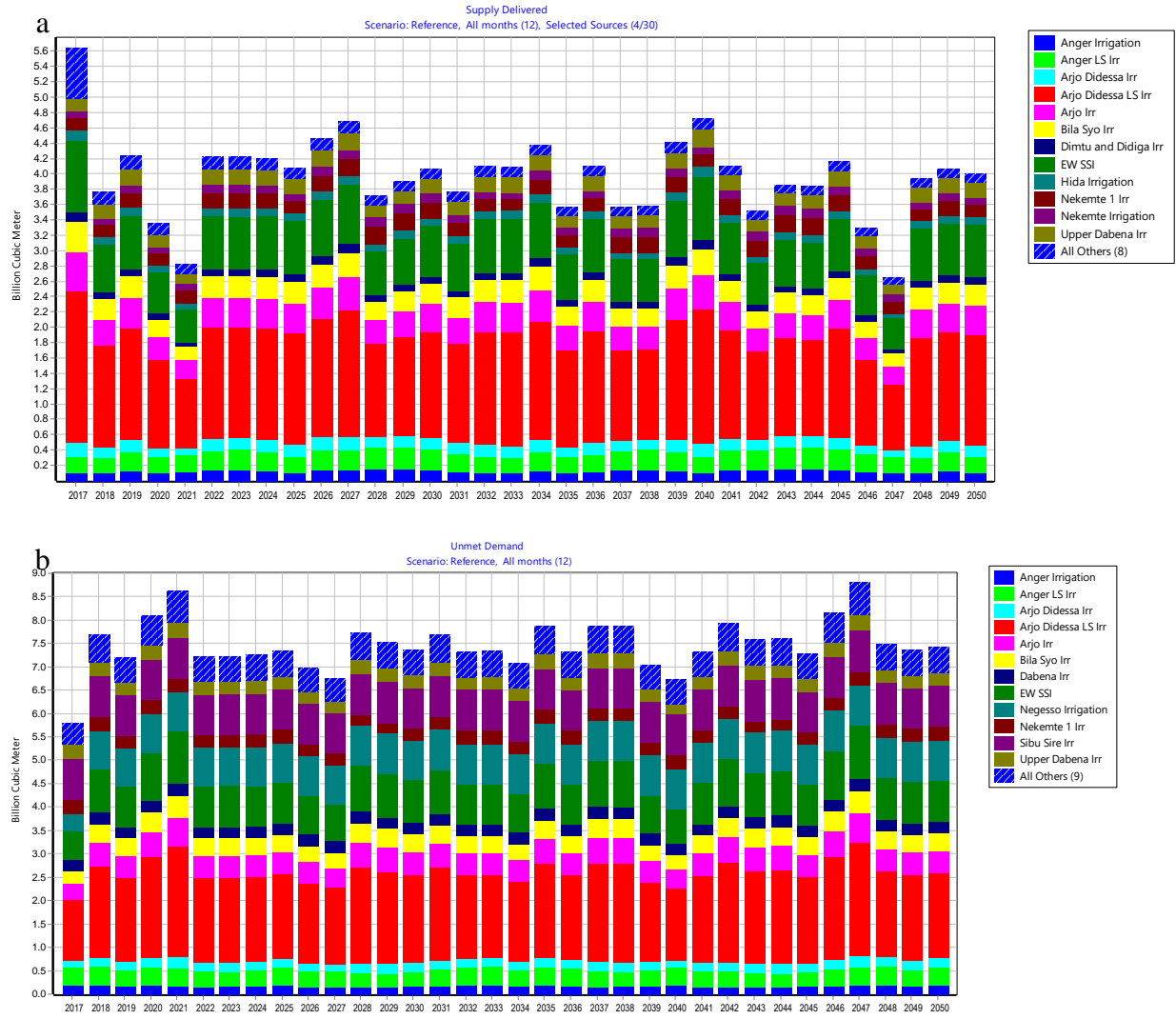
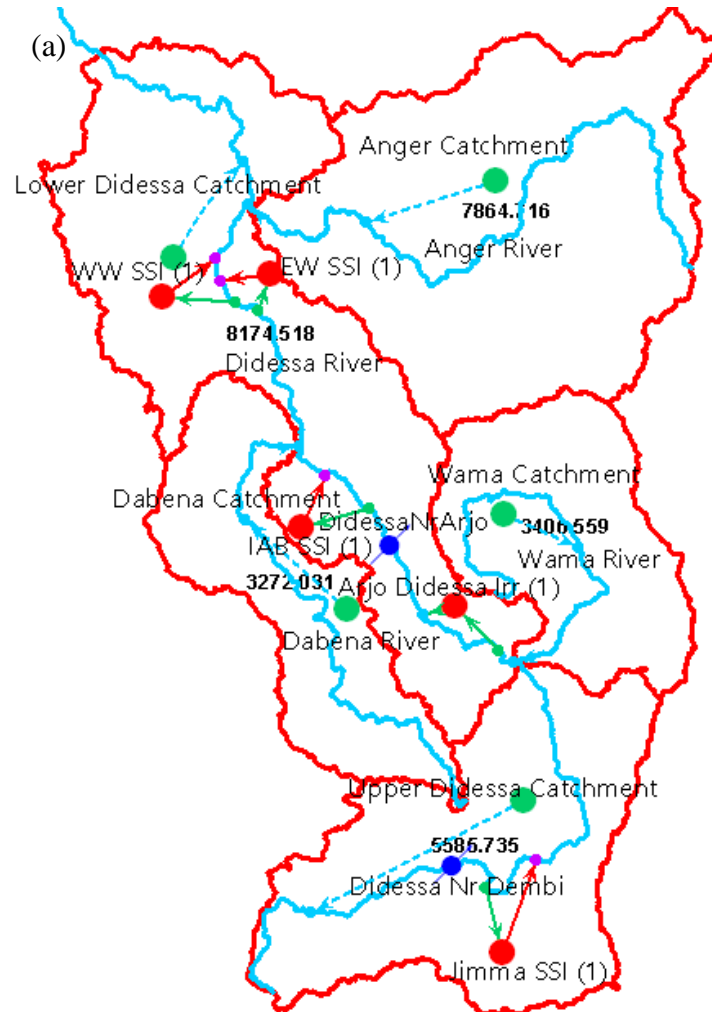
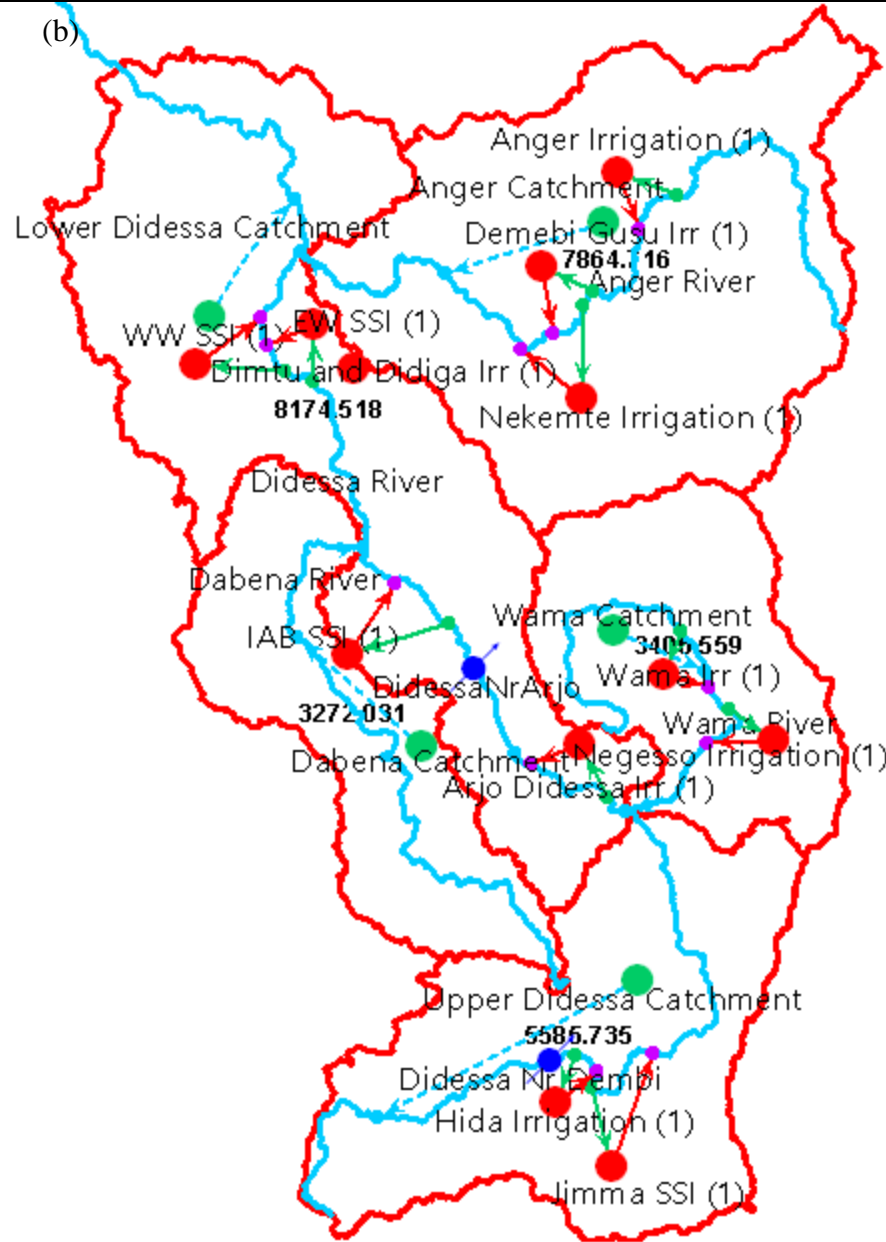


Figure 4-10 Expansion of irrigation for long future development: Supply delivered (a) and unmet demand (b)

The following Figure 4-11 (a), (b), and (c) showed that the schematic diagram of the study area under Reference, small development plan, and long development plan.





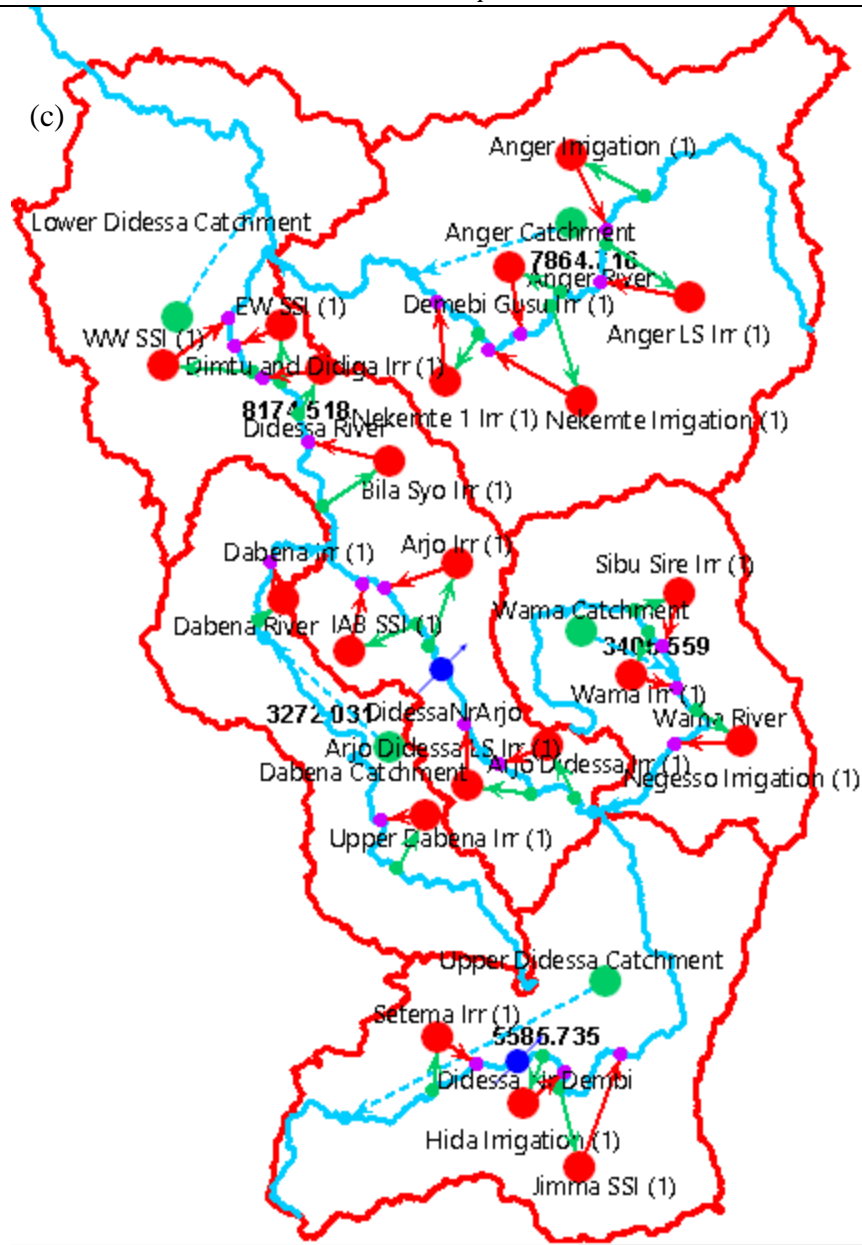


Figure 4-11 Irrigation expansion (a) Reference (1990-2017), (b) Short term future (2018-2035), (c) Long term future (2036-2050) scenarios

#### 4.4 Indicator of Hydrologic alteration Didessa River flow results

There is one big dam and reservoir project under construction, the Arjo-Didessa Dam and Reservoir Project. The reservoir was started to fill in 2012. It is possible to the comparison between pre-and-post of the dam based on the availability of streamflow considering the time from 1990-2011 as pre-fill and from 2012-2017 as post-fill. To identify the hydrologic alteration, two hydrological stations, Didessa near Arjo and Didessa near Dembi were considered. Therefore, it is possible to quantify the degree of hydrologic alteration and variation between pre and post dam reservoir.

The parameters in group one of Table 3-20 describes the magnitude of monthly flow. The deviations were relatively low in the mean monthly flow results, estimated for January, May, September, October, and June, November, and December in Didessa near Arjo and Dembi Stations. The values of degree of Hydrologic alteration of Didessa near Dembi station higher than Didessa near Arjo station illustrated in Table 4-5 and 4-6.

Table 4-5 Results of Indicator of Hydrologic Alteration (IHA) non-parametric range of variability approach (RVA) for Didessa near Arjo

<b>Groups Indicator</b>	<b>Pre-fill Period</b>		<b>Post fill Period</b>		<b>Hydrologic alteration</b>
<b>1.Monthly Discharge Median</b>	<b>Median (CMS)</b>	<b>Coefficient of dispersion</b>	<b>Median (CMS)</b>	<b>Coefficient of dispersion</b>	<b>(%)</b>
January	19.42	0.45	18.62	0.91	-14.92(L)
February	13.92	0.52	11.28	1.21	-33.3(M)
March	11.92	0.72	11.92	1.02	28.57(L)
April	16.76	0.7	16.53	1.47	-25(L)
May	36.01	0.57	36.01	1.26	-14.30(L)
June	90.8	0.62	118.4	1.77	28.57(L)
July	213.3	0.36	213.3	1.06	-33.33(M)
August	349	0.36	349.2	0.24	28.57(L)
September	304.1	0.39	321.8	0.13	0(L)
October	165.8	0.48	165.8	0.55	12.5(L)
November	50.76	0.36	48.71	0.18	71.43(H)
December	31.37	0.27	31.37	0.73	28.57(L)
<b>2.Magnitude of annual extreme flows (CMS)</b>					
1 day Minimum	9.2	0.63	0	0	-10(L)
3 day minimum	9.2	0.63	7.42	1.45	-33.33(M)
7 day minimum	9.55	0.61	7.94	1.38	-33.33(M)
30 day Minimum	11.59	0.51	10.96	1.1	12.5(L)
90 day minimum	14.3	0.47	14.3	1.0	28.57(L)
1 day Maximum	601	0.57	689.1	0.48	28.57(L)
3 day maximum	513	0.58	676.2	0.44	-10(L)
7 day maximum	474	0.54	615.7	0.34	-10(L)
30 day maximum	366.8	0.42	463.3	0.14	-14.29(L)
90 day maximum	302.8	0.22	326.6	0.26	-14.29(L)
Number of zero days	0	0	1	25	-57.14(M)
Base flow index	0.08	0.53	0.08	1.25	28.57(L)
<b>3.Duration of annual extreme flows</b>					
Date of minimum	75	0.08	75	0.18	-33.33(M)
Date of maximum	245	0.04	246	0.12	-33.33(M)
<b>4.Frequency and duration of the high and low pulses</b>					
Low pulse count	3	1	1	1	-40(M)
Low pulse duration	15	4.05	85.25	1.64	-100(H)
High pulse count	3	1.17	4	0.25	66.67(M)

High pulse duration	7	2	6.5	0.85	28.57(L)
<b>5.Rate of change and Frequency of flow</b>					
Rise rate	3.57	1.11	3.66	0.74	114.3(H)
Falls rate	-1.64	-1.63	-2.32	-1.43	-62.5(M)
Number of reversals	92	0.22	62	0.58	-14.29(L)

Table 4-6 Results of Indicator of Hydrologic Alteration (IHA) non-parametric range of variability approach (RVA) for Didessa near Dembi

Indicators		Pre-Impact Period		Post Impact Period		Hydrologic alteration
1.Monthly Discharge	Median	Median (CMS)	Coefficient of dispersion	Median (CMS)	Coefficient of dispersion	(%)
January		5.55	0.56	4.17	1.01	-54.17(M)
February		4.03	0.91	1.86	6.75	-59.26(M)
March		3,28	1.1	2.37	2.76	-63.33(M)
April		5.32	0.88	2.68	3.29	-54.17(M)
May		13.19	1.01	10.69	1.76	37.5 (M)
June		44.27	0.56	42.4	0.68	22.22(L)
July		90.75	0.31	93.83	0.35	-54.17(M)
August		123.9	0.30	125.3	0.68	37.5(M)
September		112.1	0.43	118.6	0.4	37.5(M)
October		51.94	0.598	52.18	0.82	37.5(M)
November		16.57	0.64	17.83	1.16	8.33(L)
December		8.16	0.55	19.04	1.24	8.33(L)
<b>2.Magnitude of annual extreme flows (CMS)</b>						
1 day Minimum		1.52	0.96	0.83	1.89	-54.17(M)
3 day minimum		1.7	0.88	0.87	1.82	-100(H)
7 day minimum		2.07	0.74	0.92	1.69	-100(H)
30 day Minimum		2.82	0.85	1.16	1.4	-54.17(M)
90 day minimum		4.32	0.64	2.33	1.39	54.17(M)
1 day Maximum		223.7	0.32	225	0.31	37.5(M)
3 day maximum		211.7	0.3	216.5	0.31	83.33(H)
7 day maximum		188	0.34	193,5	0.38	37.5(M)
30 day maximum		138.6	0.26	153.6	0.5	-54.17(M)
90 day maximum		112.4	0.32	121.4	0.22	-83.33(H)
Number of zero days		0	0	0	0	0(L)
Base flow index		0.05	0.8	0.02	1.74	-54.17(M)
<b>3.Duration of annual extreme flows</b>						
Date of minimum		74.5	0.09	77.5	0.14	37.5(M)
Date of maximum		248	0.12	225	0.17	-100(H)
<b>4.Frequency and duration of the high and low pulses</b>						
Low pulse count		5.5	0.73	2	2	-100(H)
Low pulse duration		8.5	2	55.5	1.62	-59.26(M)
High pulse count		5	0.8	4.5	0.56	83.33(H)
High pulse duration		8,5	1.35	10.75	1.97	-8.33(L)

5. Rate of change and Frequency of flow					
Rise rate	2.72	0.7	3.73	0.6	-54.17(M)
Falls rate	-1.1	-0.74	-1.17	-0.64	37.5(M)
Number of reversals	93.5	0.2	81	0.39	-18.52(L)

Where, L=Small or no alteration, M=Middle Alteration, H=High degree of alteration

#### 4.4.1 Ecological responses to flow alterations

The IHA determines the 34 EFCs parameters that apply to ecosystem flow components: extreme low flows, low flows, high flow pulses, small floods, and large floods (see Figure 4-12, Figure 4-13, and Figure 4-15 or 4-15). These distinct components flow have special ecological significance. The ecological responses (abundances, diversity, demographic parameters) to river flow alteration depends on river flow components affected. The IHA used in conjunction with ecological models facilitates the creation of flow-ecology hypotheses.

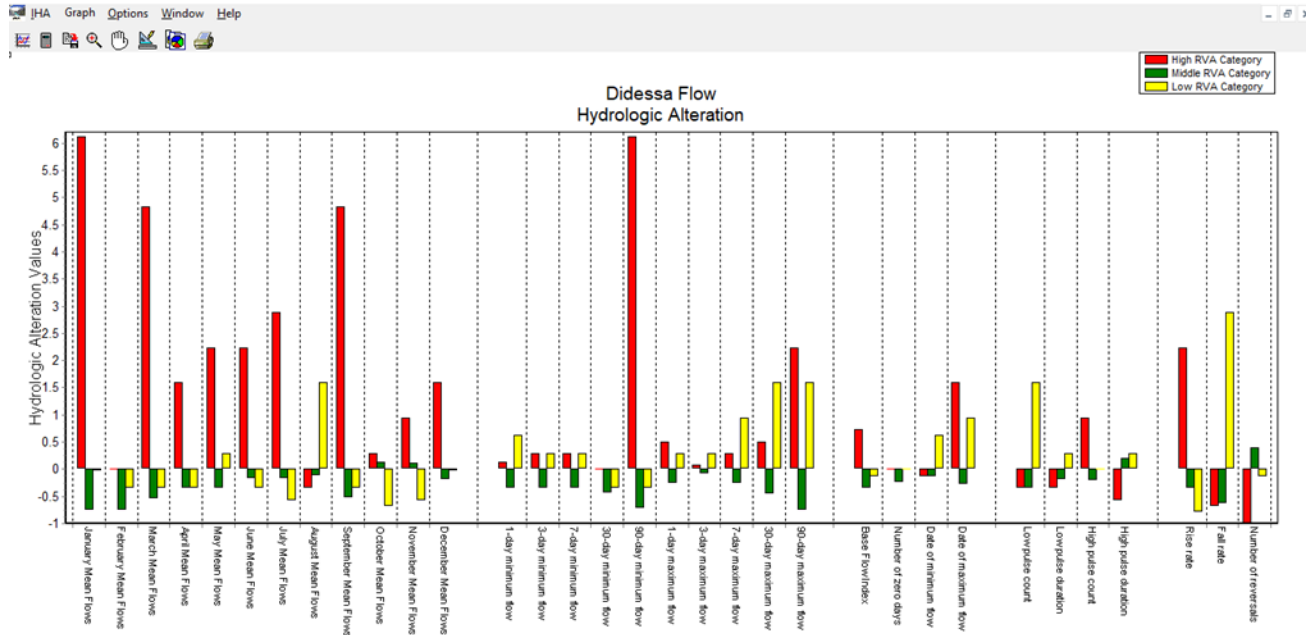


Figure 4-12 Hydrologic alteration of 33 IHAs at Didessa near Arjo Station

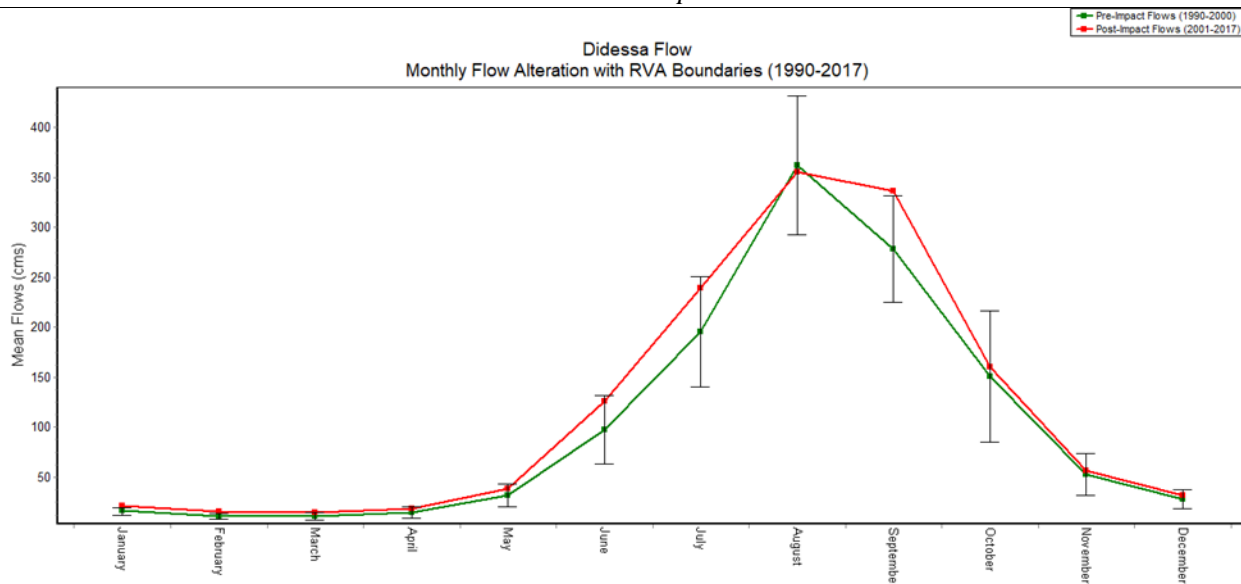


Figure 4-13 Monthly flow alteration with RVA for Didessa near Arjo station

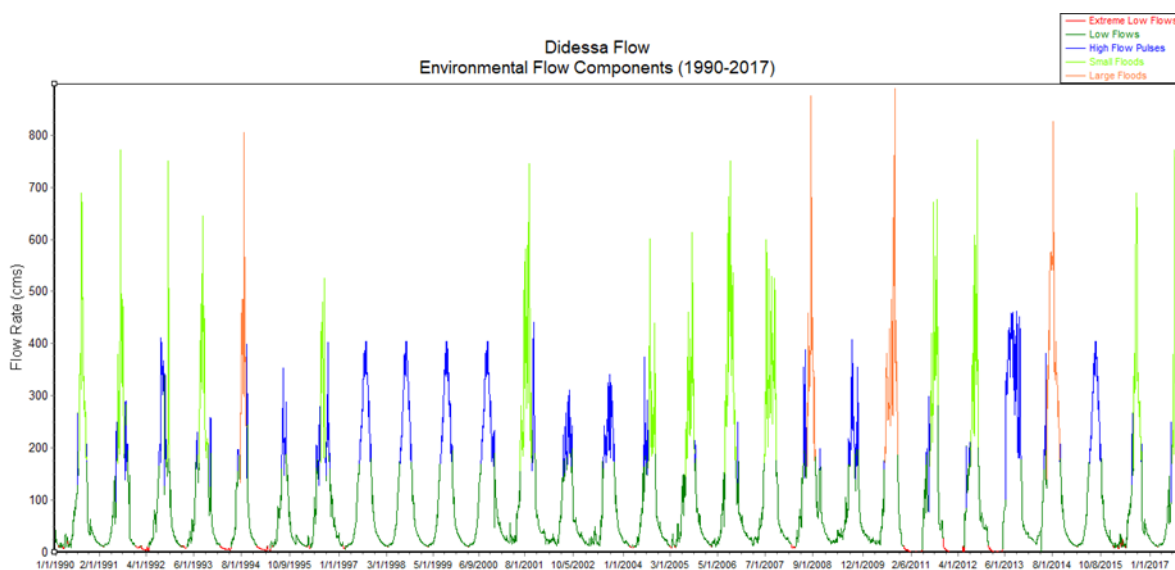


Figure 4-14 Environmental Flow Components for Didessa near Arjo station

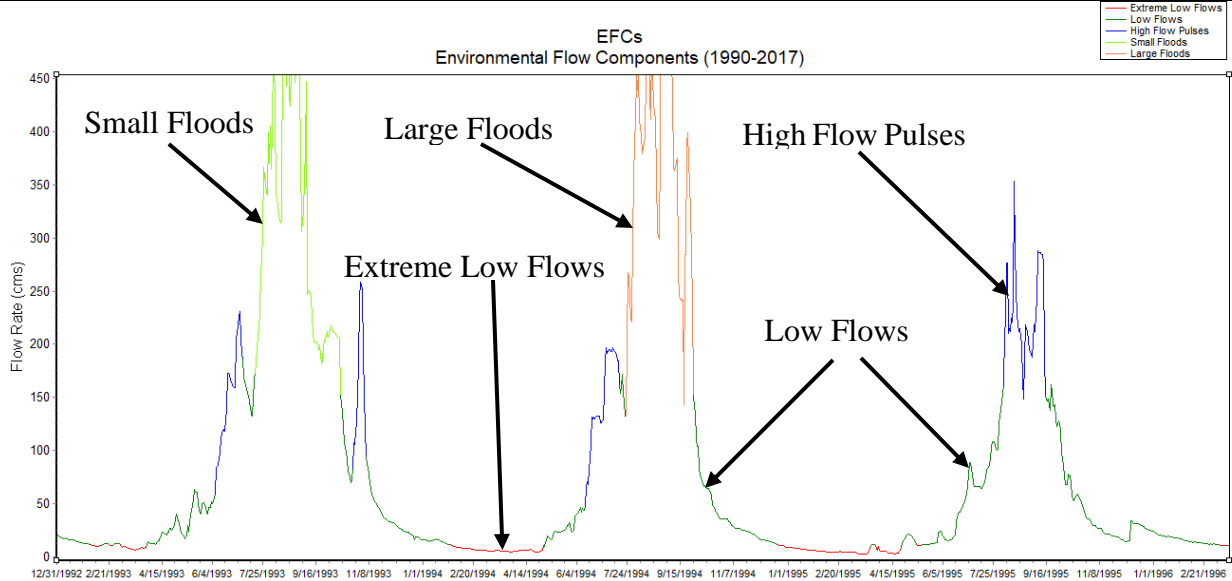


Figure 4-15 Selected year of EFCs of Didessa river at Arjo Station

Using the flow duration curve, which is a graphical representation of the cumulative frequency that shows that the percentage of time defined discharges have been equaled or exceeded during a given period, the established flow regimes are further represented. For a given river basin, the flow duration curve reflects the relationship between streamflow magnitude and frequency. The form of the curves of the flow period defines the flow features of the flow regimes. The hydrological features of the drainage area are shown by the shape of the flow duration curve. The variability of flows in the stream is shown by the slope of the flow period curves. There is greater variability on the steeper slopes than on the flatter slopes (Berhanu *et al.*, 2015).

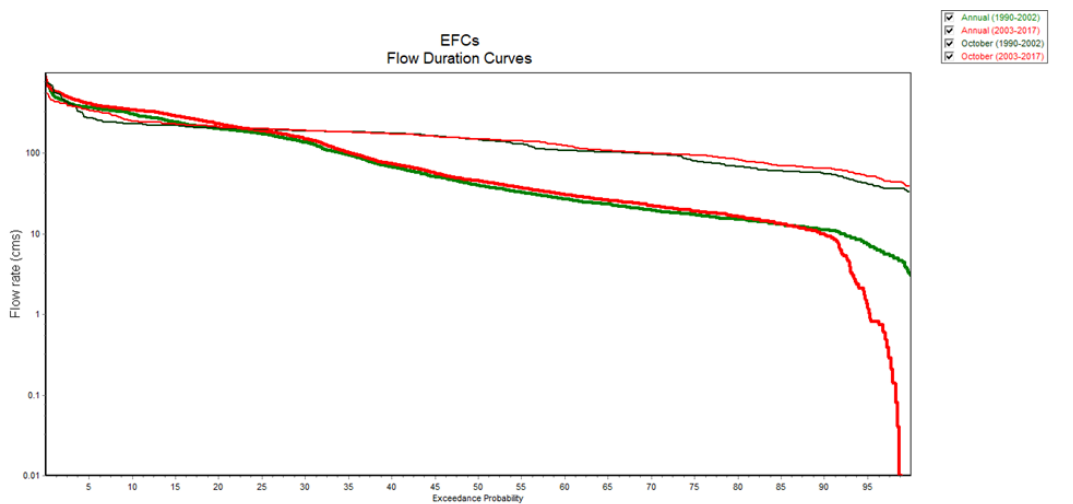


Figure 4-16 Flow Duration Curves (FDC) of Didessa River near Arjo statins

## 5 CONCLUSION AND RECOMMENDATIONS

### 5.1 Conclusion

This study was done to analyze the effects of water resources development and the change in flow alteration pre-(1990-2011 and post (2011-2017) fill using the WEAP21 model and IHA respectively. The model's input was supply sources and demand data from 1990 to 2017 to assess the effects of water resource development in the study area. The analysis was done under two different scenarios: for the population growth rate scenario and expansion of irrigation activity. In the first scenario for reference, small population growth rate, higher population growth rate the water demand and unmet values are 151.19 and 0.74, 375.6 and 297.87, 954.46 and 748.18 in the million-meter cube in respectively. For the second scenario, the results under reference, short term future expansion and long-term future expansion, the water demand and unmet are 1.65 and 0.195, 1.68 and 0.55, and 11.45 and 7.5-billion-meter cube in respectively Both results shows us the population growth rate increases and expansion of irrigation activities would happened the water demand and unmet values also increasing. Still there is susceptible to supply-demands misbalance issues in the study area.

From the second scenario, as the agricultural land coverage increase, the unmet also increase. To balance the basin's water demand by taking environmental flow from 20 up to 50 percent of mean annual runoff.

For the IHA parameters, the pre and post impacts at Didessa near Arjo and Didessa near Dembi gauge station, the degree of hydrologic alteration were quantified, from river flow components (magnitude, Frequency, Duration, Timing, and rate of change of flow) were relatively high in some months for both stations while low in most months. In general, the Didessa near Dembi station has more susceptible to flow alteration compared with Didessa near Arjo station.

In general, it can be argued that any proposed water development must include all potential possibilities that can resolve environmental change and increased water demands.

## 5.2 Recommendation

Based on the results of the study the following points was recommended for improvements to the study:

- This study was done the primary water resources such as river and rainfall, do not add the sources from the reservoir and groundwater for analysis. Other results will be obtained when considering these sources for further improvement of the study.
- The demand sites such as Industrial, institutional, and commercial water requirements were not involved in the analysis of flow alteration. Due to the unavailability of these data, further improving these data should be considered.
- The distribution of water needs considerable attention to narrow the gap between current demands and water availability to maintain the safe flows of the river. As the production of water supplies is on the rise, especially for irrigation, water-efficient crops should be more emphasized
- The study was stimulated by the soil moisture method and scenarios developed by considering the population growth rate and expansion of irrigation activity, and other results will be obtained by changing the simulation method and adding different scenarios.

## 6 Reference

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## Appendixes

**Appendix A:** -Projected Population at the wereda level that was taken from Population Projection of Ethiopia at wereda Level (2014-2017).

S.No	Woredas	2014	2015	2016	2017	S.No	Woredas	2014	2015	2016	2017
1	Abe Dongoro	80263	82191	84153	86093	26	Haru	81057	83094	85160	87219
2	Agaro	35659	37447	39174	41085	27	Horo	89996	92190	94422	96634
3	Agalo Meti	27714	28455	29198	30011	28	Jarte Jardega	59235	60769	62319	63876
4	Amuru	63654	65296	66954	68619	29	Jimma Arjo	104656	139486	110165	112950
5	Bedele	119770	123252	126734	130311	30	Jimma Genete	77806	79848	81911	83989
6	Belo Jefonfoy	36688	37670	38656	39735	31	Kamashi	24438	25445	26454	27592
7	Nekemte	105358	110640	115741	121385	32	Kersa	197918	202644	207456	212208
8	Boji Dirmeji	52484	53961	55444	56956	33	Lalo Asabi	92123	94623	97140	99691
9	Boneya Boshe	57549	58968	60408	61839	34	Leka Dulecha	86594	88725	90891	93014
10	Borecha	88267	90385	92543	94676	35	Limu	87119	89268	91450	93619
11	Chora	121211	124273	127376	130476	36	Limu Kosa	195081	200101	205180	210272
12	Chwaka	66964	68531	70131	71704	37	Limu Seka	224503	231871	237344	242736
13	Dabo Hana	50001	51303	52617	53938	38	Meko	26178	26775	27386	27984
14	Dedesa	102237	104786	107372	109949	39	Mena	175428	179600	183852	188045
15	Dega	47595	48797	50015	51233	40	Nejo	160927	165538	170159	174888
16	Diga	81108	83280	85468	87681	41	Nole Kaba	72258	74104	75972	77841
17	Gechi	85000	87149	89327	91501	42	Nunu Kumba	78093	80061	82057	84048
18	Gera	134724	137980	141294	144574	43	Sasiga	96688	98993	101341	103659
19	Gida Kiremu	194458	199935	205428	211035	44	Seka Chekorsa	249066	255020	261086	267074
20	Gimbi	132185	136387	140564	144916	45	Setema	123813	126821	129879	132910
21	Gobu Seyo	49800	51119	52450	53891	46	Sibu Sire	123794	127012	130265	133531
22	Gomma	256129	262462	268892	275289	47	Sigmo	110997	113742	116529	119300
23	Gumay	73082	74953	76845	78740	48	Wama Hagalo	58420	59753	61117	62451
24	Guto Gida	106962	109403	111901	114342	49	Wayu Tuka	75174	76891	78648	80324
25	Haro	62062	63479	64929	66345	50	Yaso	15672	16114	16553	17038

**Appendix B:** -Calculated Annual water use rate for Domestic based on the recommendation of the second Growth Transformation and plan (GTP-2) (Annual Activity Level (AAL) and Water Use Rate (AWR) in Didessa River Basin at Wereda Levels).

*Water Resource Developments and Flow Alteration in Didessa River Basin*

S. No	Woredas	Zones	Annual Activity	Water Use Rate (AWR)					For Irrigation (Duty)			
			Level (AAL)	Actual		For Domestic Standard Values						
			Year, 2020	Irrigation Area		Water Use Rate (AWR)						
		Population Number	Km <sup>2</sup>	ha	l/c/d	l/d	m <sup>3</sup> /d	m <sup>3</sup> /yr	l/s/ha	l/s	m <sup>3</sup> /s	
1	Abe Dongoro	HGW	86706	535.68	53568	35	3034709	3035	1109186	1.8	96422.4	96.42
2	Amuru	HGW	69143	265.93	26593	35	2420001	2420	884510	1.8	47867.4	47.87
3	Bedeke	IAB	131431	109.4	10940	35	4600070	4600	1681326	2	21880	21.88
4	Boji Dirmeji	WW	57430	96.12	9612	25	1435753	1436	524768	1.6	15379.2	15.38
5	Boneya Boshe	EW	62291	126.31	12631	35	2180172	2180	796853	1.8	22735.8	22.74
6	Borecha	IAB	95350	110.53	11053	35	3337244	3337	1219763	2	22106	22.11
7	Chora	IAB	131453	618.74	61874	35	4600840	4601	1681607	2	123748	123.75
8	Chwaka	IAB	72202	178.74	17874	35	2527061	2527	923641	2	35748	35.75
9	Dabo Hana	IAB	54354	208.35	20835	35	1902376	1902	695319	2	41670	41.67
10	Dedesa	IAB	110761	53.03	5303	40	4430454	4430	1619331	2	10606	10.61
11	Dega	IAB	51616	135.98	13598	35	1806576	1807	660304	2	27196	27.20
12	Diga	EW	88376	3124.6	312456	35	3093158	3093	1130549	1.8	562421	562.42
13	Gechi	IAB	92186	210.2	21020	35	3226519	3227	1179293	2	42040	42.04
14	Gera	Jimma	138969	67.46	6746	35	4863905	4864	1777757	2	13492	13.49
15	Gida Kiremu	EW	212792	152.77	15277	35	7447737	7448	2722148	1.6	24443.2	24.44
16	Gimbi	WW	146276	278.1	27810	40	5851020	5851	2138548	1.8	50058	50.06
17	Gobu Seyo	EW	54214	823.3	82330	35	1897484	1897	693530	1.8	148194	148.19
18	Gomma	Jimma	277306	177	17700	35	9705724	9706	3547442	2	35400	35.40
19	Gumay	Jimma	79337	23.5	2350	35	2776787	2777	1014916	2	4700	4.70
20	Guto Gida	EW	110144	3839.8	383984	35	3855027	3855	1409012	1.8	691171	691.17
21	Haru	WW	87868	313.43	31343	35	3075392	3075	1124056	1.6	50148.8	50.15
22	Horo	HGW	97332	636.96	63696	35	3406635	3407	1245125	1.8	114653	114.65
23	Jimma Arjo	EW	114633	721.15	72115	35	4012144	4012	1466439	1.8	129807	129.81
24	Jimma Genete	HGW	84642	1527.8	152777	35	2962471	2962	1082783	1.8	274999	275.00
25	Kersa	Jimma	213710	752.95	75295	35	7479851	7480	2733885	2	150590	150.59
26	Lalo Asabi	WW	100492	121.07	12107	35	3517210	3517	1285540	1.6	19371.2	19.37
27	Leka Dulecha	EW	93690	1478.3	147832	35	3279139	3279	1198525	1.8	266098	266.10
28	Limu	EW	94303	573.71	57371	35	3300616	3301	1206375	1.8	103268	103.27
29	Limu Kosa	Jimma	211875	142.7	14270	35	7415616	7416	2710408	2	28540	28.54
30	Limu Seka	Jimma	244665	78.99	7899	35	8563263	8563	3129873	2	15798	15.80
31	Meko	IAB	28173	229.38	22938	25	704336	704	257435	2	45876	45.88
32	Mena	Jimma	189371	282.59	28259	35	6627982	6628	2422528	2	56518	56.52
33	Nejo	WW	176370	1934.8	193477	35	6172936	6173	2256208	1.6	309563	309.56
34	Nole Kaba	WW	176211	204.71	20471	35	6167381	6167	2254178	1.6	32753.6	32.75
35	Nunu Kumba	EW	84676	328.58	32858	35	2963646	2964	1083213	1.8	59144.4	59.14
36	Sasiga	EW	104392	1296.4	129643	35	3653708	3654	1335430	1.8	233357	233.36
37	Seka Chekorsa	Jimma	86703	526.1	52610	35	3034612	3035	1109151	2	105220	105.22
38	Setema	Jimma	133867	269.4	26940	35	4685345	4685	1712493	2	53880	53.88
39	Sibu Sire	EW	134559	1577.3	157728	35	4709559	4710	1721344	1.8	283910	283.91
40	Sigmo	Jimma	120174	32.15	3215	35	4206098	4206	1537329	2	6430	6.43
41	Wama Hagalo	EW	62874	146.34	14634	35	2200583	2201	804313	1.8	26341.2	26.34
42	Wayu Tuka	EW	80864	970.2	97020	35	2830240	2830	1034453	1.8	174636	174.64

*Where, EW=East Wollega, WW=West Wollega, IAB=Ilubabor, HGW=Horro Guduru Wollega*

**Appendix C: -Five [5] Major towns considered in Didessa River Basin**

Year	Agaro	Nekemte	Gimbi	Bedele	Shambu
2020	41685	123158	50729	31960	24549
2030	43750	129257	53242	33544	25765
2040	45917	135658	55879	35206	27041
2050	48192	142376	58646	36950	28381

Year	Agaro	Nekemte	Gimbi	Bedele	Shambu
2014	35659	105358	43397	27339	21001
2015	37447	110640	45572	28711	22053
2016	39174	115741	47674	30034	23070
2017	41085	121385	49999	31500	24196

**Appendix D** Water Demand sides of the study area for the base year and future scenario

water demand	The base year (1998)	Reference current development (1999-2014)	Medium-term future development (2015-2030)	Long term future development (2031-2050)
<b>I. Domestic water demand (MCM/year at the end of scenario period)</b>				
Nekemte town domestic water demand	1.93	3.67	6.97	15.57
Bedele town domestic water demand	0.5	0.95	1.81	4.04
<b>II. Agricultural (Irrigation) Activity levels (ha)</b>				
1.EW-SSI	3161	8079	19903	37951
2.WW-SSI	80	80	80	80
3.IAB-SSI	201	401	822	822
4.Jimma-SSI	36	636	1436	2372
5.Arjo Didessa Irrigation			80000	80000
6.Anger Irrigation			8000	14450
7.Nekemte Irrigation			6000	11220
8.Negeso Irrigation			5000	21315
9.Hida Irrigation			5650	5650
10.Wama Irrigation			325	325
11.Lugo Irrigation			285	285
12.Dimtu and Didiga Irrigation			5167	5167
13.Upper Dabena Irrigation				1150
14.Dabena Irrigation				6150
15.Urgessa Irrigation				2933
<b>III. Environmental flow requirements</b>				
	√	√	√	√

Some data are adopted and updated from: [Adgolign et al. \(2016\)](#), OIDA (2014)

**Appendix E:** -Livestock Population within Five [5] Catchments considered in Didessa River Basin

<i>Catchments</i>	<i>Cattle</i>	<i>Equines</i>	<i>sheep</i>	<i>Goat</i>	<i>Poultry</i>		
<i>AC</i>	276841	29364	70318	55060	154873		
<i>UDC</i>	261732	117070	1006343	336259	561609		
<i>DC</i>	177381	22484	78796	16200	141161		
<i>WC</i>	255158	58286	47268	30195	177682		
<i>LDC</i>	83539	9571	19655	23800	67497		

*where, AC-Anger Catchment, UDC-Upper Didessa Catchment, DC-Dabana Catchment, WC-Wama Catchment, LDC-Lower Didessa Catchment*

**Appendix F:** -Annual Data of Selected Rainfall Station (in mm)

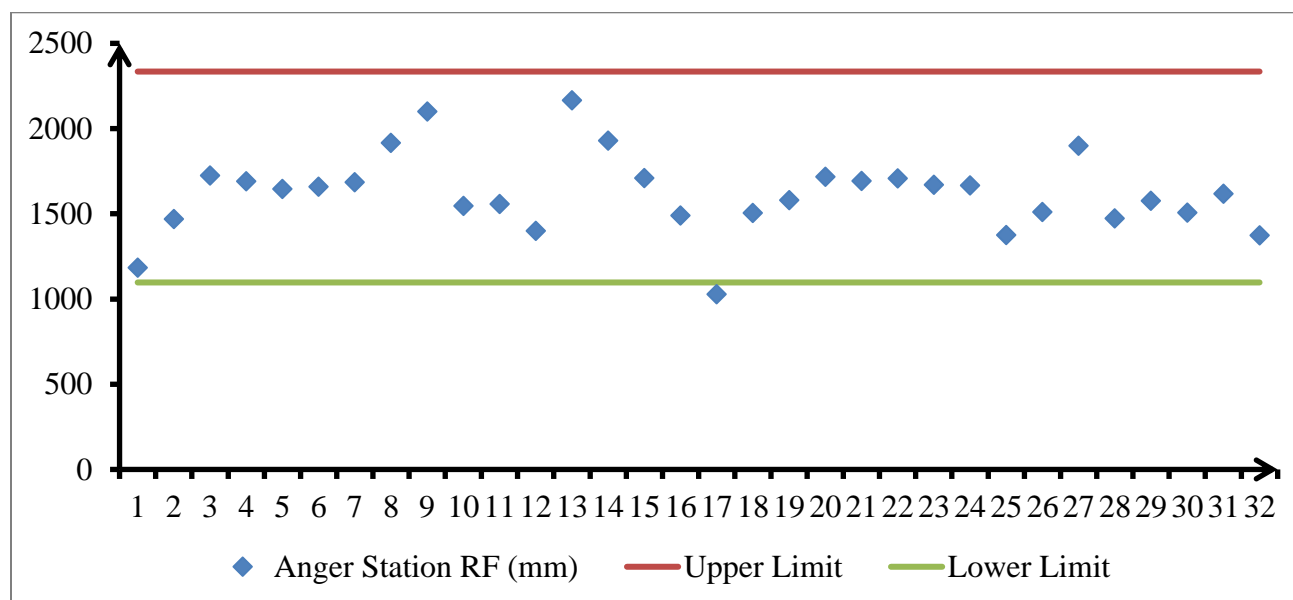
<b>Year</b>	<b>Anger</b>	<b>Arjo</b>	<b>Bedele</b>	<b>Didessa</b>	<b>Gimbi</b>	<b>Nekemte</b>	<b>Shambu</b>
1986	1183.20	1706.40	1392.70	1281.00	1521.70	1439.12	2214.73
1987	1469.47	1857.09	1991.80	1688.30	1829.80	2072.79	1496.00
1988	1723.31	2110.40	2001.50	2104.49	1980.30	1938.27	1698.60
1989	1690.76	1854.50	1810.30	1885.37	2126.48	1957.19	1688.90
1990	1644.79	1581.46	1711.50	1286.99	1664.99	1889.70	1773.11
1991	1657.88	1656.96	1722.95	1294.64	1686.57	2171.04	1560.12
1992	1683.73	2001.40	1909.20	1162.47	2170.09	2479.10	1834.80
1993	1914.50	2146.85	1779.01	1358.55	1756.80	2512.56	1875.72
1994	2098.80	1592.20	1588.05	1180.90	1826.42	2090.00	1275.80
1995	1544.80	1335.17	1838.80	1043.10	1375.80	2064.48	1376.20
1996	1557.67	1911.79	1735.00	1883.63	1576.00	2320.90	1632.50
1997	1399.30	1919.83	2001.60	1451.07	1857.00	2190.00	1809.30
1998	2165.28	1690.28	1947.77	1744.60	1888.00	2551.40	1463.99
1999	1928.26	1775.54	2322.50	1484.70	1980.70	1916.42	1548.19
2000	1708.24	1842.92	1827.80	1836.60	2028.70	2146.44	1509.54
2001	1490.10	1873.30	2166.30	1266.30	1603.60	1942.20	1350.80
2002	1026.78	1353.60	1448.20	905.24	1651.00	1706.00	1686.40
2003	1504.00	1780.90	1445.50	1571.90	1946.30	1837.50	1349.30
2004	1578.41	2360.70	1914.60	1472.20	1873.30	1792.10	1489.30
2005	1716.60	2143.00	2153.30	1549.90	1808.20	2248.70	1432.63
2006	1692.25	2026.94	2358.30	1704.62	2191.00	2139.40	1619.80
2007	1707.69	2766.50	1982.40	1463.15	1705.83	2173.00	1656.60
2008	1669.55	2666.62	2012.69	2098.14	2116.30	2441.30	1709.62

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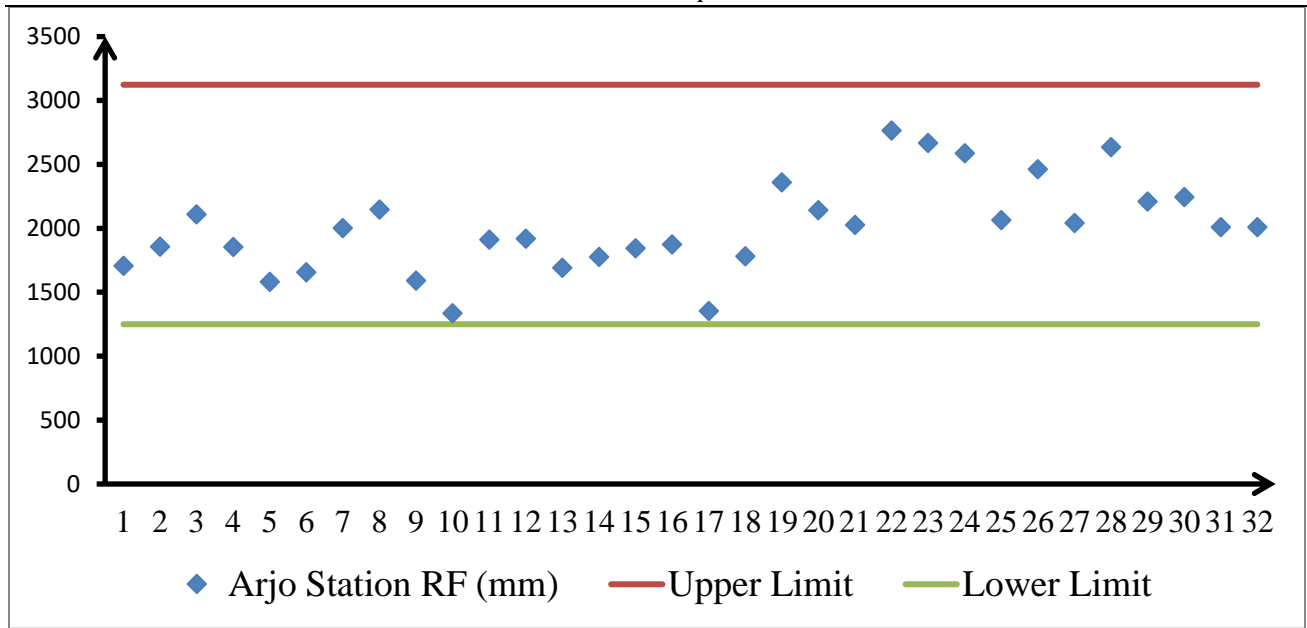
2009	1665.34	2588.00	1776.80	1447.00	1645.01	2022.80	1465.74
2010	1374.33	2065.20	1967.90	1640.60	1900.10	2482.10	1431.70
2011	1509.00	2461.70	1543.40	1305.80	1550.00	2010.40	1421.90
2012	1897.64	2041.47	1806.49	1284.76	1743.77	2109.30	1496.59
2013	1472.08	2635.70	1903.05	1474.40	1826.90	1965.30	1543.40
2014	1575.10	2209.13	1868.25	1819.54	2009.10	2531.86	1758.76
2015	1505.96	2344.06	1924.19	1303.21	1910.90	2103.54	1371.11
2016	1617.00	2010.31	1471.62	1501.13	2548.15	2103.54	1724.24
2017	1372.14	2009.89	1810.22	1533.32	1848.35	1964.94	1648.39

**Appendix G:** -Outlier tests of the selected stations

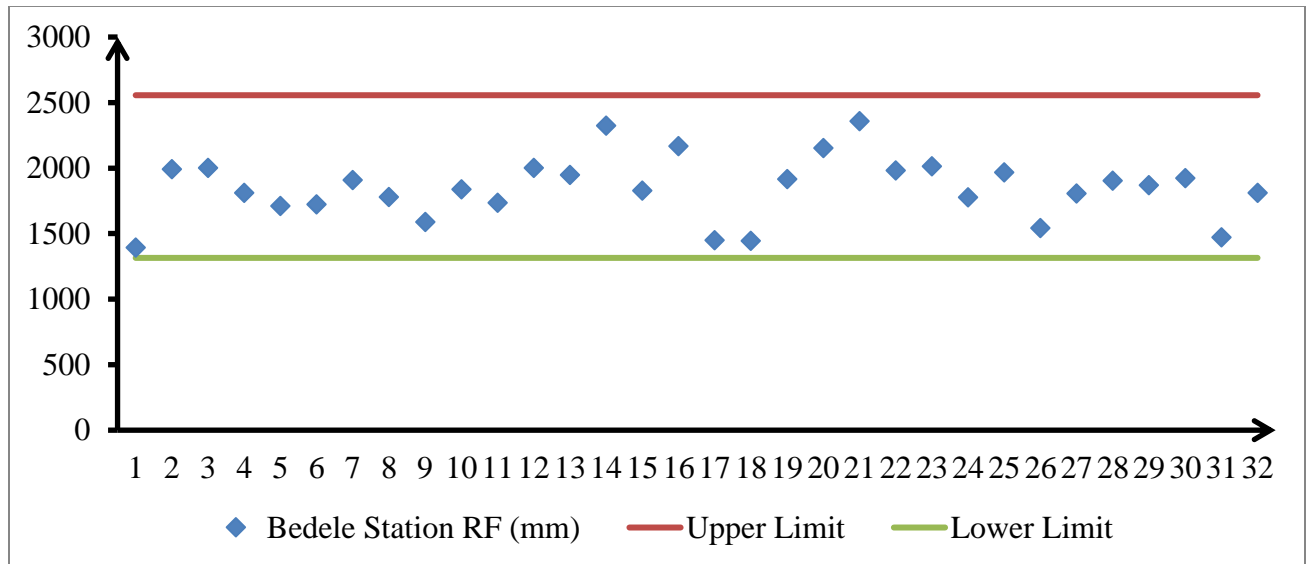
Tested outlier graph of Anger Station RF [mm]



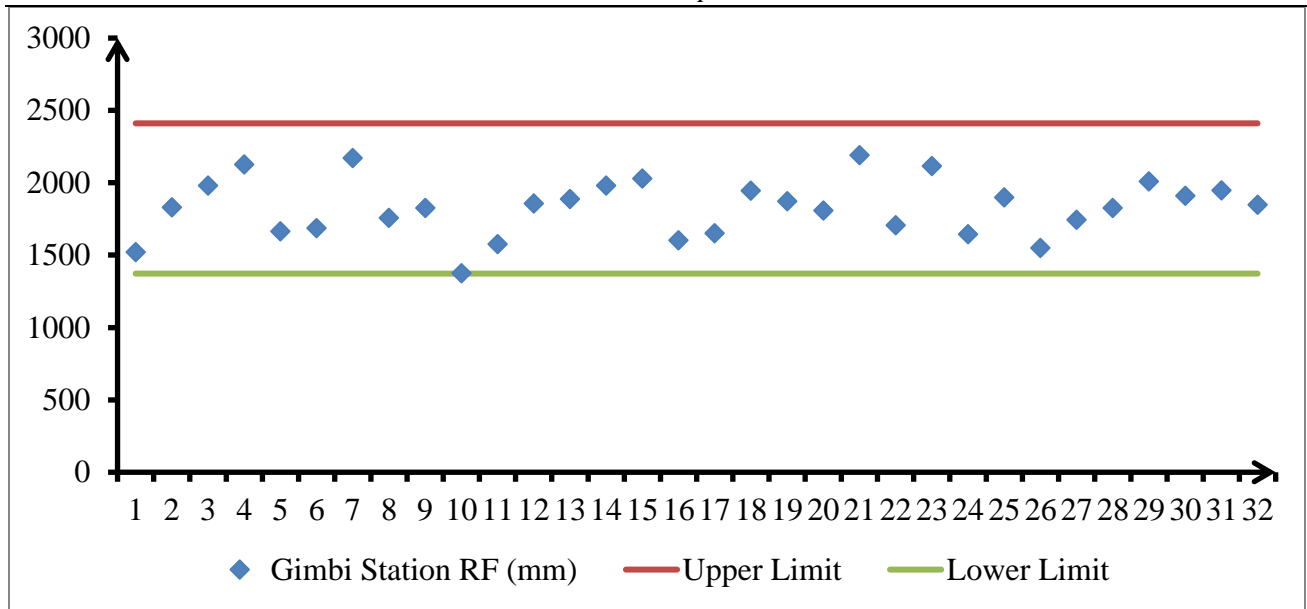
Tested outlier graph of Anger Station Rainfall [mm]



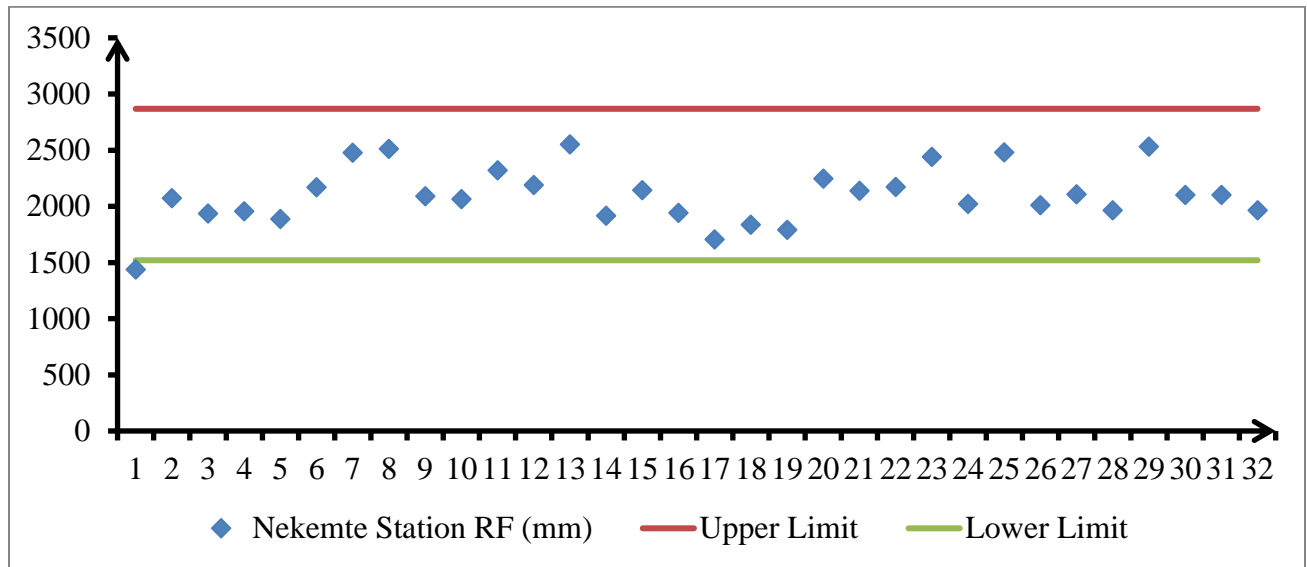
Tested outlier graph of Arjo Station Rainfall [mm]



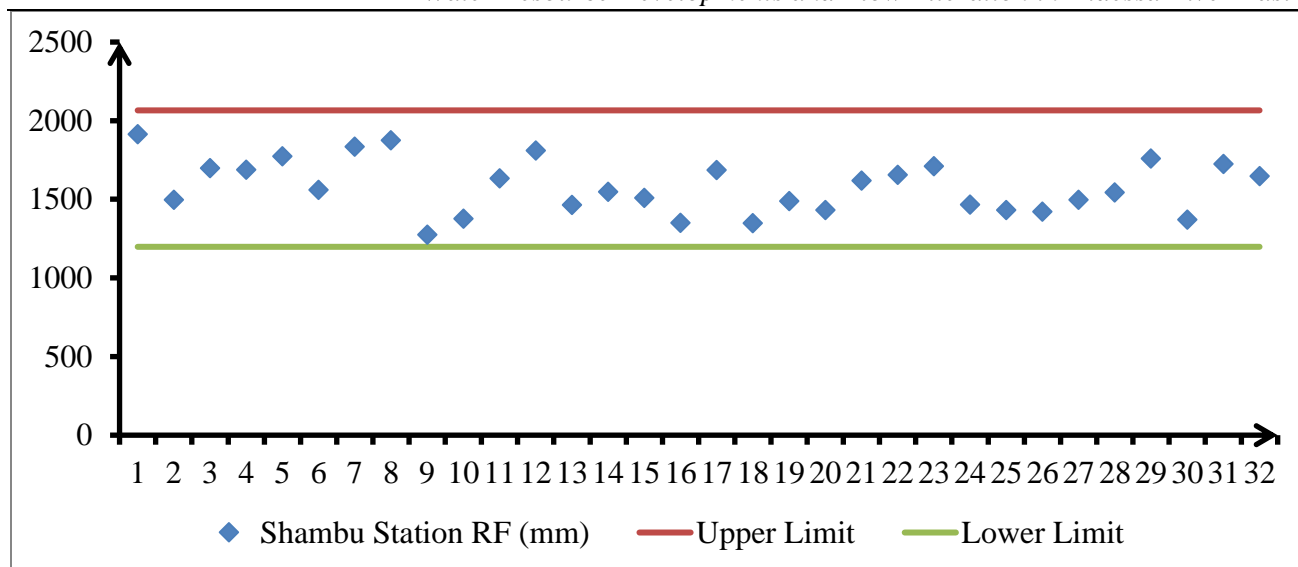
Tested outlier graph of Bedele Station RF [mm]



Tested outlier graph of Gimbi Station Rainfall [mm]

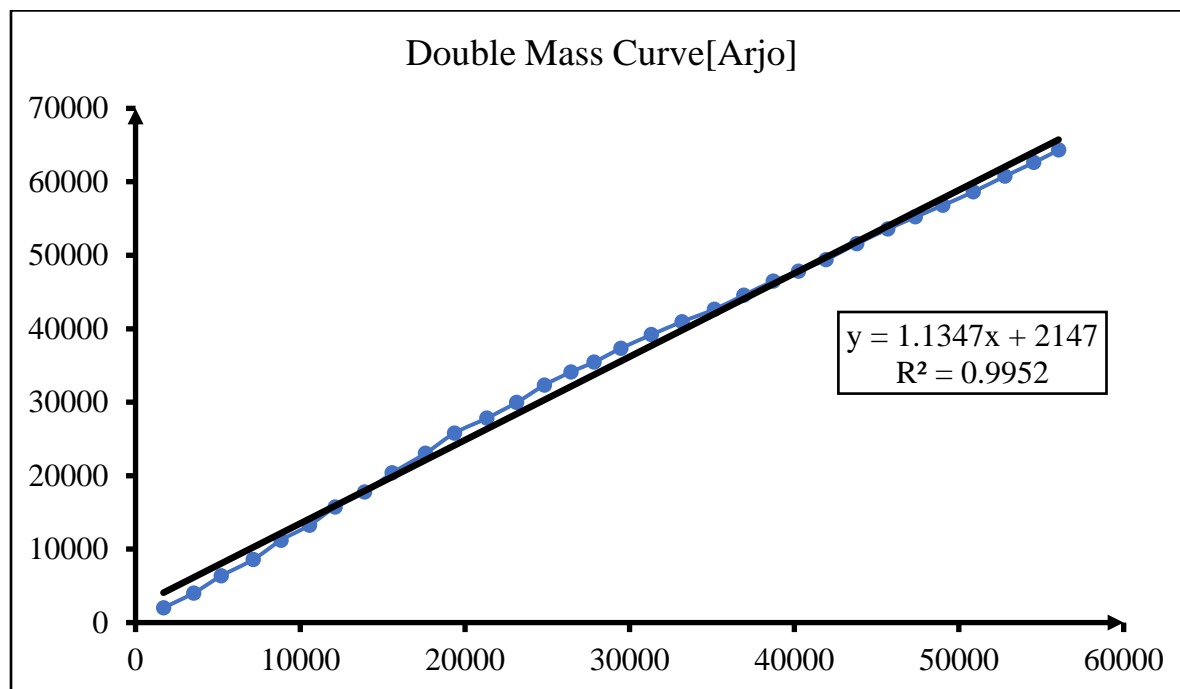


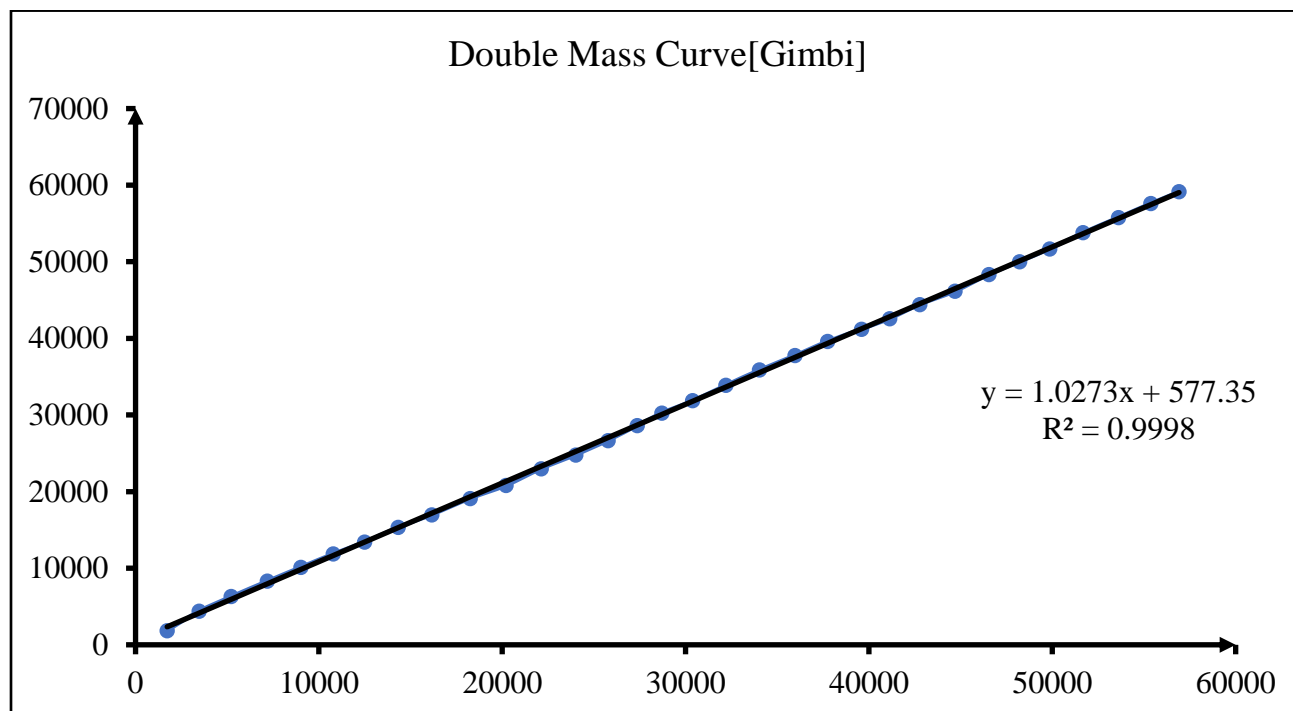
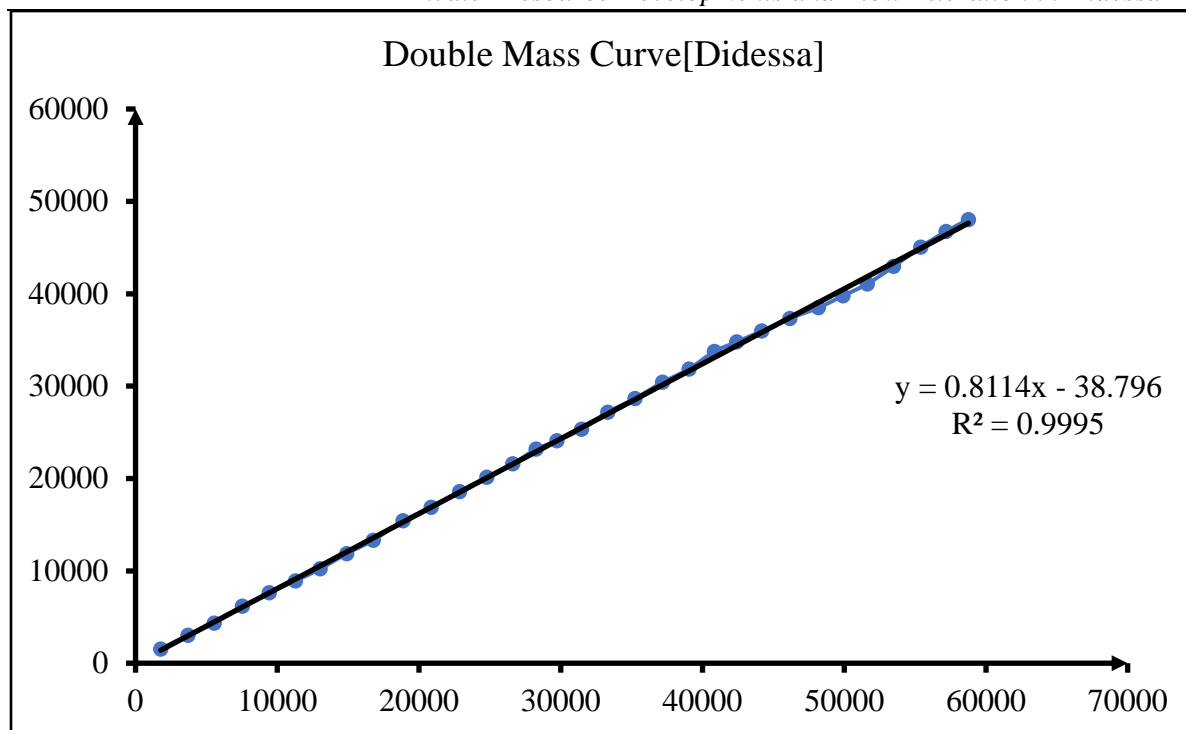
Tested outlier graph of Nekemte Station Rainfall [mm]

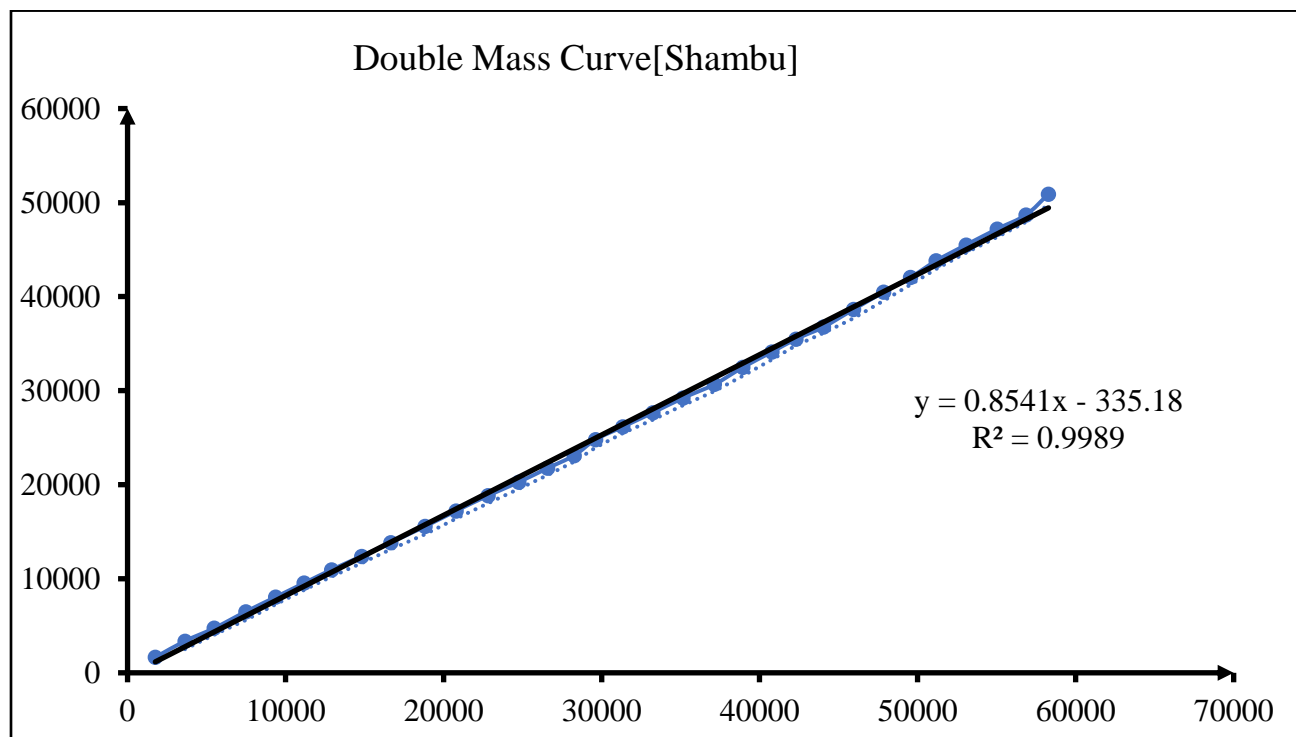
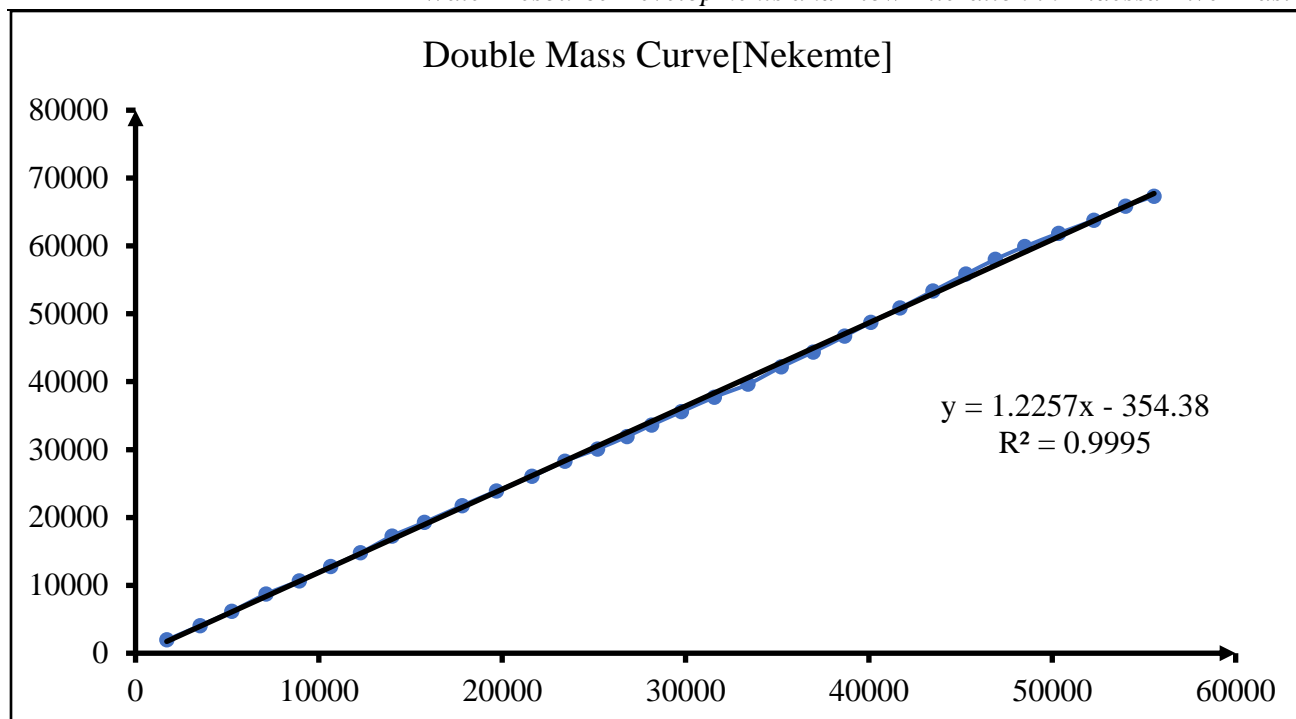


Tested outlier graph of Shambu Station Rainfall [mm]

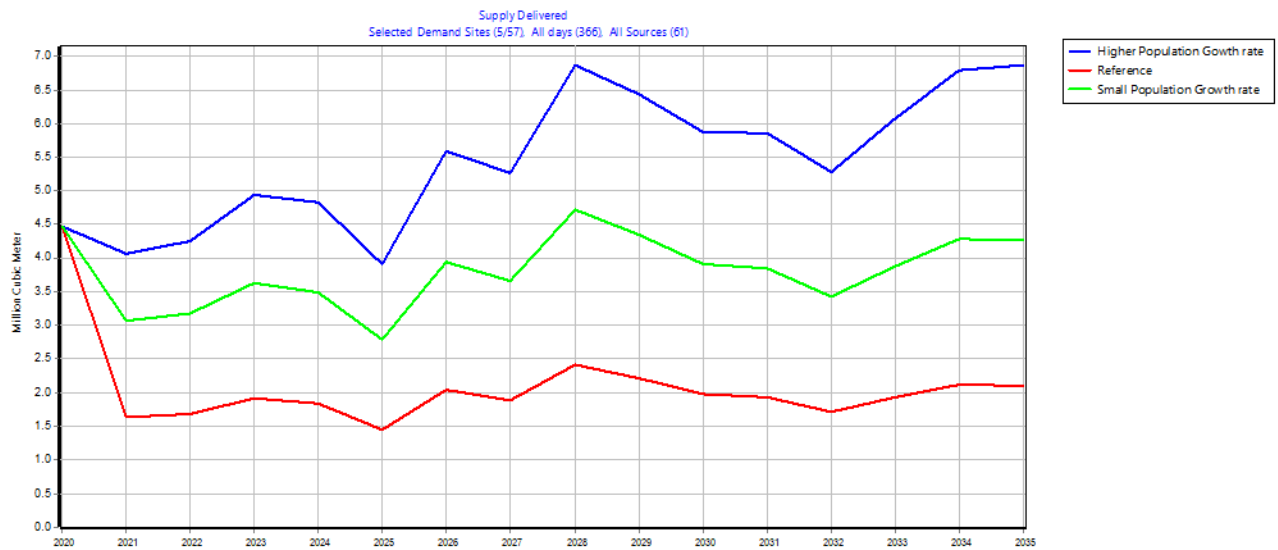
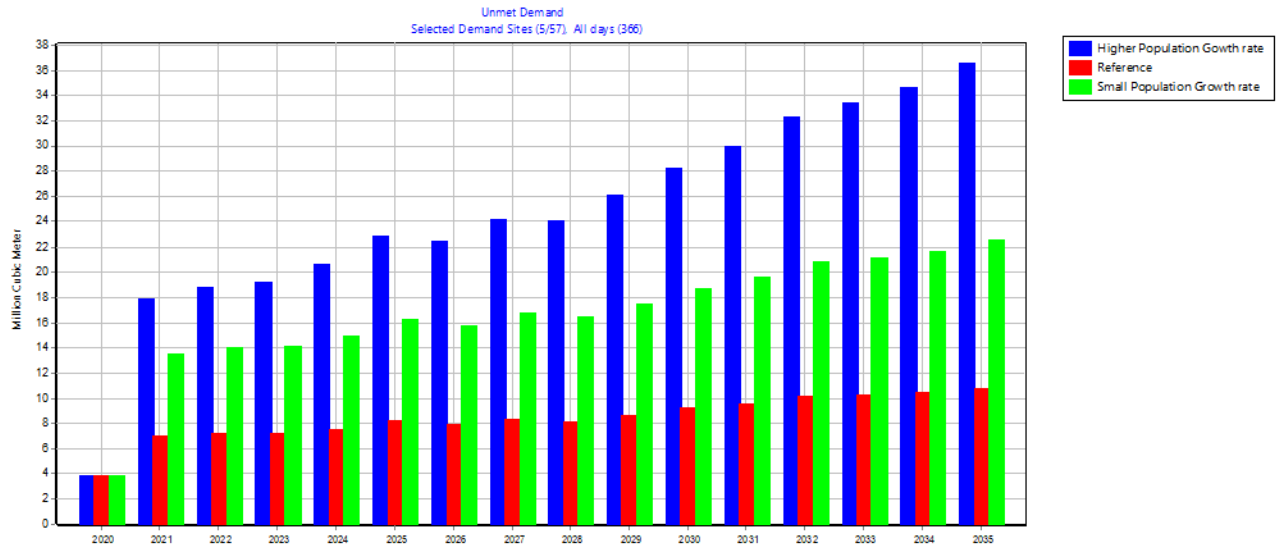
**Appendix H:** -Double Mass curves of Arjo, Didessa, Gimbi, Nekemte, and Shambu depicted in the following figure respectively.



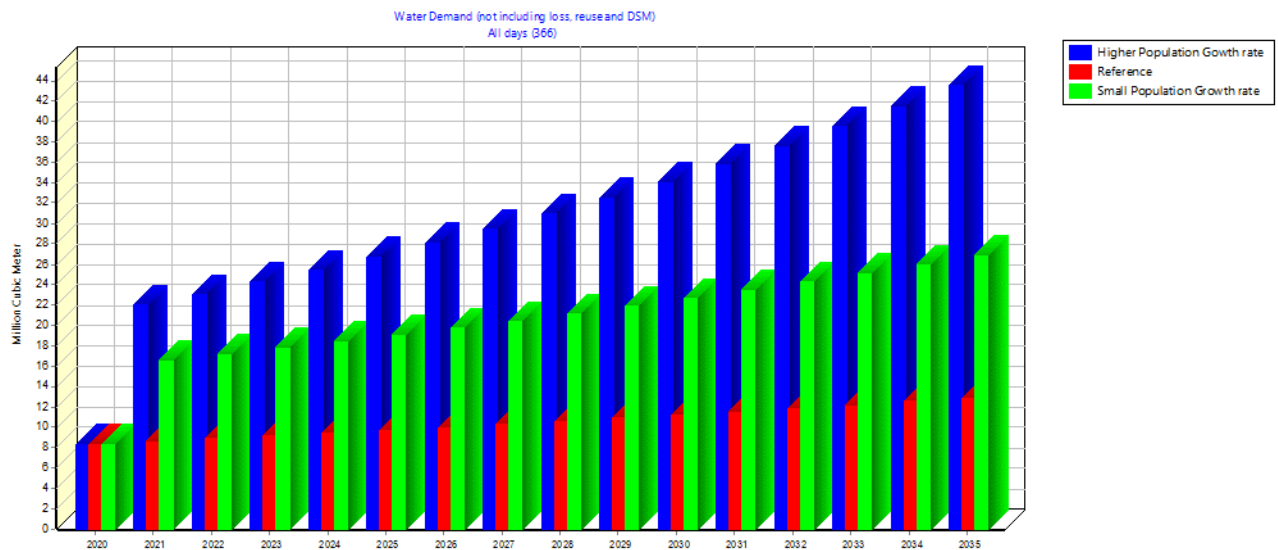
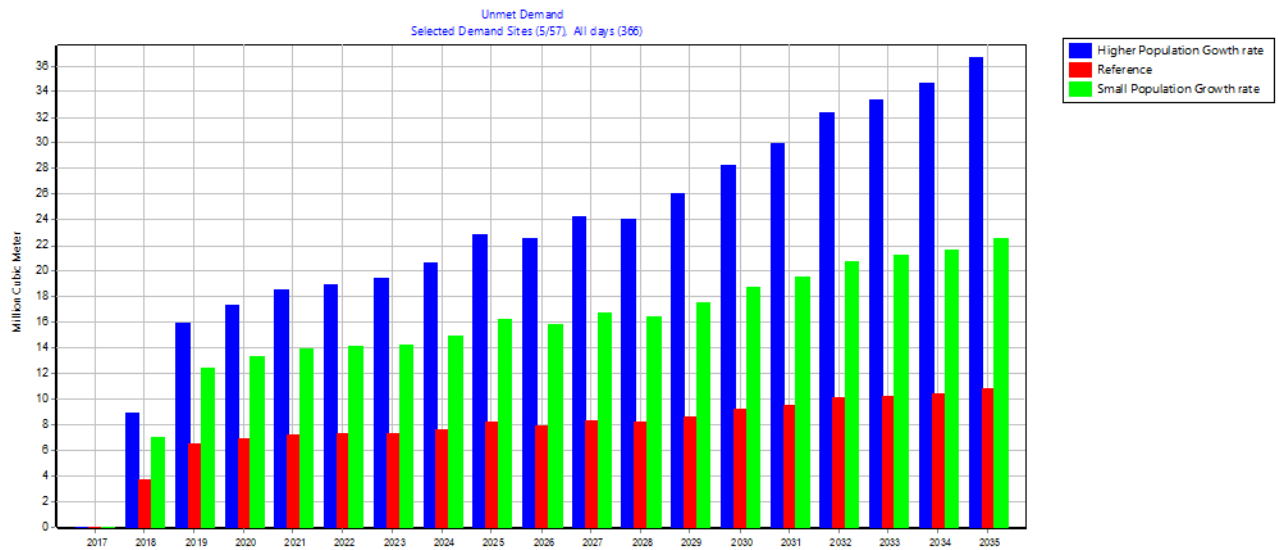
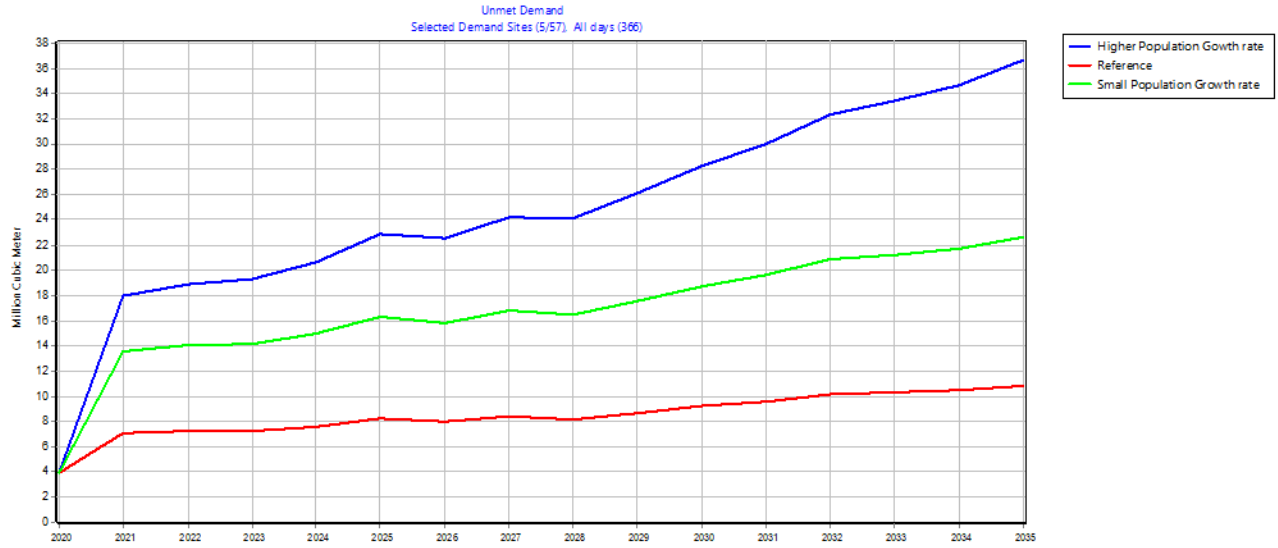




## Water Resource Developments and Flow Alteration in Didessa River Basin



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