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JIMMA INSTITUTE OF TECHNOLOGY

FACULITY OF CIVIL AND ENVIRONMENTAL ENGINEERING

CHAIR OF HYDROLOGY AND HYDRAULIC ENGINEERING

Optimal Surface Water Resources Allocation Using Water Evaluation and Planning (WEAP) Model: The Case Study of Gojjeb River Catchment

By: Frehiwot Belay

A Thesis Submitted to Jimma Institute of Technology, Faculty of Civil and Environmental Engineering, Chair of Hydrology and Hydraulic Engineering in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering.

December, 2019

Jimma, Ethiopia

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Advisor: Kassa Tadele (Dr.Ing)

Co-Advisor: Deme Betele (MSc.)

December, 2019

Jimma, Ethiopia

DECLARATION

I, Frehiwot Belay, declare that the thesis entitled **"Optimal Surface Water Resources Allocation Using Water Evaluation and Planning (WEAP) Model: The Case Study of Gojjeb River Catchment''** is entirely my original work with the exception of quotations or reference which has been attributed to their sources or authors. This thesis has not been previously submitted to any other university of degree.

Frehiwot Belay	______________	December, 2019
Candidate	Signature	Date

APPROVAL SHEET

The under signed certify that the thesis entitled: "**Optimal Surface Water Resources Allocation Using Water Evaluation and Planning (WEAP) Model: The Case Study of Gojjeb River Catchment**" is the work of Frehiwot Belay and has been accepted and submitted for examination with our approval as university advisors in partial fulfillment of the requirements for Degree of Master of Science in Hydraulic Engineering.

Kassa Tadele (Dr. Ing.)	___________________	__________________
Main Advisor	Signature	Date
Deme Betele (MSc)	___________________	__________________
Co-Advisor:	Signature	Date

As member of board of examiners of the MSc thesis open defense examination, we, certify that we have read, evaluated the thesis prepared by Frehiwot Belay and examined the candidate. We recommended that the thesis could be accepted as fulfilling the thesis requirement for the Degree of Master of Science in Hydraulic Engineering.

1.	___________________	_____________________	__________
	External Examiner	Signature	Date
2.	____________________	____________________	___________
	Internal Examiner	Signature	Date
3.	______________________	______________________	__________
	Chairperson	Signature	Date

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ABSTRACT

Water resources scarcity has become one of the determinants which restricts social and economic sustainable development. Improving water use efficiency by means of optimizing water resources allocation nowadays has been considered as the fundamental method for solving water scarcity in river basin. Therefore, water allocation decisions that consider equity, efficiency, and sustainability in every water sector should be treated as the main goal of decision-makers in the river basin. The objective of the research is to model surface water resource of Gojjeb river catchment for optimal surface water allocation and to propose water resource management strategies in a sustainable manner for social, economic and environmental benefits. The WEAP model has been used throughout the world to analyze a diverse set of water management issues for small communities and large managed watersheds, therefore for this study Water Evaluation and Planning (WEAP) model was used to model the current situation of water supply and demands and also to create scenarios for future water demands and supply. All the required data by the model was collected from different sources and the model was set up for a current account year in 2017 and the scenarios persists in 2045 based on the available data. The water resources system of the area were modeled and evaluated while giving consideration for existing developments in relation to current and future water demands among multiple water users in the catchment. Water demand was simulated for three different sectors, domestic, livestock and agriculture. The result from the current situation of water demands among water users were indicated that all demands were satisfied fully and there was no unmet demand under the base year (2017). Currently the catchment has the surface water availability of 2.01BCM. Three scenarios for future water demand were created namely reference scenario, scenario one and scenario two. The results of scenarios one and two were 48.57MCM and 58.51MCM water demands and 1.22MCM and 5.52MCM unmet water demands. The results of these scenario showed that the increment of water demands and unmet water demands from year to year due to reduction of crop water requirement, increment of irrigation area and increment of population growth as well increment of consumption rate. Finally further researches on groundwater availability as an alternative water sources to meet the unmet water demands were suggested.

Key Words: Water allocation, WEAP model, Gojjeb catchment

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LIST OF ABBREVATIONS

CROPWAT	Crop Water Requirements
DEM	Digital Elevation Model
DS	Demand Site
DSS	Decision Support System
EPIC	Enviromental Policy Integrated Climate
EWRMP	Ethiopian Water Resources Management policy
FAO	Food and Agricultural Organization
GIS	Geographic Information System
GPS	Geographical Positioning System
IWRM	Integrated Water Resource Management
LPC	Litre Percapta Demand
MODSIM	Modular Simulation Model
MOWR	Ministry of Water Resources
NMSA	National Metrological Service Agency
PASDEP	Plan for Accelerated Sustainable Development to End Poverty
PGM	Plant Growth Method
RIBASIM	River Basin Simulation Model
SEI	Stockholm Environment Institute
SNNPR	South Nation, Nationality People Region
SSIP	Small scale irrigation project
UNESCO	United Nations, Educational, Scientific and Cultural Organization
WARGI-SIM	Water Resources Graphical Interference Simulation Model
WEAP	Water Evaluation and Planning System

1. INTRODUCTION

1.1. Background

Water is a basic necessity for sustaining life and development of society. With the Increasing population including urbanization, economic growth, industrial production, agricultural and livestock production, demand for water has increased rapidly over the years (GWP, 2010). Population growth, urbanization, intensive agricultural development, industrial growth and environmental requirements are causes for an increment of demands for water and land. Moreover, the conversion of forest and agricultural lands to commercial and residential uses is leading to rapid transformation in agricultural production, spatial structure, social structure, land ownership and land market in the rural-urban fringe (Alcamo et al., 2012).

Water resources scarcity has become one of the determinants which restricts social and economic sustainable development. Improving water use efficiency by means of optimizing water resources allocation nowadays has been considered as the fundamental method for solving water scarcity in river basin (Zhanqi et al., 2015). Different approaches to increase water use efficiency as well as water management efficiency have been tried out in various parts of the world. However, successful water allocation strategies and mechanisms of the developed countries have not produced the expected results in the developing world. Therefore it is important to investigate the social, economic and political aspects of water management issues in the developing world and water allocation decisions must be made by considering their social, economic and environmental conditions to arrive at sustainable solutions (Weragala, 2010).

In addition, insufficient knowledge of available water resources, lack of coordination in water resources allocation and management in the river basin often result in water deficits which have hampered the harmonious development and destroyed the ecological balance in the river basin (Myronidis et al., 2012).

The main aim of water resources allocation is to find a balance for allocation methods among different water use sectors, such as domestic water, agricultural water and industrial water to ensure the sustainable development of society and economy. Therefore, water allocation decisions that consider equity, efficiency, and sustainability in every water sector should be treated as the main goal of decision-makers in the river basin as well as in the river catchment (Zhanqi et al., 2015).

Although Ethiopia's water resource is large, very little of it has been developed for agriculture, hydropower, industry, water supply and other purposes this is due to lack of well-organized researches on integrated water resource management and finance (Tadesse, 2006). Knowing the potential and availability of surface water is vital in the wise use of the resources, for designing economical and suitable hydraulic structures for water supply, hydropower, irrigation and other purposes.

The water resource of the Omo river basin are generally large and have been utilized over the last decades for hydropower, irrigation and domestic and commercial purpose , in fact the upper catchment of the Omo river basin has good potential for the construction of dams for the development of hydropower whereas the downstream section are provide water for agricultural irrigation. The out flow of this river serves as the sole input for Lake Turkana, whose waters guarantees the survival of more than 500,000 pastoral tribes around the lake (Shiferaw, 2016).

The Gojeb River is an important tributary of the Omo-Gibe from the west.The water resources of the Gojjeb river catchment is particularly important for irrigation developments as well as for domestic and industrial water supply. Hence, it needs an optimal water allocation system to allow social, environmental and economic development. Therefore, for optimal water allocation system water resources and demand assesment of the catchment is essential.

Therefore, water allocation models are useful because, by simulating scenarios of situations encompassing complicated hydrological, environmental and socio-economic factors, they can provide insights into the likely impacts of different development options (McCartney, 2007). The main objective of this study is the optimal surface water allocation of Gojeb river catchment using WEAP 21version model by taking different scenarios. The WEAP System model was developed by the SEI (Stockholm Environment Institute) to enable evaluation of planning and management issues associated with water resources development (SEI, 2011). This study also used Water Evaluation and Planning (WEAP) model for creating and analyzing scenarios of water resource development in the Gojjeb river catchment. The model was used to assess current and future water availability and investigate the impacts of different water allocation scenarios (water demand management strategies) aimed to meet various sectorial water demands in the Gojjeb river catchment.

1.2. Statement of the problem

Societies are facing major challenges in allocating water resources to growing water demands due to population growth and industrial and agricultural developments. With increasing water scarcity, the need to increase agricultural water productivity is receiving significant attention in developing countries. Allocation of water efficiently to all water uses including environmental use is a critical issue owing to challenges of valuing water uses in a particular in stream uses (Zhanqi et al., 2015).

The processes of population increase, urbanization and industrialization has resulted in a rapid demand increase for water resources in the developing world. Due to this reason, water managers in the river basins of the developing world face the increasingly difficult task of allocating the limited water resources among competing users. As a result, the difference between available water resources and water demands is ever increasing (Weragala, 2010). In addition to that, the climate change, higher living standards and the agricultural sector have also resulted in increased demand of water causing supply variation that increases the uncertainty of water allocations (Anisfeld, 2010).

As shown by MoWR (1999), in Ethiopia, the uneven spatial and temporal occurrence and distribution of the water resources among others leads to the difficulty of accurate water resources modeling both at basin and catchment level to allocate water resources effectively and efficiently. Similarly in the Gojjeb river catchment, rapid population growth, land fragmentation and poor land use practices, inadequate managerial capacity and lack of natural resources management have led to water scarcity and degradation of the environment. This has resulted in competition for water among agriculture, domestic, and environmental uses. In addition, water resources in the catchment are not evenly distributed and many areas are threatened by persistent lack of access to safe water due to poor water management practices and managerial control. Moreover, lack of hydrological knowledge, unimplemented water allocation strategies and mechanisms and ignorance of allocation priority in the catchment have led to insufficient or excessive water allocation within each sector (Kochito, 2014).

It is obviously impossible to plan the development of the basin without a full knowledge of all its natural resources, of which the water resource is one of the most important. Thus an assessment of these water resource of Gojeb River catchment, in relation to the existing and potential future demands is an essential base for the development of all sectors in the river basin. This requires that all aspects of the water resource of the basin are measured, estimated or simulated using the most appropriate hydrological models the outcomes of such hydrological simulation can be used by various water using sectors to prepare effective and economically viable plans for sustainable future development and to take measurement from sectors offices. This paper attempts to solve the problem of insufficient or excessive water allocation, which may occur under the traditional way of water allocation and propose a water resources allocation scheme that can well match water requirements of various competing sectors including domestic water demand and agricultural water demand of Gojjeb river catchment.

1.3. Objectives

1.3.1. General Objective

The general objective of the research is to model surface water resource of Gojjeb river catchment for optimal surface water allocation and to propose water resource management strategies.

1.3.2. Specific Objective

1. To asses surface water resources capability in fulfilling current water demand.
2. To forecast the future trend of water demands by creating scenarios.
3. To allocate available water resources optimally for domestic and agriculture sector in the catchment

1.4. Research Questions

To reach the specific objective of the study, these questions will need to be answered;

1. Is there enough surface water in the catchment to satisfy the current demand?
2. What will be the future trend of water demand in the catchment?
3. Is there available water resource to allocate optimally for domestic and agricultural sector in the catchment?

1.5. Significance of the Study

Management of water resources require approaches that it need more and better quality information about the current and potential future states of the water resources systems. The main goal of this paper is to assessing the deficiencies in present water allocation and to check whether the existing water resource might fulfill present and future water requirements or not.

1.6. Scope and limitations

Due to time constraint and data availability, the scope of this research has been limited to surface water resources allocation in a sustainable manner for social, economic and environmental benefits in the Gojjeb catchment. The allocation of the surface water over the most dominant water users such as irrigated land for agriculture, domestic water users and livestock water demand in the catchment were considered.

1.7. Structure of the thesis

This thesis is structured into five chapters and a brief summary of each chapter is given below. Chapter one which is the introduction part gives a general overview of the subject matter to be studied and problem statement of why it is studied, general and specific objective and how the objectives can be achieved through research questions, significant, scope and limitation of the study as well as thesis structure. Chapter two which is a literature review discusses the optimal water allocation, water demands, objectives and principles of water allocation, water allocation mechanisms, and overview of different water allocation models, Application of WEAP, catchment simulation methods in WEAP and scenario analysis in WEAP. Chapter three which includes materials and methods gives a brief description of the study area, materials used, model selection criteria, method of data collection, data analysis and modeling process of WEAP. Chapter four which includes results and discussion deals with the result and discussion of the study area. Finally, Chapter five which includes conclusions and recommendations summarizes the main results of findings based on the research findings and recommend further researches.

2. LITRETURE REVIEW

2.1. Optimal Water Allocation

The aim of optimal water resources allocation is to reallocate the limited water resources scientifically among different water use sectors based on a fair, effective and sustainable principle in a given region through measures such as restraining water demand reasonably, increasing water supply effectively, and protecting the ecological environment positively (Xiang et al., 2015).

Water allocation is essentially an exercise in allocating available water to demanding users. In order to make wise operational decisions regarding solutions to sharing water in a river basin or watershed, a fundamental scientific understanding of how the limited available water resources can be shared efficiency is required. Historically, access to water has been regulated to meet a wide range of social objectives, including agricultural production, economic development, public health and more recently environmental protection. The allocation should be done efficiently, practically and economically, technically and socially fair. Economical efficient allocation means distribution of water to maximize profit. Socially fair allocation tends toward distribution for preserving interests and fair allocation of water to weaker economical groups. Hence it is necessary to have a proper water allocation system, in which water is considered as a socially and economically merchandise (Bahram et al., 2015).

Allocation objectives have evolved over time, and different approaches have emerged to calculating, defining and managing water resources. Ultimately, though, water resource allocation has persisted the process of deciding who is entitled to the available water. Fundamentally, this consists of: Determining how much water is available for allocation. This can include assessing different locations, different sources (such as groundwater and surface water), for different times of the year, or under different climatic conditions. Determining how that water should be shared between different regions and competing users: who should be entitled to what? The water allocation process may distinguish between different administrative or geographic regions, different sectors, and (ultimately) individual water abstractors and users (Zhanq et al., 2015).

2.2. Criteria for Allocation

Appropriate means of resource allocation are necessary to achieve optimal allocation of the resource. Several criteria are used to compare forms of water allocation (Weragala, 2010) such as: Flexibility in the allocation of supplies; Security of tenure for established users; Real opportunity cost of providing the resource is paid by the users; Predictability of the outcome of the allocation process; Equity of the allocation process and Political and public acceptability.

2.3. Objectives and Principles of water allocation

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

Water allocation in general aims to maximize the benefits to the society from the resource. However, the general objective has implication to the more specific objectives such as social, economic and environmental with the corresponding principles of equity, efficiency and sustainability, respectively (UNESCAP, 2000). Equity indicates a fair sharing of water resources in river basin at all level (local, national and international) and among all users. Efficiency guides to a financially sustainable use of water resources; however, it also implies the fair compensation for water reallocation between users. Sustainability on the other hand advocates the environmentally sound use of the resource. Water allocation follows either of the principles of water right such as riparian right, prior appropriation rule, public ownership along with a number of mechanisms such as administrative, user-based, marginal cost pricing and water market (Savenije and Van der Zaag, 2000).

2.4. Water Demand

Water demand is defined as the volume of water requested by users to satisfy their needs. Water demand forecasting is a process achieved through several techniques and is typically used to predict future water requirements for different uses including hydropower, domestic and agriculture water demands. Water demand is increasing with population growth and agricultural practice leading into industrialization. The demand of a water use is determined by social, economic and environmental needs (number of households, hectares of irrigated areas and crop types, minimum stream flows and other needs) and the water use rate of each activity. Where resources are restricted compared to demands, as for irrigation in some regions, conflicts can arise among competing users.

According to Williams,2010 the accelerating growth of human population, the rapid advances made in industry and agriculture have resulted in a rapidly increasing use of water by man, to the extent that the availability of water as well as the control of excessive water has become a critical factor in the development of every regions of the world.

Although Ethiopia's water resource is large, very little of it has been developed for agriculture, hydropower, industry, water supply and other purposes. National coverage of potable water supply stood at 26% by 1992 while coverage of sanitation services is only 7%, which is low by even the Sub-Saharan standards. There is also a wide divergence in the water supply coverage between urban (76%) and rural (18.8%) areas (Seleshi, 2010).

In order to meet the demands of different users, efforts should be intensified on the efficient use of all water resources (surface water, ground water, and rainfall) and also on water allocation plans that maximize the resultant economic returns to limited water resources and, at the same time, protect the fragile ecosystem.

Water demand management (WDM) is essential being part of the challenge to sustain the water resources. It is well known that the main principle in water demand management is "efficient use of water in order to maintain vital environment flow and to reduce dependence on costly infrastructure projects". For instance, a toilet may be flushed clean or laundry washed with one third than the amount of water that is normally used with equal or better efficiency (Wong et al., 2009).

2.4.1. Irrigation Water Demand

Ethiopia has a significant irrigation potential identified from both available land and water resources. Irrigation would provide farmers with sustained livelihoods and improve their general well-being (Belay et al., 2013). However, the country's irrigable land has been underutilized, and only 4 to 5% of the potential area has been developed for irrigation (Awulachew et al., 2007). Consequently, the agricultural economy of the country is largely based on rain fed cultivation, but while employing 85% of the population, it only contributes 50% to the gross domestic product (Berry et al., 2003). Ultimately, increasing agricultural production using irrigation is one of the main drivers to end poverty caused by insufficient output from these rain fed systems.

According to the Ministry of Water, Irrigation & Energy of Ethiopia irrigation command areas can be classified into three groups (Awulachew et al., 2005). The first group is small-scale irrigation areas of less than 200 ha, medium-scale between 200 and 3000 ha and large-scale above 3000 ha. For this study, small scale projects are considered based on this classification.

Ethiopia has developed irrigation schemes in many parts of the country at different scales. Data and information are not uniformly available to accurately know the existing irrigation schemes. While it is possible to capture the medium and large schemes data accurately, it is difficult to account for the small-scale irrigation development, particularly, the traditional irrigation development and the privately developed household-based irrigation schemes which use traditional diversions, water harvesting and ground water development.

Currently, the government is giving more emphasis to the sub sector by way of enhancing the food security situation in the country. Efforts are being made to involve farmers progressively in various aspects of management of small-scale irrigation systems, starting from planning, implementation and management aspects, particularly, in water distribution and operation and maintenance to improve the performance of irrigated agriculture.

2.4.2. Domestic Water Demand

Domestic water demand is the amount of water needed for drinking, food preparation, washing, cleaning, bathing and other miscellaneous domestic purposes. The amount of water used for domestic purposes greatly depends on the lifestyle, living standard, and climate, mode of service and affordability of the users. The per capita domestic water demand for various demand categories varies depending on the size of the town and the level of development, the type of water supply scheme, the socioeconomic condition of the town and the climatic condition of the area.

2.5. Models for Water allocation

A model is a package that facilitates the simulation of a system out of a conceptual framework of the system. By manipulating a set of variable parameters, it becomes possible to predict the performance of the system under a set of operating rules (Makurira and Mul, 2004). Models are developed to and used in order to facilitate decision making.

Models perform several functions; they generate information, predict impacts, identify data needs and assumption; increase system understanding and hence enhance judgment. Models also identify and evaluate alternatives and help to predict and better understand trade-off among goals, objectives and interests (Makurira and Mul, 2004). Models can be applied to vast problems in water resources like simulation of natural discharge, operational forecasting, and prediction of effects of future physical changes in a catchment. There are various models which are capable of modeling water demand in a given catchment or basin. The relevant models which are commonly used in modeling water demand all over the world along with their suitability and limitations are presented here. Based on different selection criteria WEAP model is comparably selected to allocate surface water resources of Gojeb catchment.

Modular Simulation Model (MODSIM) is a generic system management DSS originally conceived in the late 1970s at the Colorado State University, United State, and continuously maintained. MODSIM simulates water allocation in the system at each time step through sequential solution of a network flow optimization problem where nonlinearities (i.e. evaporation, groundwater return flows, channel losses etc.) are assessed within a successive approximations solution procedure (Sechi and Sulis, 2010). MODSIM would not be able to obtain the optimum design and operation of the system components. MODSIM requires significance user investment to learn and due diligence from the user (Berhe et al., 2013).

River Basin Simulation Model (RIBASIM) is a generic model package for simulating the behavior of river basins under various hydrological conditions developed by Delft Institute in Netherlands. RIBASIM particularly address the hydrological and hydrographical description of the river-basins and links the hydrological water inputs at various locations with the specific water-users in the supply system. It allows the user to define operating/planning scenarios where each scenario is characterized by a particular operating rule and or water supply projection. Different scenarios can be easily compared based on user-defined objectives through the powerful graphical interface (Sechi and Sulis, 2010).

Water Resources Graphical Interface Simulation Tool (WARGI-SIM) developed at University of Cagliari, Italy, is a user-friendly tool specifically developed to help users understanding interrelationships between demands and resources for multi-reservoir water systems under water scarcity conditions, as frequently occur in the Mediterranean regions. The DSS makes it possible to take into account a large number of system components that typically characterize water resources models. The tool is flexible and generalized in the system configuration and data input, in the attribution of planning and operating policies and in processing output (Sechi and Sulis, 2009).

Water Evaluation and Planning (WEAP) model is a generic simulation model developed at the Stockholm Environment Institute, Boston, Massachusetts. It integrates some physical hydrological processes with the management of demands and infrastructure to allow for multiple scenario analysis, including alternative climate scenarios and changing anthropogenic stressors. WEAP model simulations are constructed as a set of scenarios with different simulation time steps. The physical hydrology model updates the hydrologic state of the system at each time step, and thus provides mass balance constants used in the allocation phase within the same time step. A groundwater module in WEAP allows for the water transfer between stream and aquifer. The main point of the water management analysis in WEAP is the analysis of water demand configuration. These demand scenarios are applied deterministically to a linear programming allocation algorithm where each demand and source is assigned a user defined priority. The linear program solves the water allocation problem trying to maximize satisfaction of demand, subject to supply preferences and demand priorities, and using reservoir operating policies to minimize the distance to ideal conditions. The water allocation problem is solved at each time step using an iterative, computationally expensive approach. Traditional target storage levels, multiple zones, and reduced releases by a buffer coefficient are implemented in WEAP.

MODSIM and WEAP are models where optimization methods are developed on the single time period and results are used as an efficient mechanism for performing simulations, whereas WAGRI-SIM and RIBASIM are simulation only model based on a more conventional if-then approach and give lower values of performance system index. Operating policies in WAGRI-SIM and RIBASIM are fixed whereas operating policies in MODSIM and WEAP are defined as a combination of system states and hydrologic conditions and can be linked to a more detailed higher dimensional models (e.g. QUAL2E, MODFLOW) to provide comprehensive modeling of water quality conditions and effect of groundwater (Sechi and Sulis, 2010).

Although, MODSIM and WEAP have better advantages over the other models and are equally important to model water demand in the study area, MODSIM is not an easy task as it needs an extensive calibration phase. Therefore, WEAP model is easy and best suited to allocate Gojjeb river as it can be licensed online annually free of cost.

As mentioned by (Mounir et al., 2011), Water Evaluation and Planning (WEAP) model provides a seamless integration of both the physical hydrology of the region and water management infrastructure that governs the allocation of available water resources to meet the different water needs. It is a priority driven software, employs priority based optimization algorithm as an alternative to hierarchal rule based logic that uses a concept of equity group to allocate water in time of inefficient supply.

According to (Wallace, 2001), with supply and demand data in a base year, projections of future water supply availability can then be made. Detailed projection of future water demand must account for changes in the amount of water use activities and the rates of water use within those activities, but a simplified procedure was applied here. Total off stream water use was averaged over the population in the base year to determine per-capita off stream use, which is assumed to remain constant in the future in this preliminary assessment procedure. Population was then projected and demand was forecasted as a function of the projected population. The supply quantity was projected assuming each flow parameter derived from the historical record will remain constant in the future year. By comparing projected supply and demand estimates, water supply availability in future years can be anticipated in the planning area.

As indicated by (Mounir et al., 2011), in WEAP the typical scenario modeling effort consists of three steps. First, a Current Accounts year is chosen to serve as the base year of the model; two a Reference scenario is established from the Current Accounts to simulate likely evolution of the system without intervention; and thirdly “what-if” scenarios created to alter the “Reference Scenario” and evaluate the effects of changes in policies and/or technologies.

In this study, the current accounts year was chosen to serve as the base year for the model with input data, reference scenario was developed from the base year without intervention and finally “ what if “ scenarios were developed using high population growth rate to show how the water supply demand behaves as the population growth rate changes.

2.6. Applications of the Water Evaluation and Panning (WEAP) Model

Water Evaluation and Planning System (WEAP) is a microcomputer tool for integrated water resources planning and water allocation, developed by the Stockholm Environmental Institute (SEI, 2012). It is easy to use and offers a comprehensive approach to water resources management. The model functions on the principle of water balancing. It has been applied in a lot of research work conducted in quite a number of basins in different countries. Specifically, it has been applied to Lake Naivasha in Kenya to develop an integrated water resource management plan for economic and ecological sustainability (Alfara, 2004). Also, WEAP has been applied in complex situations such as the Aral Sea to evaluate water resources development policies. In that study, some scenarios in the model were used to provide a structured approach to integrated water-demand analysis. Under the ADAPT project, the model was again applied to the Volta Basin to investigate the effect of changing climate on the already stressed water resources, food security as well as the environmental and the socioeconomic consequence on the people living in the basin .The model has been applied in the following areas: In South Africa, it was applied on water demand management scenario in a water stressed basin. In the River Basins in Zimbabwe and Volta in West Africa, it was used for Planning and Evaluating groups of small, multi-purpose reservoirs for the improvement of smallholder livelihoods and food security tools (SRP, 2017).

The model has also been applied in other areas like in the United State of America the model has been used for a number of research projects and is still active in some States; South Africa on water demand management scenario in a water stressed basin, and Limpopo and the Volta River Basins in Zimbabwe and West Africa for Planning and evaluating ensembles of small, multi-purpose reservoirs for the improvement of smallholder livelihoods and food security tools and procedures (SRP, 2017).

The Water Evaluation and Planning (WEAP) model was used developed by the Stockholm Environment Institute-Boston, Tell us Institute, U.S.A. It is an integrated Decision Support System (DSS) designed to support water planning that balances water supplies and multiple water demands. WEAP incorporates issues such as allocation of limited water, environmental quality and policies for sustainable water use, unlike the conventional supply oriented simulation models. It gives a practical integrated approach to water resources development incorporating aspects of demand, water quality and ecosystem preservation (SEI, 2015).

WEAP is a river basin simulation model with geo-spatial capabilities that is capable of simulating the allocation on water throughout a river basin based upon a user specified time step. WEAP is a laboratory for examining alternative water development and management strategies. As a policy analysis tool, WEAP evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems (Yates, 2005).

WEAP can address a wide range of issues, e.g., sectoral demand analyses, water conservation, water rights and allocation priorities, groundwater and stream flow simulations, reservoir operations, hydropower generation, pollution tracking, ecosystem requirements, vulnerability assessments, and project benefit-cost analyses.

One of the strengths of WEAP is that it is adaptable to whatever data is available to describe a water resources system. That is, it can use daily, weekly, monthly, or annual time-steps to characterize the system's water supplies and demands. This flexibility means that it can be applied across a range of spatial and temporal scales. Indeed, WEAP has been used throughout the world to analyze a diverse set of water management issues for small communities and large managed watersheds alike. WEAP operates always in an optimization water allocation model, based on priorities set for each demand site. This makes WEAP unique in comparison to other water allocation tools (SEI, 2015).

WEAP applications generally include several steps. The study definition sets up the time frame, spatial boundary, system components and configuration of the problem. The current accounts provide a snapshot of actual water demand, pollution loads, resources and supplies for the system.

A project using WEAP needs to gather information on water balances within a watershed or basin, and water allocation among different uses. By setting allocation priorities, different water rights regimes can be simulated. WEAP is designed around a scenario approach, where scenarios reflect alternative changes in water allocation, water supply infrastructure, water management, land use, climate, and other water-related variables.

In order for users to allow simulation of water allocation, the elements that comprise the water demand-supply system and their spatial relationship are characterized for the watershed under consideration. The system is represented in terms of its various water sources (for instance surface water, groundwater, desalination and water re-use elements), withdrawal, transmission, reservoirs, wastewater treatment facilities and water demands (user-defined sectors but typically comprising industry, mines, irrigation, domestic and supply). The data structure and level of model detail can be customized (by combining demand sites) to correspond to the requirements of a particular analysis and constraints imposed by limited data. A graphical interface facilities visualization the physical features of the system and their layout within the watershed (Sieber, et al., 2012).

2.7. Catchment Simulation Methods of Water Evaluation and Planning (WEAP)

There are five methods to simulate catchment processes such as evapotranspiration, runoff, infiltration and irrigation demands using WEAP. These methods include (1) The Rainfall Runoff (simplified coefficient method), (2) Irrigation Demands Only (Simplified Coefficient Approach), (3) The Soil Moisture Method, (4) The MABIA Method, and (5) The Plant Growth Method (PGM). The choice of method should depend on the level of complexity desired for representing the catchment processes and data availability. Of these four methods, the Irrigation Demands Only method is the simplest. It uses crop coefficients to calculate the potential evapotranspiration in the catchment, then determines any irrigation demand that may be required to fulfill that portion of the evapotranspiration requirement that rainfall cannot meet. It does not simulate runoff or infiltration processes, or track changes in soil moisture. The rainfall runoff method also determines evapotranspiration for irrigated and rain fed crops using crop coefficients, the same as in the irrigation demands only method. The remainder of rainfall not consumed by evapotranspiration is simulated as runoff to a river, or can be proportioned among runoff to a river and flow to groundwater via runoff/infiltration links (SEI, 2015).

The soil moisture method is more complex, representing the catchment with two soil layers, as well as the potential for snow accumulation. In the upper soil layer, it simulates evapotranspiration considering rainfall and irrigation on agricultural and non-agricultural land, runoff and shallow interflow, and changes in soil moisture. This method allows for the characterization of land use and/or soil type impacts to these processes. Base flow routing to the river and soil moisture changes are simulated in the lower soil layer. Correspondingly, the soil moisture method requires more extensive soil and climate parameterization to simulate these processes (Yates et al., 2005). The MABIA method is a daily simulation of transpiration, evaporation, irrigation requirements and scheduling, crop growth and yields, and includes modules for estimating reference evapotranspiration and soil water capacity. The MABIA method uses the 'dual' Kc method, whereby the Kc value is divided into a 'basal' crop coefficient, Kcb, and a separate component, Ke, representing evaporation from the soil surface. The basal crop coefficient represents actual ET conditions when the soil surface is dry but sufficient root zone moisture is present to support full transpiration. In this way, MABIA is an improvement over CROPWAT, which use a single Kc method, and hence, does not separate evaporation and transpiration (SEI, 2012).

The plant growth model simulates plant growth, water use, and yield using a daily time step. It was developed to provide a method for studying the impacts of altered atmospheric CO_2 concentration, temperature stress, season length variability, and water stress on plant water use and crop yields. It requires specification of parameters that control the rate of plant development and water use. The growth routines in the model are based on the approach taken in the SWAT and environmental policy integrated climate (EPIC) models allowing use of their databases for parameterization of the model. Soil moisture hydraulics is simulated using a 13 layer model that represents the top 3.5 meters of the soil profile. Outputs from the model include surface runoff, deep percolation, plant ET, water and temperature stress, biomass production and yield (SEI, 2015).

2.8. Scenarios in WEAP

Scenarios are alternative sets of assumptions such as different operating policies, costs, and factors that affect demand such as demand management strategies, alternative supply sources and hydrologic assumptions, with changes in these data able to grow or decline at varying rates over the planning horizon of the study (Yates et al., 2005). The typical characteristic of this method is that it can model many real problems where decisions are based on uncertain information presented as a set of possible outcomes (Weng et al., 2010).

The scenarios can address a broad range of "what if" questions, such as: What if population growth and economic development patterns change? What if reservoir operating rules are altered? What if groundwater is more fully exploited? What if water conservation is introduced? What if ecosystem requirements are tightened? What if new sources of water pollution are added? What if a water-recycling program is implemented? What if a more efficient irrigation technique is implemented? What if the mix of agricultural crops changes? What if climate change alters the hydrology? These scenarios may be viewed simultaneously in the results for easy comparison of their effects on the water system. Among others, the scenarios are evaluated with regards to supply sufficiency, cost, and average cost of delivered water, the meeting of in-stream flow requirements, hydropower production, and sensitivity of results based on uncertainty of key variables. These could include reductions in water demand due to demand side management, assumptions of rates of growth, incorporation of technical innovation, changes in supply (Yates et al., 2005).

3. MATERIALS AND METHODS

3.1. Description of the study area

3.1.1. Location

The Omo-Gibe basin is one of the major river basins in Ethiopia and is situated in the south western part of the country covering parts of Southern Nations Nationalities and people Region (SNNPR) and Oromia region. The basin covers an area of 79,000 km^2 with a length of 550 km and an average width of 140 km. The basin lies between 34^{0}44' E & 38^{0}24'E longitude and 4^0 00'N & 9^0 22'N latitude. It is an enclosed river basin that flow in to the lake Turkana which forms its southern boundary the total mean annual flow from the river basin is estimated about 16.6 billion cubic meter (BMC) (Abdella, 2013) .

The Gojeb River is an important tributary of the Omo-Gibe basin from the west. Geographically Gojeb river catchment is located 7º00'00'' to 7°50'00''N and 35°33'32''to 37°20'00'' E. The total area of the watershed covers about 3,577 km^2. The Topography or elevation of the watershed ranges from 824 to 3851 above mean sea level. The majority of the area is characterized by humid tropical climate with heavy rainfall and most of the total annual rainfall is received during kiremt (June to September). The mean average monthly temperature of the catchment varies from 18^{0}C to 22^{0}C. The average monthly maximum temperature is between 26^{0}C to 31^{0}C and the average monthly minimum is between 11.5^{0}C to 15.5^{0}C. According to National Atlas of Ethiopia Gojeb river catchment categorized as "Weina Dega" (Sub tropical), 1500 to about 2300m of elevation.

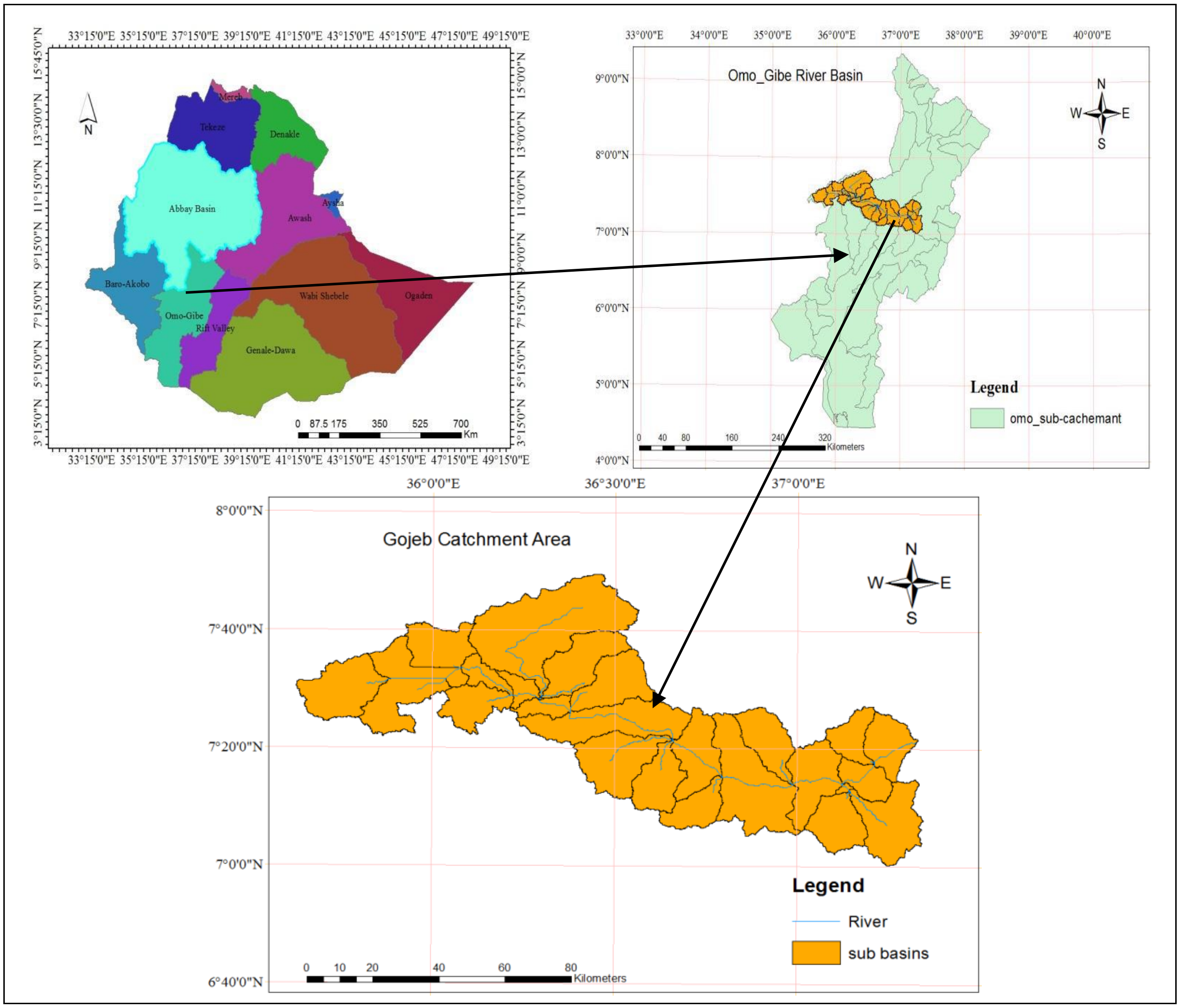

Figure 3.1: Location map of the study area

3.1.2. Climate

The climate of the Omo-Gibe River Basin varies from a hot arid climate in the southern part of the floodplain to a tropical humid in the highlands that include the extreme north and north western part of the basin. Intermediate between these extremes and for the greatest part of the basin the climate is tropical sub-humid. The climate of the study area is similar to the Basin and classified as tropical humid in the highlands where the source of the rivers start and decline and changed in to the tropical sub-humid, hot arid climate characteristic towards the middle and downstream drainage system respectively. The Study area receives moderately much rainfall thorough out the year. As shown on the figure below, maximum rainfall occurs in months of August and minimum in months of February. The study area receives a uni-modal rainfall distribution. The mean average monthly temperature of the catchment varies from 18^0C to 22^0C. The average monthly maximum temperature is between 26^0C to 31^0C and the average monthly minimum is between 11.5^0C to 15.5^0C. Temperature variations from month to month are small between the warmest and the coolest average monthly temperatures. The average monthly rainfall, maximum and minimum temperature of the study area is shown in the Figure 3.2 and 3.3 below respectively.

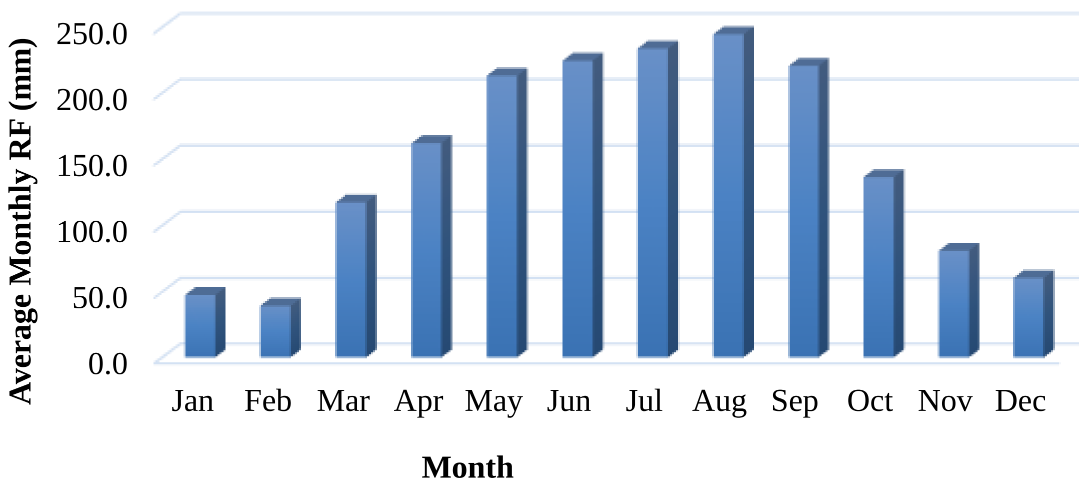

Figure 3. 2: Average monthly rain fall of the study area

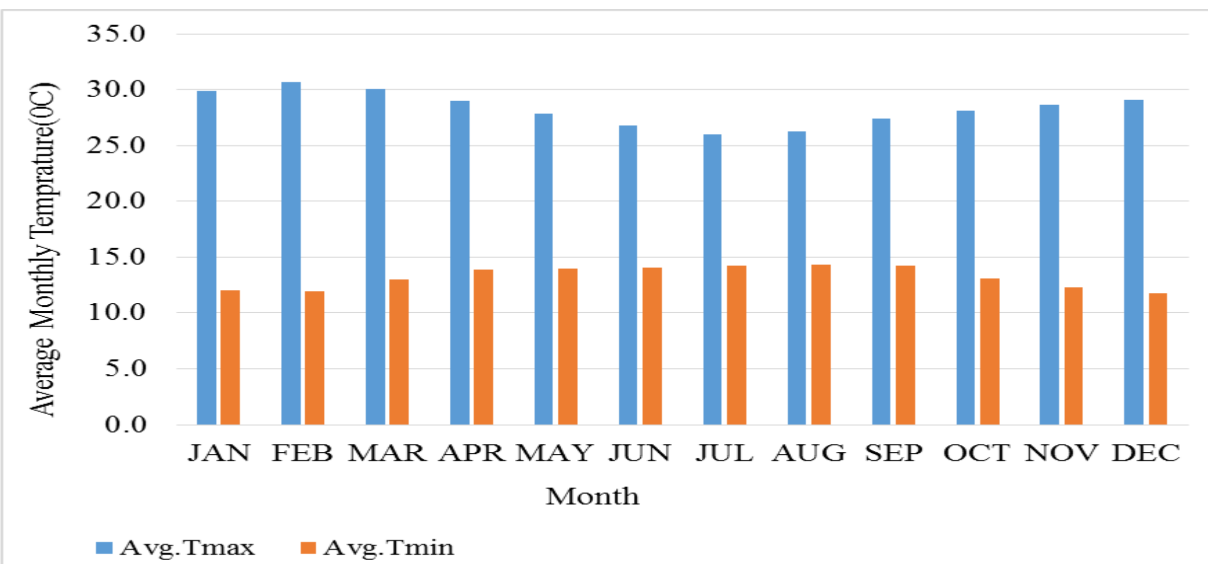

Figure 3.3: Average monthly maximum and minimum temperature of the study area

3.2. Materials and Tools Used

The materials and software used in this study were include: WEAP model, DEMs, Arc GIS software, GPS and CROPWAT8. The Digital elevation model (DEM) is used to delineate the study area and used as the basic indicator of the actual area. Microsoft Excel is also used for data processing, CROPWAT is used for calculating crop water requirement and WEAP model is used for allocating available water resources.

3.2.1. GIS software for watershed delineation

Identifying the drainage boundaries is one of the crucial work to be done. With the availability of digital elevation models (DEM) and GIS tools, watershed properties can be extracted by using automated procedures. The processing of DEM to delineating watersheds is referred to as terrain processing. In this study, Arc GIS 10.1 has been used for mapping and to geo-reference the collecting information and create spatial database. These shape files also uploaded into WEAP system and used for schematic view of the study area. Arc-Hydro is a tool which is GIS extension tool is also used to processing a DEM and to delineating the whole of Gojjeb river catchment area.

3.2.2. CROPWAT

The CROPWAT 8.0 software is used in calculating crop water requirements. This software uses monthly averages of the climatic parameters. The software provides data on crop such as Kc, growing stage, rooting depth, soil moisture.

3.2.3. Water Evaluation and Planning

The Water Evaluation and Planning software is used for this study. The WEAP model essentially calculates a mass balance of flow sequentially down a river system, making allowance for abstractions and inflows.

3.3. Model selection criteria

Due to the complexity of water resources management at the basin and sub-basin levels, models such as RIBASIM (Delft Hydraulics, 1991), MODSIM (Labadie, 1995), WEAP (SEI, 1999), River Ware (Zagona et al., 2001), OASIS (Hydrologics, 2009) and Mike Basin (DHI, 2006) have been developed over the last three decades to help allocate the available water resources among the different users in an optimum way. WEAP model was selected for this study because of its adaptability to whatever available data to describe a water resources system, its ability to use daily, weekly, monthly, or annual time-steps to characterize the system's water supplies and demands, its flexibility to be applied across a range of spatial and temporal scales, its usability throughout the world to analyze a diverse set of water management issues for small communities and large managed watersheds alike, its operation in an optimization of water allocation based on priorities set for each demand site (SEI, 2012). Moreover, the model was selected for this study due to its two primary functions, namely: simulation of natural hydrological processes to enable assessment of the availability of water within a sub catchment and, simulation of anthropogenic activities superimposed on the natural system to influence water resources and their allocation to enable evaluation of the impact of human water use (Yates et al., 2005).

3.4. Calculation Algorithm in WEAP

3.4.1. Demand calculations

A demand site's (DS) demand for water is calculated as the sum of the demands for all the demand site's bottom-level branches (Br). A bottom-level branch is one that has no branches below it. Annual water demand was calculated as follows

Annual Demand DS = ∑Br (Total activity level Br *Water Use Rate Br)………………….3.1

The total activity level for a bottom-level branch is the product of the activity levels in all branches from the bottom branch back up to the demand site branch (where Br is the bottom-level branch, Br' is the parent of Br, Br'' is the grandparent of Br, etc.). The total activity level was given as:

Total Activity level Br = (Activity level Br * Activity level Br'* Activity level Br''*…)…3.2

The activity level for a branch, and the water use rate for a bottom-level branch, are entered as input data into a model. Monthly demand were calculated based on each month's fraction specified as data under Demand\Monthly Variation of the adjusted annual demand.

Monthly Demand DS, m=Monthly Variation fraction DS, m*Adjusted Annual Demand DS………………………..3.3 (SEI, 2015).

3.4.2. Rainfall Runoff Method (Simplified Coefficient Method)

The Rainfall Runoff method was used for this work because, it determines evapotranspiration for irrigated and rain fed crops using crop coefficients. The remainder of rainfall not consumed by evapotranspiration is simulated as runoff to a river, or can be proportioned among runoff to a river and flow to groundwater via runoff/infiltration links. Crop requirements are calculated assuming a demand site with simplified hydrological and agro hydrological processes such as precipitation, evapotranspiration and crop growth emphasizing irrigated and rainfall agriculture. Non-agricultural land classes can be included as well. The following equations were used to implement this approach where subscripts LC is land cover, HU is hydro-unit, TS is time step (e.g., month), I is irrigated, and NI is non-irrigated:

Precip Available for ETLC = Precip HU * Area LC* 10^{-5}* precip Effective LC…………..3.4

ET potential for LC = ET reference HU * Kc LC* 10^{-5}…………………………………….3.5

Precip Shortfall LC, I = Max (0, ET potential LC, I – Precip Available for ETLC, I)……..3.6

Supply Requirement LC, I = (1/Irr Fra LC, I) * Precip Shortfall LC, I…………..…………3.7

Supply Requirement HU = ∑ LC, I Supply Requirement LC, I……………………………3.8

The above four equations are used to determine the additional amount of water (above the available precipitation) needed to supply the evapotranspiration demand of the land cover (and total hydro unit) while taking into account irrigation efficiencies.

Based on the system of priorities, the following quantities can be calculated:

Supply HU = Calculated by WEAP allocation algorithm

Supply LC, I = Supply HU * (Supply Requirement LC, I/ Supply Requirement HU)…....3.9

ETActual LC, NI =Min (ET potential LC, NI, Precip Available for ETLC, NI)………….3.10

ETActual LC, I =Min (ET potential LC, I, Precip Available for ETLC, I) + IrrFrac LC, I * Supply LC, I………………………………………………………………………………..3.11

EF LC = ∑ TS ET Actual LC/∑TS ET potential LC…………………………………….……………3.12

In the Rainfall Runoff method, runoff to both ground water and surface water can be calculated with the following equations:

Run off LC = Max (0, precip Available for ETLC – ET potential LC) + (Precip LC*(1-precip Effective LC) + (1- Irr Frac LC, I) * Supply LC, I………………………………...3.13

Run off to GW HU = ∑ LC (Run off LC * Run off to GW fraction LC)………………...3.14

Run off to Surface water HU =∑LC (Run off LC *(1- Run off to GW Fraction LC))…...3.15

(SEI, 2015).

3.5. Methods of data collection

The data source were Ministry of Water, Irrigation & Energy, Ethiopian Mapping Agency, National Meteorological Agency, and Kafa zone water, mine and energy department. For the research, the following basic and secondary data sets were necessary for the modeling works.

Primary data collection technique includes observation of the study area and collection of UTM locations by using GPS. Secondary data collection technique include the design documents for small scale irrigation and water supply projects, Metrological data (rain fall, temperature, relative humidity, solar radiation and wind speed), hydrological data (stream flow data), DEM data, land use data, water supply data (population number, growth rate, per capita water consumption), irrigation data (agricultural land area, agricultural monthly variation demands, water requirements per hectare of the crops).

3.5.1. Hydrologic data

Hydrology data is an important aspect of modeling in water resources system and helps in understanding how it operates under a variety of hydrologic conditions. Every hydrological and water resource model has its own way and format to accept data, WEAP is a very flexible model which takes daily, monthly and annual data. However, average monthly data were used for running the model. In this study daily river discharge was collected from the Hydrology department of Ministry of Water, Irrigation and Electricity of Ethiopia.

3.5.2. Meteorological Data

The meteorological data used in this study were obtained from National Meteorological Service Agency (NMSA) of Ethiopia and design document of the irrigation projects. Most of this climate data was used for the purpose of determination of crop water requirement of the crops and some of them were used as an input to WEAP model to assess water resources of the catchment.

3.5.3. Spatial Data

A 30 m by 30m of Digital Elevation Model (DEM) was collected from Geo-information and Information Technology Directorate of Ministry of Water, Irrigation and Electricity of Ethiopia. The DEM data was used as a basic input for the watershed delineation and also uploaded into the schematic view of the WEAP model to orient and construct the system and develop area boundaries.

3.5.4. Sectoral Water Demands

Sectoral information of data were collected from different sources in order to evaluate and fully understand the current and future water demands in relation with the available supply of Gojjeb catchment. For the modeling of water demands in the catchment the following different secondary data were used and collected from different sources for each sector.

3.5.4.1. Domestic water demand

In order to model the current and future sectoral water demands among multiple water users, current information and future projection are necessary therefore in this study total current population with an annual population growth rate were obtained from the Kafa zone finance and economic development department. According to the analytical report the population growth rate for rural areas in SNNPR is 2.9% and the total population of the catchment were estimated to be 298967people. In reference scenario, it was assumed that the annual growth rate to be constant without change while other developed scenarios which were based on 'what if questions' assumed that annual growth rate to be 2.6% in scenario one and 2.15% in scenario two. As a general guideline, the SNNPR Water sector recommends 25 litres per capita per day with in 1km radius for rural consumption were used.

3.5.4.2. Agricultural water demand

For Agricultural water demand, as per the WEAP model data input requirement, potential of irrigated land, type of crops and seasons of cultivation are important. The data for the irrigation projects were collected from SNNPR Irrigation Development Authority of Kafa zone agriculture branch. Irrigation projects which were selected for this study in the catchment are listed in table 3.1 below with their areas.

Table 3.1: Selected irrigation projects and their areas

Irrigation projects	Net irrigated area(ha)	Scale
Geshi Small Scale Irrigation Project	239	Small
Beyemo Small Scale Irrigation Project	20	Small
Choba Small Scale Irrigation Project	50	Small
Yabe kicha Small Scale Irrigation Project	20	Small

(Source; Southern nations, nationalities and people's regional state development and scheme administration agency, 2017)

In order to model the irrigation water demands both in the base year and in the future, annual activity level, annual water use rate, consumption rate and monthly variation is necessary. The crop water requirement were determined by using the CROPWAT. Finally, the consumption rate was obtained from the design document of the projects. Accordingly the consumption rate of 50% was used for small-scale projects.

3.5.4.3. Livestock Water Demand

Recognize that livestock water supply is an integral part of the overall water sector and agriculture incorporate to its development plans with comprehensive water resources management was undertaking. The livestock population of the area is Cattle 120,957, Sheep 63,352, Goats 58,240, Donkey 7,412, Mule 3,368 and Horses 8,673. According to the livestock sector of the study area the total livestock water demand is 80 litre per day in the current account year (Table 3.2).

Table 3.2: Estimated Livestock Population and their water demand

Species	Total number	Average water demand (lpd)	Total demand
Cattle	120957	25	3023925
Sheep	63,352	5	316760
Goats	58,240	5	291200
Donkey	7,412	15	111180
Mule	3,368	15	50520

3.6. Rainfall-Runoff Simulation using WEAP Model

There was a choice among five methods to simulate catchment processes such as Evapotranspiration, runoff, infiltration and irrigation demands. These methods include (1) the Rainfall Runoff (simplified coefficient method), (2) Irrigation Demands Only (Simplified Coefficient Approach), (3) the Soil Moisture Method, (4) the MABIA Method, and (5) the Plant Growth Method (PGM).From those methods the rainfall runoff method was used to simulate river flows in this study; because this method constrains by the type of data available (Rainfall, Evaporation and crop data). To perform rainfall-runoff simulation Land use and Climate data is required.

Depending on these crop water requirement have been computed using CROPWAT 8.0 software. The inputs for the calculations were climatic data (precipitation and ETO) and crop data. Climatic data were obtained from the National Meteorological Service Agency (NMSA) of Ethiopia and design document of the irrigation projects and processed as per the CROPWAT requirement. The processed climate data as per the CROPWAT requirement is shown in the appendix 2 for each of the selected station. Crop water requirement have computed for each of the selected irrigation project using the climate data of the selected stations. The selection of station for each of the irrigation project depends on climatic behavior, elevation, agro climatic categories, proximity and the agro-ecological similarity of the station with the irrigation project. Depending on these criteria the irrigation projects with their selected climate station is shown in table 3.2 below. Data related to crops were collected from the design document of the irrigation projects and FAO no.56 document. There were several types of crops practiced when the irrigation infrastructure was operated. The crop types dominantly practiced for the irrigated agriculture in Gojjeb catchment consists of millet, potato, onion, tomato, maize, sweet potato and pepper were considered for this study. Using the above data the calculated crop water requirements for each of the irrigation projects and their monthly variation of consumption is shown in Appendix 3.

Table 3.3: Irrigation projects with their selected climatic stations

Irrigation projects	**Selected metrological station**
Geshi Small Scale Irrigation Project	Bonga
Beyemo Small Scale Irrigation Project	Gojjeb
Choba Small Scale Irrigation Project	Shebe
Yabe kicha Small Scale Irrigation Project	Jimma

3.7. Methods of Data Analysis

3.7.1. Filling Missing Rainfall Data

Missed measured precipitation data may face to many problems in hydrologic analysis and design. Because of some natural and man-made conditions sometimes it is very difficult to have complete records of data at every stations clearly. For gauges that require periodic observation, the failure or absence of the observer to make the necessary visit to the gauge, destruction of recording gauges, and instrument failure because of mechanical or electrical malfunctioning can result in missing data. Any such causes of instrument failure reduce the length and information content of the precipitation record. Missing data is a known problem in hydrology. There are different methods to estimate the missing data, from those methods station average, normal ratio, inverse distance weighting, and regression methods are commonly used to fill the missing records. In this study linear regression ,which substitutes the value using available observed data developing the corresponding regression equation to predict the missed from nearest station were used.

Table 3.4: Regression equations to fill missed rain fall data

Station(Y)	R^2	Coefficient of a	Coefficient of b	Regression Equation
Jimma	0.7723	0.9084	0.2452	Y=0.9084*(Bonga)+0.2452
Gojjeb	0.862	0.799	10.2966	Y=0.799*(Shebe)+10.2966
Shebe	0.776	0.9531	3.0725	Y=0.9531*(Jimma)+3.0725
Bonga	0.891	0.965	6.43	Y=0.965*(Gojjeb)+6.43

3.7.2. Filling Missing Temperature Data

By applying the same procedure, which has been done for rainfall data gap filling, linear regression equations for both maximum and minimum temperatures were developed. The missing maximum and minimum temperature values for the selected representative stations were filled by selecting stations with the best correlation value (R^2) and the regression equations are shown in table 3.5 and 3.6 below.

Table 3.5: Regression equation to fill missed maximum temperature data

Station(Y)	R^2	Coefficient of a	Coefficient of b	Regression Equation
Jimma	0.8521	0.9851	3.798	Y=0.9851*(Shebe)+3.798
Gojjeb	0.7519	0.787	1.298	Y=0.787*(Bonga)+1.298
Shebe	0.953	0.716	3.0756	Y=0.716*(Jimma)+3.0756
Bonga	0.796	0.5476	2.593	Y=0.5476*(Jimma)+2.593

Table 3.6: Regression equation to fill missed minimum temprature data

Station(Y)	R^2	Coefficient of a	Coefficient of b	Regression Equation
Jimma	0.8741	0.6491	0.2966	Y=0.6491*(Gojjeb)+0.2966
Gojjeb	0.981	1.0853	1.351	Y=1.0853*(Shebe)+1.351
Shebe	0.772	1.3799	0.2966	Y=1.3799*(Jimma)+0.2966
Bonga	0.8871	1.293	0.2358	Y=1.293*(Shebe)+0.2358

3.7.3. Wind Speed, Sunshine Hours and Relative Humidity Data Analysis

In the study area only Jimma station has the recorded wind speed, sunshine hours and relative humidity value. For other stations wind speed, sunshine hours and relative humidity data were obtained from the design document of each irrigation projects and the results of the processed data are available in Appendix 2.

3.7.4. Checking Data Consistency

Consistency of time series data analyzed based on a theory of a plot of two cumulative quantities, that are measured for the same time period should be straight line and their proportionality remain unchanged. This is represented by the slope. To check the in consistency of data double mass curve was used to correct rain gauge data for the station. In this method the accumulative annual rainfall of an uncertain each station has been compared with the concurrent accumulated value of mean rainfall of group of neighbor surrounding station. In general, when the neighboring station records are more homogenous the more accurate will be the corrected values at the target station (Ksubrmanaya, 2008). On the other hand, inconsistent data will exhibit a change in slope or break at the point where the inconsistency occurred. The inconsistency of a recorded data was done by double mass curve technique as shown below. The curves on Figures 3.4 and 3.5 shows that all stations are consistent and homogeneous depending on the criteria set above.

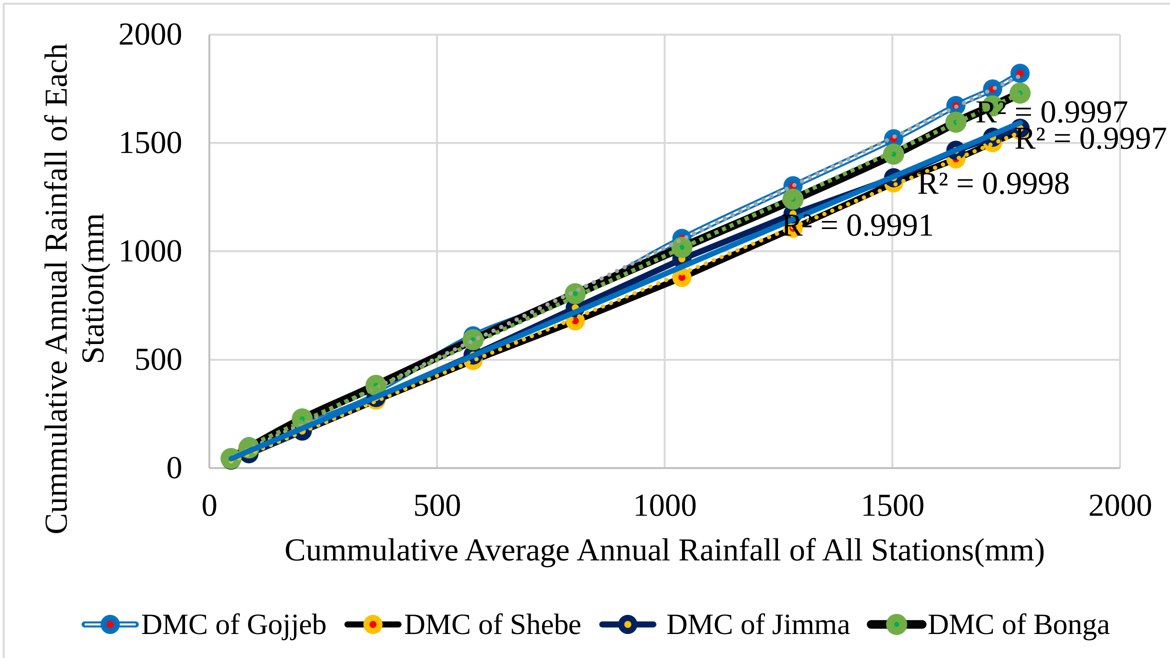

Figure 3.4: DMC of all stations

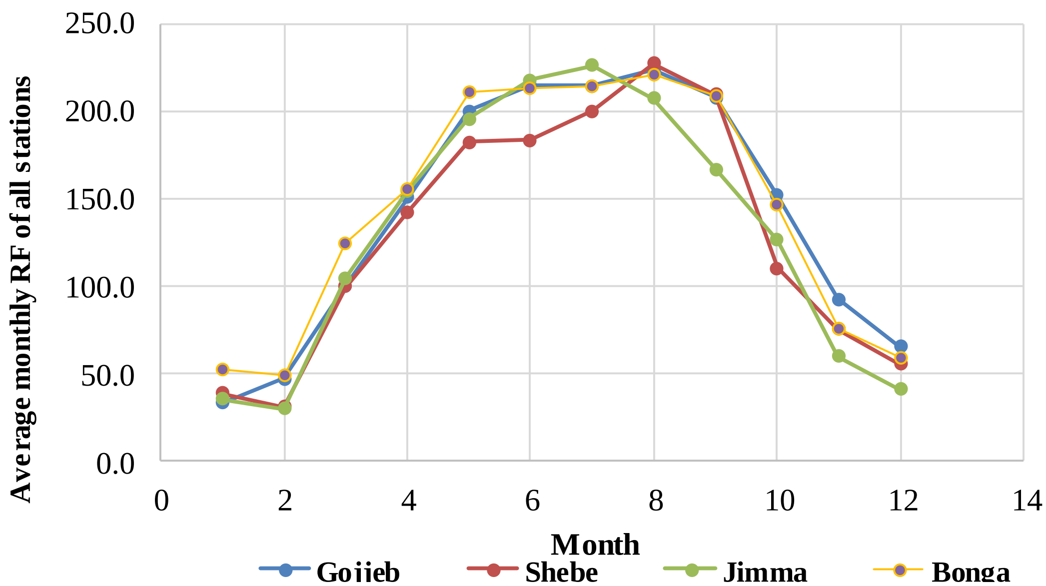

Figure 3.5: Homogeneity of stations

3.8. WEAP Model Structure and Modeling Process

The WEAP model used to simulate alternative scenarios of different development and management options in the future. The application defined by time frame, spatial boundaries and system components.

WEAP is a river basin simulation model with Geo-spatial capabilities that is capable of simulating the allocation of water throughout a river basin based upon a user specified time step while also it is a modeling tool for water planning and allocation that can be applied at multiple scales, from community to watershed to basin (Yates, 2005; Sieber et al, 2005). To allow simulation of water allocation, the elements that comprise the water demand-supply system and their spatial relationship are characterized for the watershed under consideration. The system is represented in terms of its various water sources (e.g. Surface water, groundwater, and desalinization and water reuse elements); withdrawal, transmission, reservoirs, and wastewater treatment facilities, and water demands (i.e., user-defined sectors but typically comprising industry, mines, irrigation domestic supply, etc.). The data structure and level of detail is customized (e.g., by combining demand sites) to correspond to the requirements of a particular analysis and constraints imposed by limited data. A graphical interface facilitates visualization of the physical features of the system and their layout within the catchment.

WEAP21 is structured as a set of five different "views" onto the working Area: Schematic, Data, Results, Overview and Notes. These views are listed as graphical icons on the View Bar, located on the left of the screen. The Current Accounts represent the basic definition of the water system as it currently exists, and forms the foundation of all scenarios analysis. Scenarios are self-consistent story-lines of how a future system might evolve over time in a particular socio-economic setting and under a particular set of policy and technology conditions. The main screen of the WEAP21 system consists of the View Bar on the left of the screen and a main menu at the top providing access to the most important functions of the program. WEAP21 calculates a water quantity and pollution mass balance for every node and link in the system on a monthly time step. Water is dispatched to meet in stream and consumptive requirements, subject to demand priorities, supply preferences, mass balance and other constraints.

WEAP model was used to evaluate and analyses the surface water resources available in Gojjeb catchment based on the observed stream flow data at gauging station at Gojjeb near Shebe. The flow data was input to WEAP system in order to know the available water resources in monthly and annual bases. WEAP rainfall runoff model was used to understand the potential of the Gojjeb river catchment. Land use (Area and Kc), climate (Precipitation, Effective precipitation and ETO) Where Kc-crop coefficients and ETO is the reference crop evapotranspiration was input data to the WEAP to simulate the runoff. The crop coefficient is relative to the reference crop. For simplified coefficient method KC= 0 means the area is double cropped with another area. In this study Kc = 1.00 as a default taken for monthly variation of crops based on WEAP user guide. Effective precipitation is the percentage of rainfall available for evapotranspiration. The remainder is available for runoff.

The Current and future water demands to domestic, agriculture and livestock were analyzed using WEAP model. The steps below were followed for current situation water demands and scenario analysis:

Definition of the study area and time frame

The setting up of the time frame includes the last year of scenario creation (last year of analysis) and the initial year of application. The study area was defined and set its boundary by adding the vector layer of Gojjeb catchment which has been prepared using ArcGIS 10.1 to the WEAP system because WEAP reads vector shape file format of WGS1984 projection. Therefore, in this study the time frame was set from 2017 and the last year of the scenario was set to be 2045 based on availability of the current, projected and planned development in the study area to all water sectors.

Creation of the current account

Which is more or less the existing water resources situation of the study area. Under the current account available water resources and various existing demand nodes are specified. This is very important since it forms the basis of the whole modelling process. This can be used for calibration of the model to adapt it to the existing situation of the study area. The current accounts represent the basic definition of the water system as it currently exists. The current accounts are also assumed to be the starting year for all scenarios. The current accounts include the specifications of supply and demand for the first year of the study on a monthly basis. In this study, as mentioned above the year 2017 were the initial year while last year of scenario were set to be 2045 therefore all the collected current information on both water supply and demand were the data input to the current accounts.

Creation of scenarios

Creation of scenarios based on future assumptions and expected increases in the various indicators. This forms the core or the heart of the WEAP model since this allows for possible water resources management processes to be adopted from the results generated for running the model. In this study, three scenarios were developed namely reference scenario, scenario one for increment of population number and consumption rate and scenario two for increment of irrigation area and reduction of crop water requirement .The scenarios were used to address a lot of “what if situations”, like what if population growth and economic development pattern change, and what if more irrigation efficiency technology applied. For this study, scenario analysis was carried out in order to assess the future water demand change due to domestic water consumption rate, population growth rate and the potential of irrigated land, but consumption rate of livestock will remain constant, and the trend would follow the same pattern as the water demand is increasing. Which means the livestock will increase in population, but the water consumption rate will be constant.

Evaluation of the scenarios

With regards to the availability of the water resources for the study area. Results generated from the creation of scenarios can help the water resources planner in decision making, which is the core of this study.

WEAP Schematic

The Schematic View is the starting point for all activities in WEAP. It is formed from the setup

“Area”. It defines the physical elements comprising the water demand supply system and their spatial relationships, the study time period, units and the hydrologic pattern. The graphical interface is used to describe and visualize the physical features of the water supply and demand system (SEI, 2012). The system formed is a spatial layout called the schematic. GIS Vector layers were added as overlay or background on the Schematic view as shown in Figure3.6below

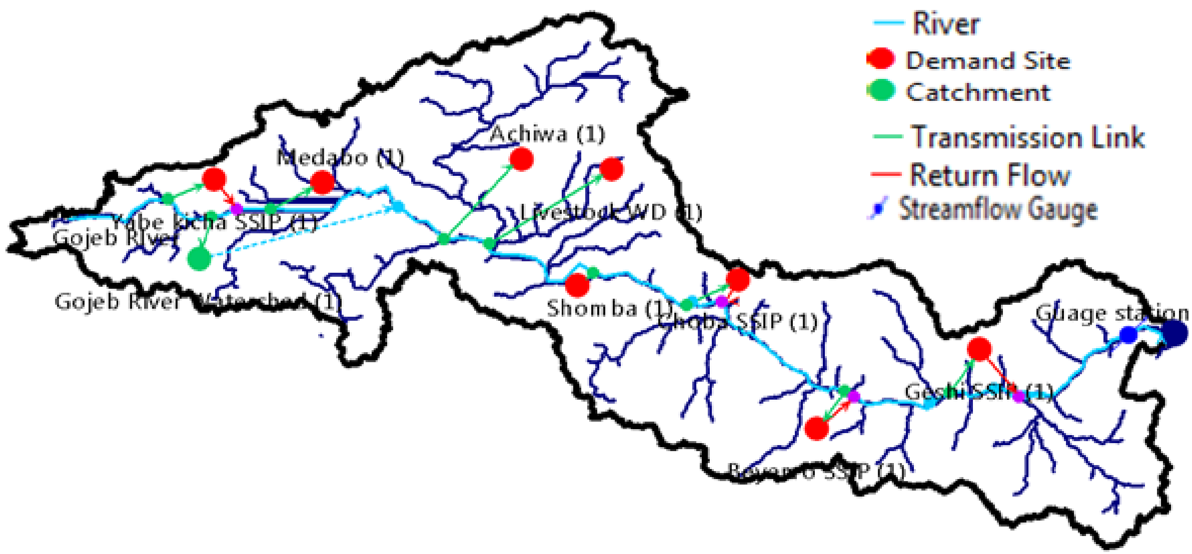

Figure 3.6: Schematic view of the study area

Demand Sites

A demand site is defined as a set of water users that share a physical distribution system that are all within a defined region or that share an important withdrawal supply point (Sieber et al., 2005). Demand sites used in this study are classified in to three main demand sites domestic demand, agricultural and livestock. Each demand site has a transmission link to its source and where applicable a return link directly to a river. In order to inform WEAP how the demand is satisfied, the water supply source (rivers) was connected to each demand sites. These were accomplished in the schematic view by adding the transmission link. The link was first positioned on the supply source, then pointing to each demand nodes. The return flow links were connected back to the rivers and return flow routing was set to be 100% so as to use the return flow for other demands effectively. The return flow routing is the percent of total outflow from a demand node, and then the return flow routing for that link must be 100%. Return flows from irrigation sites were configured downstream of the sources. However return flow from domestic water supply was not included since the quantity is insignificant it is preferred to overlook.

3.9. Scenario Creation

Scenarios are self-consistent storyline of how a future system might evolve over time in a particular socioeconomic setting and under a particular set of policy and technology conditions (SEI, 2012). Using WEAP, scenarios can be built and then compared to assess their water requirements, costs and environmental impacts. Scenarios can address a broad range of what if questions. An important concept of WEAP is the distinction between a reference or "business as usual" scenario and alternative policy scenarios (Raskin et al., 1992). The "business-as-usual" scenario incorporates currently identifiable trends in economic and demographic development, water supply availability, water-use efficiency and other aspects. No new water conservation measures or supply projects are included in the "business-as-usual scenario. This scenario provides a reference against which the effects of alternative policy scenarios may be assessed. In any study the current water accounts and the reference or "business-as-usual" scenarios are outlined based on the continuation of current patterns. Population growth as demand driving variable is relied on for this purpose. "What-if" scenarios based on the reference scenario are then introduced. The following scenarios were developed based on current situation and future water demands to domestic and agriculture as well as livestock demand.

1. Reference scenario

2. Scenario one for increment of population number and consumption rates

3. Scenario two for increment of irrigation area and reduction of crop water requirement

1. Reference Scenario

The Reference scenario is the scenario in which the current situation, the current account year as 2017 and is extended to the future (2018-2045). No major changes are imposed in this scenario, simply linear population increase.

2. Scenario one

In this scenario population growth and consumption rate for domestic and livestock were considered and all the other factors are assumed to be similar as in the case of reference scenario. This scenario itself was divided into two, namely reference scenario in the first term plan and reference scenario in the second term plan. Regarding to consumption rate the master plan of the study area recommend to use per capita water consumption of greater than 25lcd for domestic purpose for rural towns in the first term plan and greater than 100lcd in the second term plan. Therefore this study has used 50lcd for first term plan and 120lcd for second term plan scenarios. Thus under the scenario one the considered scenarios were:

I. What happen to the future water demands if the consumption rate is increased from 25 l/c/d to 50 l/c/d in the year 2018 to 2030?

II. What happen to the future water demands if the population in the catchment will grow by 2.6% in the year 2018 to 2030?

III. What happen to the future water demands if the crop water requirement of crops reduced by 5% in the year 2018 to 2030 due to the implementation of modern irrigation technology?

IV. What happen to the future water demands if Geshi irrigation projects increased from 239ha to 350ha in the year 2018-2030?

2. Scenario two

In this scenario increment of irrigation area and reduction of irrigation water requirement was considered and all the other factors are assumed to be similar as in the case of reference scenario. This scenario itself was divided into two, namely reference scenario in the first term plan and reference scenario in the second term plan. Under the scenario two the considered scenarios were:

I. What happen to the future water demands if the consumption rate is increased from 50 l/c/d to 120 l/c/d in the year 2031 to 2045?

II. What happen to the future water demands if the population in the catchment will grow by 2.15% in the year 2031 to 2045?

III. What happen to the future water demands if all the selected irrigation projects increased by 10% in the year 2031 to 2045?

IV. What happen to the future water demands if the irrigation water requirement of crops reduced by 10% in the year 2031 to 2045 due to the implementation of modern irrigation technology?

Model calibration

WEAP includes a linkage to a parameter estimation tool (PEST) that allows the user to automate the process of comparing WEAP outputs to historical observations and modifying model parameters to improve its accuracy. Calibration of model parameters was performed by automatic optimization methods.

4. RESULT AND DISCUSSION

4.1. Surface water resources Availability

Planning and allocation of water resources to different uses within the basin as well as in the catchment is one of the basic activities of water resource management to fill the gaps in water use. The procedures of the water use and allocation is used to determine water requirements and allocations for domestic, livestock and agricultural use at each stage of the development plan. This analysis takes into account of the increasing demands for water resulting from a growing population and irrigation area under cultivation, and has been then balanced these requirements with the abstractions needed for other consumptive and non-consumptive uses.

In this study, the year 2017 served as the "current account" year. The current account year is chosen to serve as the base year for the model, and all system information (e.g., demand, supply data) is input into the currents accounts. The current account is the dataset from which scenarios are built. Scenarios explore possible changes to the system in future years. The reference scenario carries forward the current accounts data into the entire project period specified (here, 2017 to 2045) and serves as a point of comparison for other scenarios in which changes may be made to annual water use per hectare due to demand site management and technology. This year is chosen because of the availability of the data both water supply and water demand therefore in order to understand the available and reliable water resources of Gojjeb river catchment. To model the river flow system of the catchment in both upstream and downstream of the catchment to be well understood the capability of the study area based on monthly and yearly available water, the monthly average stream flow of 1997-2017 from Shebe near to Gojjeb station was used as WEAP input.

The result of the average monthly surface water resources availability of the Gojeb catchment is shown in the Figure 4.1 below.

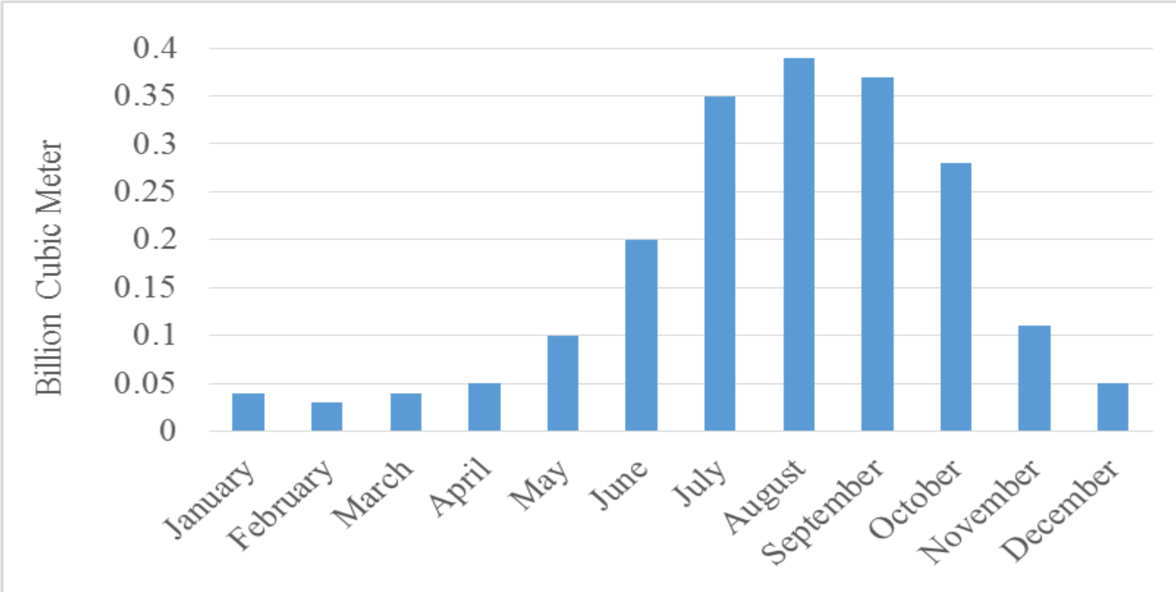

Figure 4.1: Monthly Average Stream Flow of Gojeb River

As shown in the Figure 4.1 above, the total annual stream flow of Gojeb River has been estimated to be 2.01BCM. This means currently the catchment has the surface water availability of 2.01 BCM at the outlet of the catchment from which all the demand sites abstract their sources to fulfill their demand. The peak flow in Gojeb River is occurring on August to October. The highest monthly average flow occurs in August and the lowest occurring in February with values 389.19 MCM and 27.63 MCM respectively.

Despite this resource potentials, the people around the catchment so far benefited little. The people around the Omo River still continue to practice traditional recession flood agriculture for crop production. According to Endalamaw, 2015 lower and west Omo valley people are exposed to Malaria, different waterborne diseases, and benefited little from the economic development of the country. Inline to MoWE, 2013 the Omo Ghibe Basin contributes close to 18% of the annual surface water resource of Ethiopia next to Abay and Baro-Akobo. As the estimated surface water potential of Gojeb river catchment is 2.01 BCM, the catchment has more than enough capability to satisfy the currently demanded water which is 1.51MCM. The people need to change their life to a better way of living. Moreover, the country should benefit more from the huge natural resources of the catchment at economic scale.

4.2. Water Demand in the Current Account Year (2017)

The current account represent the basic definition of the water system as it currently exists. It is also assumed to be the starting or base year for all scenarios. Hence, it is important to look at the nature of the demand in the current account year as it is the base for all scenarios and future demands. Current situation of water demand and supply was modeled before any scenario was developed in order to know the current water resources system of the basin and water demands to domestic, agriculture and livestock. Therefore monthly average of available water in relation to demand was done. The result of the water demands for a selected demand sites in the catchment is depicted in the Figure 4.2 below.

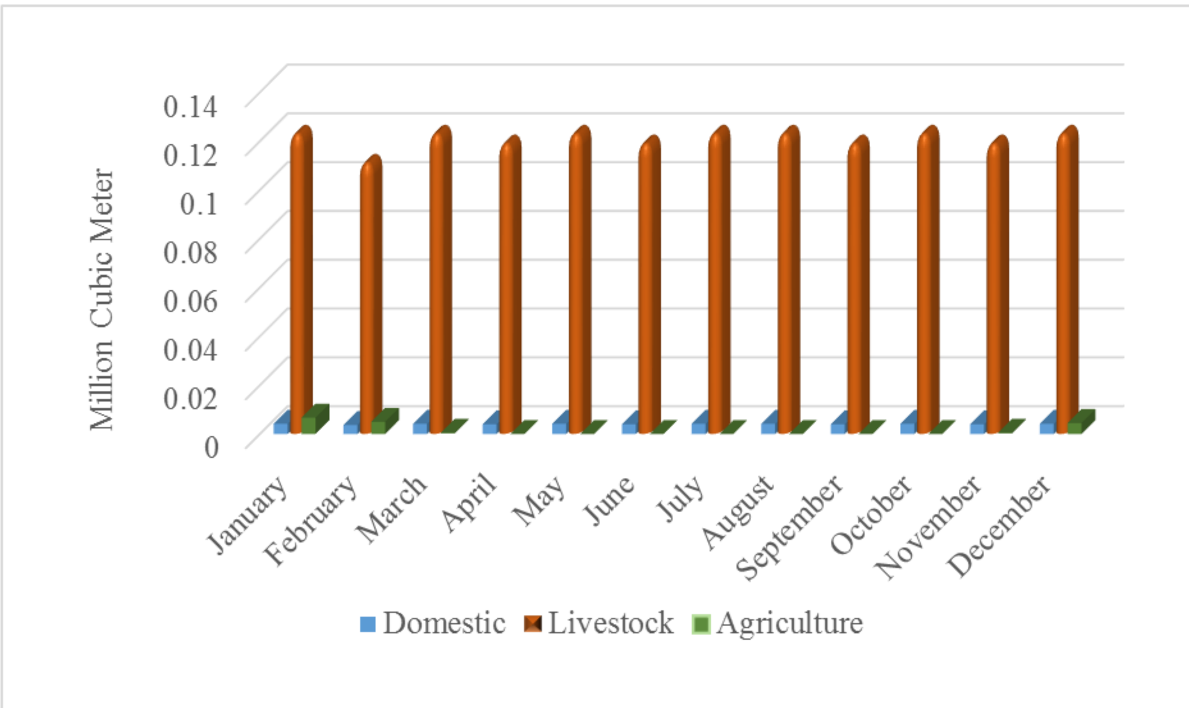

Figure 4. 2: Annual Water Demand in a current account year

As shown in the Figure 4.2 above, a total of 1.5076 MCM of water is required by the three water users (domestic, livestock and agriculture) for the current account year. The available water resources is compared to the requirement, the requirement is low. Therefore, the water consumption in the current situation is around 0.075 % of the total surface water available in the study area, which is 2.01 BMC. From the total demand 95.6 % is consumed by livestock, because of high population number of livestock's around the study area and the remaining 4.4 % has shared by domestic and Agricultural usages. Generally as shown in the Figure 4.1

and Figure 4.1 above, the total available resource is greater than the requirement for the current account year for the selected demand sites. This shows that, for the case of the current account year the available water has more than enough capability to satisfy the currently demanded water.

4.3. Unmet Water Demand in the Current Account Year (2017)

Unmet demand is the difference between supplies required and supply delivered to a particular demand site. The result of the unmet water demand for the current account year for the selected demand sites are fully supplied. The overall unmet demand of all demand sites in the current account year is found to be 0.00 %. This implies that the overall coverage of supply is 100% in the current account year.

4.4. Scenario Analysis

Regarding to scenario analysis, three different scenarios were created for water demand to analyze the future water demands without and with the effects of technological change in the future water demands. Accordingly, the first scenario which is the reference scenario focuses on the future water demands without the effects of technological change on water demands and the other two scenarios considers the effect of technological changes. The results of these scenarios are discussed in the section below.

4.4.1. Reference Scenarios

Reference scenarios represents the change that are likely to occur in the future without any intervention or no new policy measures. Thus, according to this scenario, what happen to the future water demands if no policy change occurs between the years 2018 to 2045? The result obtained from this scenario is portrayed in the Table 4.1.

Table 4.1: Water demand under reference scenario

Demand Branches (MCM)									
Year	Achiwa	Beyemo SSIP	Choba SSIP	Geshi SSIP	Livestock WD	Medabo	Shomba	Yabe kicha SSIP	Sum
2018	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2019	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2020	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2021	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2022	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2023	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2024	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2025	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2026	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2027	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2028	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2029	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2030	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2031	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2032	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2033	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2034	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2035	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2036	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2037	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2038	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2039	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2040	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2041	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2042	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2043	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2044	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
2045	0.0224	0.001	0.0028	0.0124	1.441	0.0198	0.007	0.0012	1.5077
Sum	0.6283	0.0276	0.0786	0.3475	40.3483	0.5555	0.196	0.0329	42.2148

As shown in the Table 4.1 above, water demands for a selected demand site shows similar trend from year to year. This is because no any policy change is considered under this scenario. Hence, the amount of water needed in the base year is similar to that needed at the end of the reference scenario (2045). Accordingly, a total of 1.4MCM for domestic, 0.5MCM for irrigation and 40.35MCM for livestock is needed in the reference scenario. Generally a total of 42.22MCM of water is required by the above all demand sites. Similarly, as shown in the Table 4.2 below, unmet water demands show similar trend from year to year and a total of 0.58 MCM of unmet water demand is occurred at the end of this scenario (2045) from the all demand sites. Generally, as indicated in the Table 4.1 above, a total annual water demand of 42.22MCM is required by the demand sites between 2018 and 2045. In addition, as indicated in the Table 4.2 below, a total unmet water demand of 0.58MCM will be occurred between 2018 and 2045 if no policy change is considered. This means if all the factors which affect irrigation, domestic and livestock water demand is assumed to be constant and no policy change will be occur between the years 2018 and 2045.The result of unmet water demands under reference scenario is depicted in Table 4.2 below.

Table 4.2: Unmet demand under reference scenario

	Demand Branches(MCM)								
Year	Achiwa	Beyemo SSIP	Choba SSIP	Geshi SSIP	Livestock WD	Medabo	Shomba	Yabe kicha SSIP	**Sum**
2018	0	0	0	0	0	0.0198	0	0.0012	0.0210
2019	0	0	0	0	0	0.0198	0	0.0012	0.0210
2020	0	0	0	0	0	0.0198	0	0.0012	0.0210
2021	0	0	0	0	0	0.0198	0	0.0012	0.0210
2022	0	0	0	0	0	0.0198	0	0.0012	0.0210
2023	0	0	0	0	0	0.0198	0	0.0012	0.0210
2024	0	0	0	0	0	0.0198	0	0.0012	0.0210
2025	0	0	0	0	0	0.0198	0	0.0012	0.0210
2026	0	0	0	0	0	0.0198	0	0.0012	0.0210
2027	0	0	0	0	0	0.0198	0	0.0012	0.0210
2028	0	0	0	0	0	0.0198	0	0.0012	0.0210
2029	0	0	0	0	0	0.0198	0	0.0012	0.0210
2030	0	0	0	0	0	0.0198	0	0.0012	0.0210
2031	0	0	0	0	0	0.0198	0	0.0012	0.0210
2032	0	0	0	0	0	0.0198	0	0.0012	0.0210
2033	0	0	0	0	0	0.0198	0	0.0012	0.0210
2034	0	0	0	0	0	0.0198	0	0.0012	0.0210
2035	0	0	0	0	0	0.0198	0	0.0012	0.0210
2036	0	0	0	0	0	0.0198	0	0.0012	0.0210
2037	0	0	0	0	0	0.0198	0	0.0012	0.0210
2038	0	0	0	0	0	0.0198	0	0.0012	0.0210
2039	0	0	0	0	0	0.0198	0	0.0012	0.0210
2040	0	0	0	0	0	0.0198	0	0.0012	0.0210
2041	0	0	0	0	0	0.0198	0	0.0012	0.0210
2042	0	0	0	0	0	0.0198	0	0.0012	0.0210
2043	0	0	0	0	0	0.0198	0	0.0012	0.0210
2044	0	0	0	0	0	0.0198	0	0.0012	0.0210
2045	0	0	0	0	0	0.0198	0	0.0012	0.0210
Sum	0	0	0	0	0	0.5555	0	0.0329	0.5884

4.4.2. Scenario One

This scenario considers the effect of population growth on the future water demands and increment of consumption rate. Under this scenario, both under the second term and the first term plan only population growth and consumption rate is considered. All the other factors which affect either water demand or water supply are assumed to be constant. Accordingly, two different population growth rates were considered depending on the growth rate planned by the kafa zone finance and economic development plan. These are: 2.6% growth rate which will be implemented in the first term plan (2018-2030) and 2.15% growth rate which will be implemented in the second term plan (2031-2045). The consumption rate were considered depending on rural water demand consumption rate. Different policy factors were considered under this scenario and what if questions were answered depending on the questions asked.

Scenario one of first plan

If the population in the catchment will grow with a growth rate of 2.6 % and the consumption rate will grow from 25lpc to 50lpc in the years between 2018 and 2030, the results of the changes that will observed on the domestic water demand and unmet water demand are shown below in the form of table and graph. The result of annual water demand and unmet water demand for domestic sector in which the population will grow with a growth rate of 2.6% in the first term plan (2018-2030) is portrayed in the Table 4.3 and figure 4.6 below. The result obtained from this scenario is shown in the Table 4.3 below.

Table 4.3: Water demand in scenario one of first plan

	Demand Branches(MCM)								
Year	Achiwa WS	Beyemo SSIP	Choba SSIP	Geshi SSIP	Livestock WD	Medabo WS	Shomba WS	Yabekicha SSIP	Sum
2018	0.1	0.0	0.0	0.0	1.41	0.1	0.0	0.0	1.64
2019	0.0	0.0	0.0	0.1	1.41	0.1	0.0	0.0	1.64
2020	0.0	0.0	0.0	0.0	1.42	0.1	0.0	0.0	1.55
2021	0.0	0.0	0.0	0.0	1.42	0.1	0.0	0.0	1.55
2022	0.0	0.0	0.0	0.0	1.42	0.1	0.0	0.0	1.55
2023	0.0	0.0	0.0	0.0	1.42	0.1	0.0	0.0	1.55
2024	0.0	0.0	0.0	0.0	1.43	0.2	0.0	0.0	1.58
2025	0.0	0.0	0.0	0.0	1.43	0.1	0.0	0.0	1.56
2026	0.0	0.0	0.0	0.1	1.44	0.1	0.0	0.0	1.67
2027	0.0	0.0	0.0	0.0	1.44	0.1	0.0	0.0	1.54
2028	0.0	0.0	0.0	0.0	1.45	0.1	0.0	0.0	1.58
2029	0.0	0.0	0.0	0.0	1.47	0.2	0.0	0.0	1.62
2030	0.0	0.0	0.0	0.0	1.49	0.1	0.0	0.0	1.62
Sum	0.1	0.0	0.0	0.2	18.7	0.9	0.0	0.0	19.58

As the result shown in table 4.3 above the total water demand under scenario one of the first plan is 19.58MCM. This shows that due to increasing of consumption rate and increasing of population growth the water demand is increased year by year in the future.

The result of unmet water demands under scenario one of first plan is depicted in Figure 4.4 below.

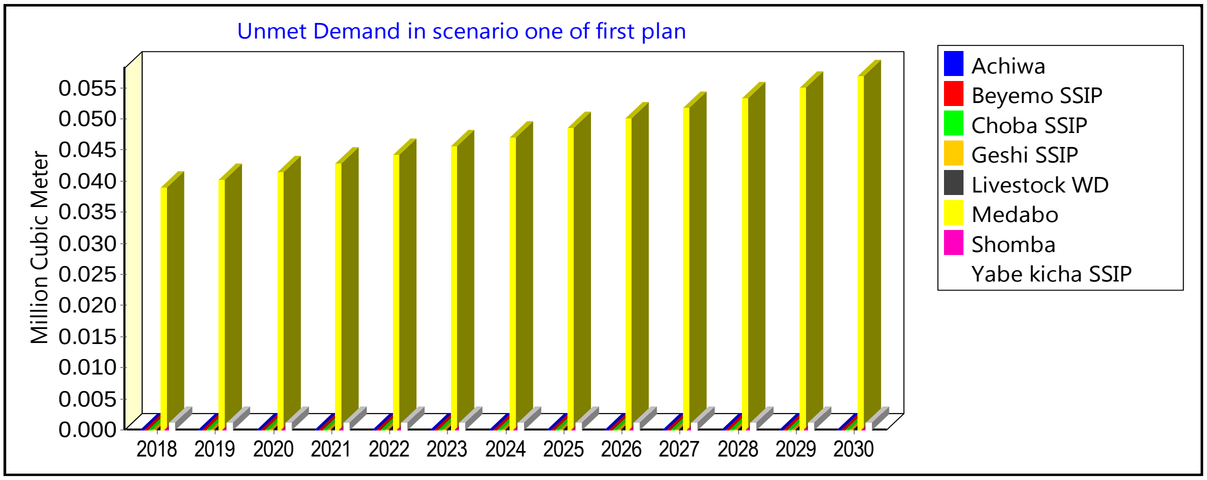

Figure 4.4: Unmet water demand under scenario one of first plan

As the results indicates that the total unmet water demand under this scenario is 0.59MCM.when this is compared to the previous scenario and the current account year it shows increment. This is caused by increment of population growth and consumption rate. Generally, under this scenario from the total water required 3% is unmet.

Scenario one of second plan

The second division of scenario one gives answer for what happen to water demands if the crop water requirement will be reduced by 5% and if all irrigation projects will be increased by 5% in the year between 2018 and 2030 the result of the change that will be observed on a domestic water demand and unmet water demand obtained from this scenario is shown in the Figure 4.5 and 4.6 below.

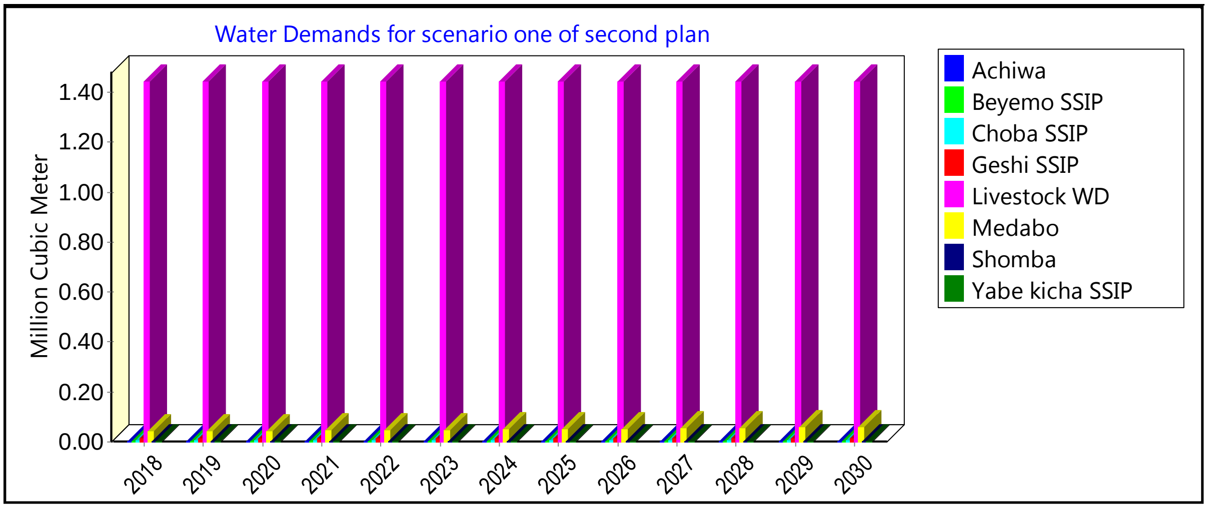

Figure 4.5: Water demand under scenario one of second plan

Due to reduction of crop water requirement and increment of irrigation area there has been a change in water demand for the selected demand sites. Because, the considered factors under this scenario is related to irrigation demand sites the effect is observed on the irrigation demand sites. Generally, a total of 28.36 MCM of water is required by the selected demand sites. Finally a total of 47.92MCM of water is needed in the Gojjeb catchment between the year 2018and 2030 if the above considered factors will be implemented according to the plan.The result of unmet water demands under scenario one of second plan is depicted in Figure 4.6 below.

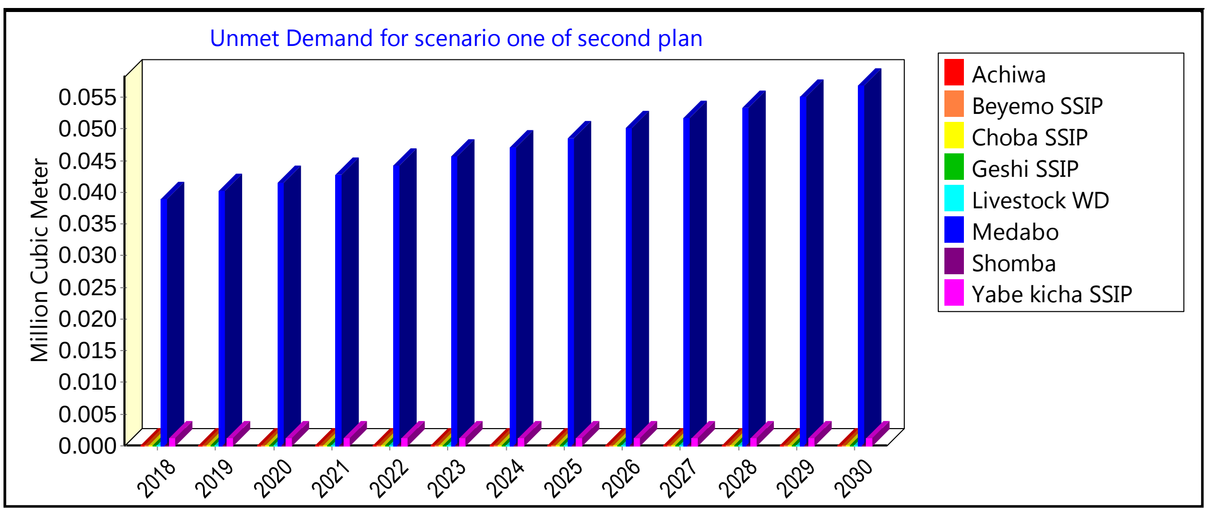

Figure 4.6: Unmet water demand under scenario one of second plan

As shown in the figure above the unmet water demand compared to the previous scenario it shows increment. This is caused by reduction of crop water requirement due to change of implementation of modern irrigation technology and increment of all the selected irrigation command areas. Generally, scenario one is compared to the current account year the annual total unmet water demand for domestic, irrigation and livestock sectors shows increment. The unmet water demand in the current account year is 0.00MCM and under scenario one of the first it was 0.59MCM and the second plan it was 0.63MCM if all the above parameters will be implemented according to the plan.

4.4.3. Scenario Two

Under this scenario, both the second term and the first term plan population growth, increment of consumption rate, increment of irrigation command area and reduction of crop water requirement is considered. All the other factors which affect either water demand or water supply are assumed to be constant. Accordingly, population growth rates were considered depending on the growth rate planned by the kafa zone finance and economic development plan. These are: 2.15% growth rate which will be implemented in the year between 2031 and 2045. Different policy factors were considered under this scenario and what if questions were answered depending on the questions asked.

Scenario two of first plan

If the population in the catchment will grow with a growth rate of 2.15 % and the consumption rate will grow from 50lpc to 120lpc in the years between 2031 and 2045, the results of the changes that will observed on the domestic water demand and unmet water demand are shown below in the form of table and graph. The result obtained from this scenario is shown in the Table 4.4 below.

Table 4.4: Water demand under scenario two of first plan

		Demand branches (MCM)							
Year	Achiwa	Beyemo SSIP	Choba SSIP	Geshi SSIP	Livestock WD	Medabo	Shomba	Yabe kicha SSIP	**Sum**
2031	0.15378	0.00103802	0.002955	0.01305743	1.441011	0.13594	0.04795	0.00123459	1.79697
2032	0.159	0.00103802	0.002955	0.01305743	1.441011	0.14056	0.04958	0.00123459	1.80845
2033	0.16441	0.00103802	0.002955	0.01305743	1.441011	0.14534	0.05127	0.00123459	1.82032
2034	0.17	0.00103802	0.002955	0.01305743	1.441011	0.15028	0.05301	0.00123459	1.83259
2035	0.17578	0.00103802	0.002955	0.01305743	1.441011	0.15539	0.05481	0.00123459	1.84529
2036	0.18176	0.00103802	0.002955	0.01305743	1.441011	0.16068	0.05668	0.00123459	1.85841
2037	0.18794	0.00103802	0.002955	0.01305743	1.441011	0.16614	0.05861	0.00123459	1.87198
2038	0.19433	0.00103802	0.002955	0.01305743	1.441011	0.17179	0.0606	0.00123459	1.88601
2039	0.20093	0.00103802	0.002955	0.01305743	1.441011	0.17763	0.06266	0.00123459	1.90052
2040	0.20777	0.00103802	0.002955	0.01305743	1.441011	0.18367	0.06479	0.00123459	1.91552
2041	0.21483	0.00103802	0.002955	0.01305743	1.441011	0.18991	0.06699	0.00123459	1.93103
2042	0.22213	0.00103802	0.002955	0.01305743	1.441011	0.19637	0.06927	0.00123459	1.94707
2043	0.22969	0.00103802	0.002955	0.01305743	1.441011	0.20305	0.07162	0.00123459	1.96366
2044	0.2375	0.00103802	0.002955	0.01305743	1.441011	0.20995	0.07406	0.00123459	1.9808
2045	0.24557	0.00103802	0.002955	0.01305743	1.441011	0.21709	0.07658	0.00123459	1.99854
Sum	2.94542	0.01557025	0.0443246	0.19586138	21.615165	2.60382	0.91848	0.01851885	28.3572

Due to increment of consumption rate and population growth the water demand shows increment. Annual total of 28.36 MCM amount of water is required. When this is compare to scenario one of first plan it is increased by 9.04MCM. The result of unmet water demands under scenario two of first plan is depicted in Figure 4.7 below.

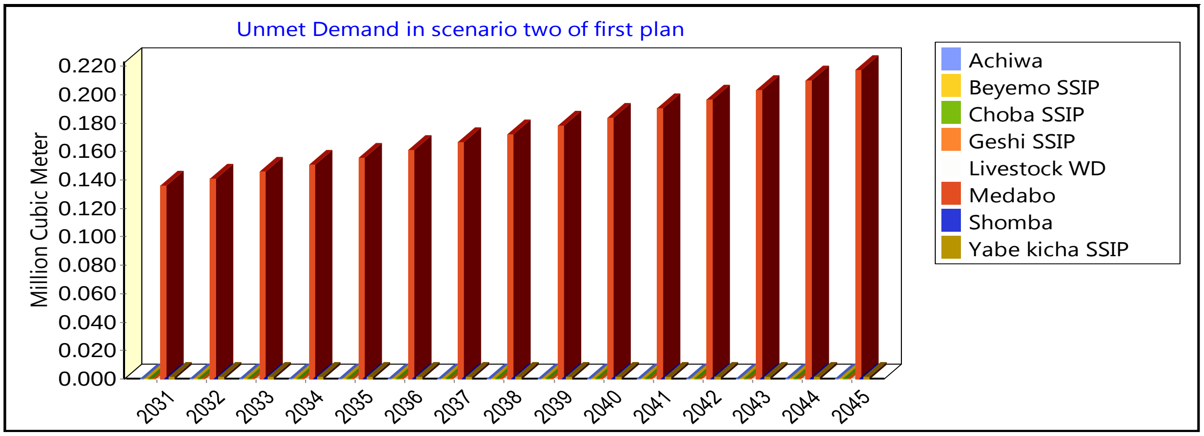

Figure 4.7: Unmet water demand under scenario two of first plan

The total annual unmet water demand under this scenario is 2.6 MCM. When this is compare to scenario one of first plan it is increased by 2.01MCM. Generally, 90.83% is satisfied if all the above parameters are implemented and the rest of 9.16% is unmet.

Scenario two of second plan

The following what if questions were asked under this scenario; what happen to future water demands if crop water requirement will be reduced by 10% in the year between 2031 and 2045? And what happen to in the future water demands if all irrigation projects will be increased by 10% in the year between 2031 and 2045? The water demand result obtained from this scenario is shown in the Figure 4.8 below.

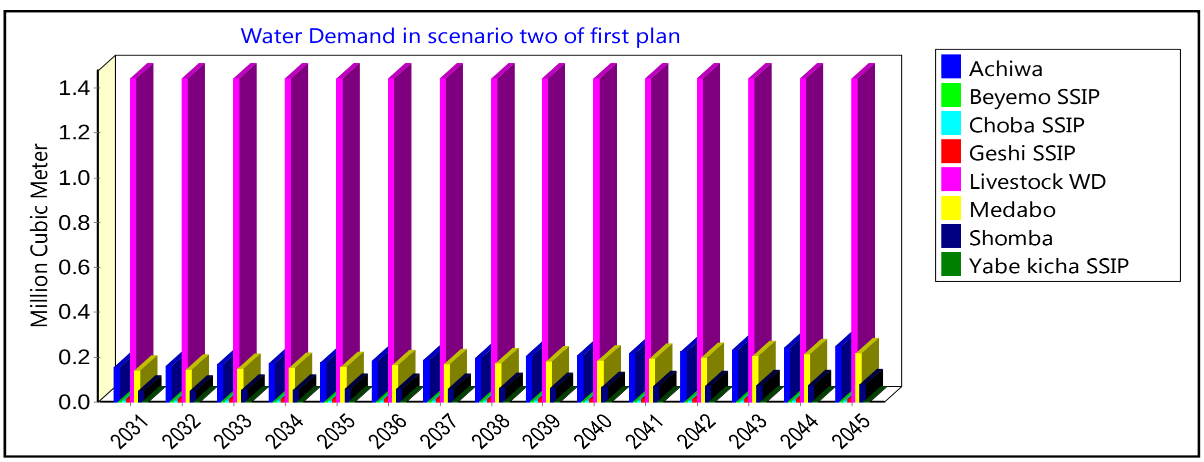

Figure 4.8: Water demand under scenario two of second plan

Due to reduction of crop water requirement and increment of irrigation area there has been a change in water demand for the selected demand sites. Because, the considered factors under this scenario is related to irrigation demand sites the effect is observed on the irrigation demand sites. Generally a total of 28.35 MCM of water is needed in the Gojjeb catchment between the year 2031 and 2045 if the above considered factors will be implemented according to the plan. The result of unmet water demands under scenario two of second plan is depicted in Table 4.5 below

Table 4.5: Unmet water demand under scenario two of second plan.

unmet water demand under scenario two of second plan									
Year	Achiwa	Beyemo SSIP	Choba SSIP	Geshi SSIP	Livestock WD	Medabo	Shomba	Yabe kicha SSIP	**Sum**
2031	0	0	0	0	0	0.13594	0	0.0012344	0.13718
2032	0	0	0	0	0	0.14056	0	0.0012344	0.1418
2033	0	0	0	0	0	0.14534	0	0.0012344	0.14658
2034	0	0	0	0	0	0.15028	0	0.0012344	0.15152
2035	0	0	0	0	0	0.15539	0	0.0012344	0.15663
2036	0	0	0	0	0	0.16068	0	0.0012344	0.16191
2037	0	0	0	0	0	0.16614	0	0.0012344	0.16738
2038	0	0	0	0	0	0.17179	0	0.0012344	0.17302
2039	0	0	0	0	0	0.17763	0	0.0012344	0.17886
2040	0	0	0	0	0	0.18367	0	0.0012344	0.1849
2041	0	0	0	0	0	0.18992	0	0.0012344	0.19115
2042	0	0	0	0	0	0.19637	0	0.0012344	0.19761
2043	0	0	0	0	0	0.20305	0	0.0012344	0.20428
2044	0	0	0	0	0	0.20995	0	0.0012344	0.21119
2045	0	0	0	0	0	0.21709	0	0.0012344	0.21832
Sum	0	0	0	0	0	2.60382	0	0.018516	2.62233

As shown in the table 4.5 above the unmet water demand compared to the previous scenario it shows increment. This is caused by reduction of crop water requirement due to change of implementation of modern irrigation technology and increment of all the selected irrigation command areas. Generally, scenario two is compared to the current account year the annual total unmet water demand for domestic, irrigation and livestock sectors shows increment. The unmet water demand in the current account year is 0.00MCM and under scenario two of the first and the second plan it will be 5.523MCM if all the above parameters will be implemented according to the plan.

4.5. Allocate available water resources

WEAP is unique in its capability of representing the effects of demand management on water systems. Water requirements may be derived from a detailed set of final uses or water services in different economic sectors. For example, the agricultural sector could be broken down by crop types, irrigation districts and irrigation techniques. The results of this study shows that, the total water resource has enough potential to fulfill current and future water demands among multiple water users and no unmet demands were encountered for a current account year if the available water resource is used properly. The result also indicates that there is scarcity of supply in all scenarios and unmet water demand were observed in the future scenario. The result of domestic, agriculture and livestock demand portrayed below for reference scenario, scenario one and scenario two.

Table 4.6: Annual water demands under reference scenario

Reference scenario in the first term plan(2018-2030)				Reference scenario in the second term plan(2031-2045)			
Demand Branches(MCM)				Demand Branches(MCM)			
Year	Domestic	Agriculture	Livestock	Year	Domestic	Agriculture	Livestock
2018	0.0492	0.0174	1.441	2031	0.0492	0.0174	1.441
2019	0.0492	0.0174	1.441	2032	0.0492	0.0174	1.441
2020	0.0492	0.0174	1.441	2033	0.0492	0.0174	1.441
2021	0.0492	0.0174	1.441	2034	0.0492	0.0174	1.441
2022	0.0492	0.0174	1.441	2035	0.0492	0.0174	1.441
2023	0.0492	0.0174	1.441	2036	0.0492	0.0174	1.441
2024	0.0492	0.0174	1.441	2037	0.0492	0.0174	1.441
2025	0.0492	0.0174	1.441	2038	0.0492	0.0174	1.441
2026	0.0492	0.0174	1.441	2039	0.0492	0.0174	1.441
2027	0.0492	0.0174	1.441	2040	0.0492	0.0174	1.441
2028	0.0492	0.0174	1.441	2041	0.0492	0.0174	1.441
2029	0.0492	0.0174	1.441	2042	0.0492	0.0174	1.441
2030	0.0492	0.0174	1.441	2043	0.0492	0.0174	1.441
Sum	0.6396	0.2262	18.733	2044	0.0492	0.0174	1.441
				2045	0.0492	0.0174	1.441
				Sum	0.738	0.261	21.615

As shown in the Table 4.6 above, annual water demands for a selected demand site shows similar trend from year to year. This is because no any policy change is considered under this scenario. Hence, the amount of water needed in the base year is similar to that needed at the end of the reference scenario (2045). Accordingly, a total of 42.21MCM of water is required by the above three demand sites at the end of reference scenario. Similarly, as shown in the Table 4.6 above, water demands for domestic show similar trend from year to year and a total of 1.38MCM of water is required by domestic demand sites, a total of 0.48MCM of water is required by agricultural demand sites and a total of 40.38MCM is required by livestock's.

This means if all the factors which affect irrigation, domestic and livestock water demand is assumed to be constant and no policy change will be occur between the years 2018 and 2045.

Table 4.7: Annual water demands under scenario one

Scenario one of First term plan(2018-2030)					Scenario one of second term plan(2031-2045)				
Demand branches (MCM)					Demand branches (MCM)				
Year	Domestic	Agriculture	Livestock	Sum	Year	Domestic	Agriculture	Livestock	Sum
2018	0.2	0	1.41	1.61	2031	0.337671	0.018285	1.441011	1.796967
2019	0.1	0.1	1.41	1.61	2032	0.349152	0.018285	1.441011	1.808448
2020	0.1	0	1.42	1.52	2033	0.361023	0.018285	1.441011	1.820319
2021	0.1	0	1.42	1.52	2034	0.373298	0.018285	1.441011	1.832594
2022	0.1	0	1.42	1.52	2035	0.38599	0.018285	1.441011	1.845286
2023	0.1	0	1.42	1.52	2036	0.399114	0.018285	1.441011	1.85841
2024	0.1	0	1.43	1.53	2037	0.412684	0.018285	1.441011	1.87198
2025	0.1	0	1.43	1.53	2038	0.426715	0.018285	1.441011	1.886011
2026	0.1	0.1	1.44	1.64	2039	0.441223	0.018285	1.441011	1.900519
2027	0.1	0	1.41	1.51	2040	0.456225	0.018285	1.441011	1.915521
2028	0.1	0	1.45	1.55	2041	0.471737	0.018285	1.441011	1.931033
2029	0.1	0	1.47	1.57	2042	0.487776	0.018285	1.441011	1.947072
2030	0.1	0	1.49	1.59	2043	0.50436	0.018285	1.441011	1.963656
Sum	1.4	0.2	18.62	20.22	2044	0.521508	0.018285	1.441011	1.980804
					2045	0.53924	0.018285	1.441011	1.998536
					Sum	6.467716	0.2742751	21.61517	28.35716

As shown from the Table 4.7 above water demand for domestic is increased from year to year. This is because domestic water demand is directly proportional to the controlling factor under this scenario which is the population. Generally, from the results of the analysis of this scenario, domestic water demand shows an increment as compared to the base year (2017) and the first term plan of the reference scenario. Thus, when compared to the base year water demand for domestic, agriculture and livestock is increased from 1.507MCM in the base year (2017) to 20.22MCM at the end of the first term plan of scenario one (2030) (Table 4.7). And also the water demand is increased from 20.22MCM at the end of the first term plan of scenario one to 28.36MCM at the end of the second term plan of scenario one. From the total available water demand 7.87MCM is needed by the domestic users and a total of 0.48MCM is required by agricultural sector at the end of scenario one if the considered parameters were implemented according to the plan. Generally, in scenario one a total of 48.58MCM water is needed by the three sectors. From the total demand 16.19% is consumed by domestic users and the remaining 83.8% has shared by livestock and Agricultural usages. Therefore, the total available resource is greater than the requirement for scenario one for the selected demand sites. This shows that, for the case of the scenario one the available water has more than enough capability to satisfy the future demanded water.

Table 4.8: Annual water demands under scenario two

Scenario Two of First term plan(2018-2030)					Scenario Two of Second term plan(2031-2045)				
	Demand Branches(MCM)					Demand Branches(MCM)			
Year	Domestic	Agriculture	Livestock	Sum	Year	Domestic	Agriculture	Livestock	Sum
2018	0.338	0.018	1.461	1.817	2031	0.429	0.089	1.512	2.030
2019	0.349	0.018	1.461	1.828	2032	0.440	0.089	1.512	2.041
2020	0.361	0.018	1.461	1.840	2033	0.452	0.089	1.512	2.053
2021	0.373	0.018	1.461	1.853	2034	0.464	0.089	1.512	2.066
2022	0.386	0.018	1.461	1.865	2035	0.477	0.089	1.512	2.078
2023	0.399	0.018	1.461	1.878	2036	0.490	0.089	1.512	2.091
2024	0.413	0.018	1.461	1.892	2037	0.504	0.089	1.512	2.105
2025	0.427	0.018	1.461	1.906	2038	0.518	0.089	1.512	2.119
2026	0.441	0.018	1.461	1.921	2039	0.532	0.089	1.512	2.134
2027	0.456	0.018	1.461	1.936	2040	0.547	0.089	1.512	2.149
2028	0.472	0.018	1.461	1.951	2041	0.563	0.089	1.512	2.164
2029	0.488	0.018	1.461	1.967	2042	0.579	0.089	1.512	2.180
2030	0.504	0.018	1.461	1.984	2043	0.595	0.089	1.512	2.197
Sum	5.407	0.238	18.993	24.638	2044	0.600	0.089	1.512	3.273
					2045	0.610	0.089	1.512	3.302
					Sum	7.800	1.339	22.680	33.981

As shown from the Table 4.8 above 58.51MCM of a total annual water demand is needed by all water users at the end of scenario two. Accordingly, the water demand is increased from 24.64MCM at the end of the first term plan of scenario two to 33.98MCM at the end of the second term plan of scenario two. From the total available water demand 13.207MCM is needed by the domestic users and a total of 1.58MCM is required by agricultural sector at the end of scenario two if the considered parameters were implemented according to the plan. Generally, in scenario two from the total demand 22.57% is consumed by domestic users and the remaining 77.43% has shared by livestock and Agricultural usages. Therefore, for the case of scenario two the available water has more than enough capability to satisfy the future demanded water.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The overall objective of this research is to model surface water resource of Gojjeb river catchment for optimal surface water allocation and to propose water resource management strategies in a sustainable manner for social, economic and environmental benefits. In order to determine whether the available surface water potential is capable or not the Water evaluation and planning (WEAP) model was successfully used to in this study for optimum water allocation. The assessment of surface water potential of Gojjeb river catchment was carried out by using Rain fall run off method among catchment simulation of WEAP model in order to identify weather the available supply is capable or not to fulfill the water demands in the base year. According to the result showed the Gojjeb river catchment has surface water potential of 2.01BCM. In the base year 1.5076 BCM of water was required by the water users. The result shows that the total available resource is greater than the requirement for the base year for the selected demand sites and this indicates that for the base year the available water has more than enough capability to satisfy the water demand in the base year among multiple water users and no unmet demand were encountered in the base year. The water demand and supply scenarios were created to forecast the future trend of water demands and available surface water potential in the catchment. For future water demands, the result indicated that there is an increment of water demands and unmet water demands from year to year. Therefore, the result showed that an increment of water demands from 48.58MCM in to 58.51MCM in scenario two. The outcome of unmet water demands also shows an increment from 1.22MCM in scenario one to 5.52MCM in scenario two if future development scenarios will be fully implemented according to the plan.

Generally, the study concludes that future water demands and unmet water demands shows an increment due to reduction of crop water requirement, increment of irrigation command area, and increment of consumption rate as well as ever increasing of population growth rate. Thus, indicates that the demand sites serves for a long period of time without rehabilitation of the water distribution structures. And also there may be high amount of water losses in water transmission networks which causes an increment in the unmet water demands.

5.2. Recommendations

This research study was accompanied under limited data availability. Hence, the following recommendations are made for the further studies in the future. This study did not cover all demand sites found in the catchment in water demand assessment. Only some of the small scale irrigation projects and water supply schemes were involved in the assessment of demands. Therefore, it is essential if researches which consider all small, medium and large scale projects will be undertaken. As compared to the available potential the water demand in the catchment is very small so further investigation is essential to use the available surface water potential of the catchment. In future, the catchment has to be studied for more projects to use this water potential. As this study is limited to the assessment of surface water potential it will have a deep significance if a researches are drawn-out to include groundwater potential and quality analysis in the study area.

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APPENDICES

Appendix 1: Stream flow data of the gauging station (Station Name: Gojeb near Shebe)

year	month	flow(CMS)	year	month	flow(CMS)	year	month	flow(CMS)	year	month	flow(CMS)
1997	1	12.126	2000	1	1.012	2003	1	4.919	2006	1	9.164
1997	2	9.009	2000	2	0.312	2003	2	2.975	2006	2	8.111
1997	3	9.611	2000	3	0.23	2003	3	13.646	2006	3	9.881
1997	4	10.848	2000	4	2.915	2003	4	21.683	2006	4	12.21
1997	5	25.715	2000	5	42.918	2003	5	13.051	2006	5	23.419
1997	6	64.472	2000	6	68.869	2003	6	42.547	2006	6	44.387
1997	7	153.248	2000	7	151.684	2003	7	104.121	2006	7	161.49
1997	8	186.047	2000	8	132.908	2003	8	110.152	2006	8	168.377
1997	9	144.364	2000	9	74.332	2003	9	136.785	2006	9	165.95
1997	10	35.683	2000	10	145.836	2003	10	42.903	2006	10	80.249
1997	11	25.201	2000	11	29.204	2003	11	17.521	2006	11	45.819
1997	12	18.298	2000	12	2.809	2003	12	17.625	2006	12	24.901
1998	1	11.579	2001	1	0.276	2004	1	14.034	2007	1	9.928
1998	2	9.561	2001	2	0.188	2004	2	13.117	2007	2	5.686
1998	3	9.454	2001	3	0.139	2004	3	9.837	2007	3	3.944
1998	4	13.572	2001	4	23.899	2004	4	10.389	2007	4	9.038
1998	5	30.888	2001	5	81.942	2004	5	27.224	2007	5	29.521
1998	6	58.575	2001	6	88.88	2004	6	54.274	2007	6	65.829
1998	7	76.53	2001	7	158.083	2004	7	92.021	2007	7	115.653
1998	8	112.276	2001	8	153.181	2004	8	125.968	2007	8	190.862
1998	9	106.802	2001	9	135.849	2004	9	147.399	2007	9	210.312
1998	10	70.52	2001	10	161.245	2004	10	109.111	2007	10	138
1998	11	24.417	2001	11	79.021	2004	11	11.569	2007	11	14.808
1998	12	26.686	2001	12	13.563	2004	12	10.593	2007	12	4.974
1999	1	17.414	2002	1	2.985	2005	1	5.415	2008	1	4.035
1999	2	11.551	2002	2	1.078	2005	2	5.036	2008	2	2.929
1999	3	13.386	2002	3	5.681	2005	3	11.409	2008	3	2.687
1999	4	21.054	2002	4	14.403	2005	4	11.033	2008	4	1.525
1999	5	44.578	2002	5	33.339	2005	5	31.019	2008	5	1.903
1999	6	132.931	2002	6	117.935	2005	6	57.385	2008	6	30.951
1999	7	87.567	2002	7	182.867	2005	7	92.737	2008	7	303.203
1999	8	100.893	2002	8	235.258	2005	8	123.933	2008	8	161.998
1999	9	80.311	2002	9	257.722	2005	9	169.935	2008	9	254.02
1999	10	158.445	2002	10	142.039	2005	10	66.328	2008	10	144.16
1999	11	172.853	2002	11	81.452	2005	11	21.405	2008	11	53.769
1999	12	62.755	2002	12	13.58	2005	12	11.271	2008	12	40.18

year	month	flow(CMS)	year	month	flow(CMS)	year	month	flow(CMS)
2009	1	33.908	2012	1	14.312	2015	1	45.153
2009	2	30.986	2012	2	12.077	2015	2	22.516
2009	3	37.284	2012	3	12.478	2015	3	52.547
2009	4	46.347	2012	4	17.768	2015	4	22.083
2009	5	67.568	2012	5	38.911419	2015	5	65.349
2009	6	81.62	2012	6	109.773	2015	6	92.6905
2009	7	61.689	2012	7	177.521	2015	7	122.898
2009	8	112.236	2012	8	119.515	2015	8	246.07
2009	9	144.479	2012	9	77.554	2015	9	134.053
2009	10	58.665	2012	10	41.994	2015	10	215.391
2009	11	33.276	2012	11	19.362	2015	11	42.785
2009	12	18.335	2012	12	15.131	2015	12	5.995
2010	1	28.041	2013	1	11.165	2016	1	17.933
2010	2	40.112	2013	2	12.586	2016	2	9.871
2010	3	37.548	2013	3	10.813	2016	3	12.982
2010	4	37.187	2013	4	17.001	2016	4	16.49
2010	5	39.071	2013	5	44.933	2016	5	14.381
2010	6	135.672	2013	6	66.371	2016	6	42.902
2010	7	213.916	2013	7	120.819	2016	7	72.295
2010	8	185.494	2013	8	123.827	2016	8	104.312
2010	9	213.472	2013	9	125.472	2016	9	81.713
2010	10	154.511	2013	10	162.573	2016	10	50.155
2010	11	82.838	2013	11	44.342	2016	11	15.067
2010	12	2.128	2013	12	22.526	2016	12	12.368
2011	1	19.375	2014	1	17.867	2017	1	45.994
2011	2	17.401	2014	2	17.438	2017	2	5.944
2011	3	25.396	2014	3	15.011	2017	3	3.882
2011	4	24.335	2014	4	32.427	2017	4	3.303
2011	5	30.141	2014	5	78.007	2017	5	16.024
2011	6	89.062	2014	6	102.469	2017	6	49.742
2011	7	88.607	2014	7	139.375	2017	7	61.477
2011	8	170.184	2014	8	111.422	2017	8	76.117
2011	9	153.422	2014	9	117.743	2017	9	103.104
2011	10	93.45	2014	10	79.286	2017	10	47.532
2011	11	30.828	2014	11	33.646	2017	11	44.673
2011	12	19.489	2014	12	16.636	2017	12	37.187

Appendix 2: Climate Data for CROPWAT software for each stations

Appendix 2.1: Climate data for Bonga station

Month	Min Temp (°C)	Max Temp (°C)	Humidity (%)	Wind (km/day)	Sun (hours)	Rad MJ/m²/day	Eto mm/day	Rain (mm)
January	10.5	28.3	60	95	7	18.3	3.77	91.5
February	11	28.8	48	104	6.2	18.1	4.1	92.2
March	12.1	28.7	59	173	6.2	18.9	4.58	80.2
April	12.9	28	68	130	6.4	19.3	4.21	75.2
May	12.8	26.8	71	104	6.1	18.3	3.81	66.3
June	12.8	26.2	67	104	5.2	16.6	3.57	66
July	12.3	25.5	68	95	3.4	14.1	3.14	65.7
August	12.6	25.4	69	104	4	15.4	3.33	64.6
September	12.7	26.1	68	86	5.1	17.1	3.54	66.5
October	12	27.2	65	95	6.4	18.5	3.82	76.6
November	10.9	27.9	55	69	7.1	18.6	3.67	87.9
December	10.2	28.1	45	69	7.3	18.3	3.61	90.5
Average/Total	11.9	27.3	62	102	5.9	17.6	3.76	923.2

Appendix 2.2: Climate data for Gojeb station

Month	Min Temp (°C)	Max Temp (°C)	Humidity (%)	Wind (km/day)	Sun (hours)	Rad MJ/m²/day	Eto mm/day	Rain (mm)
January	15.6	32.3	65	142	6	16.9	4.17	89.9
February	14.1	33.9	63	143	6.1	18	4.6	92.4
March	14.7	33.6	73	140	6.6	19.6	4.64	77.5
April	15.2	32.5	82	134	7.5	21	4.58	68.7
May	15.6	31.3	85	133	7.6	20.6	4.32	57.6
June	16	30	87	122	6.5	18.5	3.82	53.9
July	16.4	28.5	86	120	5	16.4	3.41	52.4
August	16.5	28.6	84	114	5.6	17.8	3.65	48.7
September	16.4	29.9	80	112	7.3	20.5	4.23	51.9
October	15.7	30.8	80	129	7.7	20.5	4.29	74.1
November	15.5	31.3	74	135	7.4	19	4.16	82
December	15.8	31.5	72	135	6.4	17	3.9	86.3
Average/Total	15.6	31.2	78	130	6.6	18.8	4.15	835.4

Appendix 2.3: Climate data for Shebe station

Month	Min Temp (°C)	Max Temp (°C)	Humidity (%)	Wind (km/day)	Sun (hours)	Rad MJ/m²/day	Eto mm/day	Rain (mm)
January	12.8	29.4	59	137	4.2	14.3	3.68	93.8
February	13.1	29.3	56	140	4.1	15	3.95	94.9
March	13.3	27.8	63	144	4.5	16.3	3.94	84.0
April	14.1	26.7	76	138	4.7	16.7	3.62	77.2
May	13.8	25.4	81	138	4.8	16.4	3.35	70.8
June	13.7	24.9	87	127	4.1	15	2.95	70.6
July	13.9	24.8	90	120	3.1	13.7	2.69	68.0
August	14.1	25.5	89	116	3.5	14.6	2.89	63.7
September	14	26.6	87	113	4.7	16.5	3.29	66.5
October	13.1	26.9	81	128	4.9	16.3	3.37	82.3
November	12.7	27.5	70	133	4.6	15	3.4	87.9
December	12.8	27.9	63	132	4.2	13.9	3.38	91.2
Average/Total	13.4	26.9	75	131	4.3	15.3	3.38	950.9

Appendix 2.4: Climate data for Jimma station

Month	Min Temp (°C)	Max Temp (°C)	Humidity (%)	Wind (km/day)	Sun (hours)	Rad MJ/m²/day	Eto mm/day	Rain (mm)
January	9.1	29.5	54	30	7.8	19.4	3.43	94.4
February	9.3	30.7	51	36	7.7	20.3	3.79	95.3
March	12	30.2	57	39	7.1	20.3	3.96	83.3
April	13.5	28.9	63	39	6.8	20	3.93	75.2
May	13.7	27.9	68	38	7.4	20.3	3.91	68.7
June	13.9	26.2	73	36	5.3	16.8	3.28	65.2
July	14	25.2	75	31	4	15	2.94	63.8
August	14.1	25.7	73	31	4.6	16.3	3.16	66.9
September	13.7	27	68	32	6.3	19	3.63	73.2
October	11.7	27.6	62	31	7.5	20.2	3.72	79.7
November	10	28	57	29	7.9	19.7	3.49	90.3
December	8.4	28.7	54	29	7.8	18.9	3.29	93.5
Average/Total	11.9	28	63	33	6.7	18.8	3.54	949.5

Appendix 3: Crop water requirements for each irrigation projects

Irrigation projects	Crops commonly practiced	CWR of crops (m3/ha/yr)	Monthly Variation (%)												
			Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Total (%)
Geshi SSIP	Maize, potato & onion	51.98	38.4	28.1	2.4	0	0	0	0	0	0	0	2.9	28.3	100
Beyemo SSIP	Maize, Millet & pepper	49.38	40.5	29.6	1.8	0	0	0	0	0	0	1.7	2.3	24.2	100
Choba SSIP	Cabbage, sweet potato, and Maize	55.81	38.4	33.8	5.7	0.6	0	0	0	0	0	0.7	1.1	19.6	100
Yabe kicha SSIP	Potato, Onion, maize & Cabbage	58.79	35.1	29.1	2.1	0	0	0	0	0	0	0	6	27.7	100