JIMMA UNIVERSITY
JIMMA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR

INVESTIGATION OF THE EXISTING SURFACE WATER POTENTIAL AND ALLOCATION OF FUTURE WATER DEMAND: THE CASE OF UPPER GILGEL GIBE SUB-BASIN, ETHIOPIA.

By: Tilahun Haile Shamebo.

A Thesis Submitted to Jimma University, Jimma Institute of Technology, school of graduate studies, Hydrology and Hydraulic Engineering Chair in Partial Fulfillment of the Requirements for the Degree of Master of Science in Hydraulic Engineering

May, 2020
Jimma, Ethiopia

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Main Advisor: Dr. Zerihun Asmelash (PhD, Ass. Professor)

Co-advisor: Mr. Chala Hailu (MSc.)

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ABSTRACT

The upper Gilgel Gibe sub-basin is located in Oromiya regional state; the South-west of Ethiopia has large amount of water resource potential. However, rapid population growth and increased agricultural activities were led to Water demand and allocation stress in the sub-basin. Therefore, study was required to allocate water among water users sectors which avoid a water-based conflict and overutilization surface water resource in the sub-basin. To solve such problem this study was aimed to investigate the existing surface water potential and allocation of future water demand in the upper Gilgel Gibe sub-basin. The required data for this study was collected from different governmental institutions. The homogeneity and consistency of rain fall data for this study was done by Pi (non -dimensional) value and double mass curve methods respectively. The result of data checking shows, the rainfall data was homogeneous and consistent. Due to availability of data, the rainfall runoff method (simplified coefficient method) was used to simulate the catchment in the model. The findings of the study indicated that, surface water potential in Gilgel Gibe sub-basin was 1276 MMC. The model was simulated for the input rainfall data of year 1990-2018. The calibration of the model was assessed by simulated runoff from sub-basin and observed stream flow at Asendabo gauge station from 1990-2018. The statistical parameters values were R2 =0.9986, Nash-Sutcliffe Efficiency (NSE)=0.976, Percent of Bias (PBIAS)=-14%, Ratio of Standard Deviation of Simulated Versus Observed (SDR)=1 and Ratio of the Root Mean Squared Error to the Standard Deviation (RSR)=0.141 respectively. The result of the calibration indicates that there is good match pattern between simulated and observed stream flow. Hence, the WEAP model is applicable for water resource management. The current account for the Water Evaluation and Planning model was 2019 while last year of scenarios studies were extended up to year 2050. Under the current the water demand situation for rural accounts 70.88 MCM which was the largest water utilized sectors followed by agricultural which consumed 43.91 MCM. Livestock and urban water demand were also 28.64 MCM and 24 MCM respectively. These results indicated that under the current year all demand sites were fully satisfied. Also 20.8 % of the mean annual flow (265.83 MCM) was allocated for Environmental flow requirement to maintain the basic ecological functioning in the sub-basin which intern regulates the permanent flow of the downstream region. Four scenarios were created for future water demand estimation namely; reference, high population growth, current irrigation potential and irrigation projection scenarios. The annual water demand for reference scenario (RS), high population growth scenario (HPGS), current irrigation potential scenario (CIPS) and irrigation projection scenario (IPS) were estimated 167.72, 194.7, 176.89 and 188.32 MCM respectively. High shortage of water demand for agriculture was faced under CIPS and IPS which is 1.87 MCM and 3.47MCM respectively. Although rural and urban demand sites have got unmet demand of 8.31 and 7.52 MCM in HPGS respectively.

Keywords: Upper Gilgel Gibe sub-basin, Surface water potential, Water demand, WEAP**.**

DECLARATION

I under signed, declare that this Thesis entitled" Investigation of The Existing Surface Water Potential and Allocation of Future Water Demands: The Case of upper Gilgel Gibe Sub-Basin, Ethiopia." is my original work, and has not been presented by any others person for award of a degree in Jimma university or any other university.

Tilahun Haile	__________________	__________________
Student Name	Signature	Date

APPROVAL SHEET

We certify that the Thesis entitled "Investigation of The Existing Surface Water Potential and Allocation of Future Water Demands: The Case of upper Gilgel Gibe Sub-Basin, Ethiopia" is the work of Tilahun Haile and we here by recommend for the examination by Jimma Institute of Technology in partial fulfillment of the requirements for degree of Masters of Science in Hydraulic Engineering.

Dr. Zerihun Asmelash (PhD)	____________________	____________________
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Mr. Chala Hailu (MSc.)	____________________	____________________
(Co-Advisor)	Signature	Date

As a member of Board of Examiners of the MSc. Thesis open Defense Examination, we certify that we have read, evaluated the Thesis prepared by Tilahun Haile and examined the candidate. We recommended that the Thesis could be accepted as fulfilling the Thesis requirements for the Degree of Masters of Science in Hydraulic Engineering.

Dr. Kassa Tadele (PhD)	____________________	____________________
(External examiner)	Signature	Date
Mr. Tadele Shiferaw (MSc.)	____________________	____________________
(Internal examiner)	Signature	Date

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ACRONYMS

ADD	Average Daily Demand
BCM	Billion Cubic Meter
CaWAT	The Catchment Water Allocation Tool
CIPS	Current Irrigation Potential Scenario
CIWD	Commercial and Institutional Water Demand
CROPWAT	Crop Water Requirement software developed by FAO
CSV	Common Separated Value
CWR	Crop Water Requirement
d	day
DEM	Digital Elevation Model
DSS	Decision Support System
DWD	Domestic Water Demand
EFR	Environmental Flow Requirement
ET_o	Reference Crop Evapotranspiration
FAO	United Nations Food and Agricultural Organization
GIS	Geographical Information System
GTP	Growth and Transformation Plan of Ethiopia
HPDS	High Population Growth Scenario
IPS	Irrigation Projection Scenario
ITCZ	Inter Tropical Convergence Zone
IWD	Industrial Water Demand
IWR	Irrigation Water Requirement
IWRM	Integrated Water Resource Management
Kc	Hydraulic Conductivity
lpcd	liter per capita per day
LTP	Linear Programming Techniques
LU	Livestock Unit
LWD	Livestock Water Demand
MCM	Million Cubic Meter
MDD	Maximum Daily Demand

MODSIM	Modular Simulation Model
NIWR	Net Irrigation Water Requirement
NSE	Nash-Sutcliffe Efficiency
OSF	Observed Stream Flow
PBIAS	Percent of Bias
PEST	Parameter Estimation Tool
RAM	Readily Available Moisture
RIBASIM	River Basin Simulation Model
RS	Reference Scenario
RSR	Ratio of the Root Mean Squared Error
SEI	Stockholm Environmental Institute
SL	System Losses
SSF	Simulated Stream Flow
TAM	Total Available Moisture
Tmax	Maximum Temperature
Tmin	Minimum Temperature
WARGI-SIM	Water Resources Graphical Interface – Simulation Tool
WD	Water Demand
WEAP	Water Evaluation Assessment and Planning
WGS84	World Geodetic System
WRG	Water Research Group
Yr.	Year

1. INTRODUCTION

1.1 Background and Justification

Water is one of the most important natural resources which is necessary to ensure human health, life, socioeconomic development, Eco-environmental systems, and civilization. However, rapid population growth, urbanization, industrial development and increased agricultural activities had led to Water demand and allocation stress across globe (Katirtzidou and Latinopoulos, 2017).

Ethiopia has large amount of water resource, however, very little of this natural resource 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. Knowing the potential and availability of surface water is vital in wise use of the resource, designing economical and suitable hydraulic structure for water supply, hydropower (Adgolign *et al*., 2015).

Water conflicts arise when the demand exceeds the available supply and its water allocation fails to meet the demand. This would be aggravated further by the intensified demands from the users and the increase in the frequency of these demands. Thus, in order to avoid the present as well as future water conflicts between the competing demands, researchers and scientist have given increased emphasis in developing tools and techniques for improved management of the water resources. The development of various models, which provide a good insight into the intricacies related to water allocations and balancing mismatch between supply and demand through integrated water management is therefore necessary (Nadiah *et al.*, 2015).

Integrated water system models can increase the understanding of Water Resources Development (WRD) impacts on sectoral water users, and can predict the role of WRD with scenarios of situations encompassing expected future changes in key water-use sectors, especially agricultural, domestic and industrial. This in turn had created increased water demand and water conflicts, which need to be, addressed (Chinnasamy *et al*. 2015).

Computer based Decision Support Systems (DSS) are very useful tools to perform this kind of study, because they allow the user to forecast and evaluate the impacts of different future trends and strategies before implementing them. Since it is not possible to predict exactly how the water demands and other factors are going to evolve in the future it was considered appropriate to use a scenario analysis approach in this study. A set of realistic scenarios can be built in order to account for the uncertainty in the evolution of the water demands, the implementation of the Environmental Reserve, International Agreements, Water Conservation and Demand Management programs, Infrastructure development, etc… A Decision Support System can then be used in order to evaluate the impacts of these different scenarios and help water managers and water users in the decision making process (Ashofteh *et al*., 2014).

This study was targeted for the investigation of the existing surface water potential and allocation of future water demands in the upper Gilgel Gibe sub basin that includes: water supplying and demand for different agricultural, Livestock, domestic and industrial supply process. The assessment of this study was archived through the Water Evaluation and Planning (WEAP) in the sub-basin by using scenarios based on the current and future situation. This was done by linking the demand and the supply of surface water resource of the sub-basin until 2050 by considering environmental flow requirement, population growth, and irrigation expansion.

1.2 Statement of the Problem

Ethiopia has substantial water resources, but it is unevenly distributed across the territory and varies substantially between years. At the same time water, demand for both domestic and productive uses is expected to grow rapidly near the future. Currently utilization of water resources is very limited including domestic and minor agricultural activities, mainly through rain fed cultivation. However, knowledge and understanding of surface water and their interactions with spatial and temporal variability are essential for the present and future assessment of water resource availability (Adgolign *et al*., 2015).

General understanding of the surface water resource and its interaction is one of the gaps of water resources development in the country. Surface Water resources management on equal bases distribution have not well developed in the upper Gilgel Gibe sub basin and there is no formal water allocation practice in place. In preliminary planning of the water resource projects in the watershed, the amount of available minimum and maximum river flow, the demand for any previously implemented upstream projects and other demands including downstream environment have to be sought before implementation.

To ensure these implementations of available surface water in sufficient amount, high quality, at the right time and right place, it is important to plan and manage the technical, economic, financial and institutional aspects of water resources. Adequate planning and appropriate water resource management approach creates an opportunity to achieve governmental goals in sustainable and equitable manner. The fact is that a balancing of these uses must be accomplished, and the mechanism for doing so must be carefully constructed. The existing overlay of complex hydrological, socio-economic and property rights/legal environments predisposes water resources to open access appropriation within the watershed, and the consequence of negative environmental and economic externalities.

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 globally with their suitability and limitations are presented here to reach at a conclusion that WEAP model was selected as the best suitable to model the water demand in this study area. Therefore, this study is initiated to fulfill the surface water potential demand and allocation gap in the upper Gilgel Gibe sub-basin.

1.3 Objective of the study

1.3.1 General objective

The aim of this study was to investigate the existing surface water potential and allocation of future water demands to user sectors within upper Gilgel Gibe sub-basin.

1.3.2 Specific objectives

1. To evaluate current surface water potential in the upper Gilgel Gibe sub-basin;
2. To develop current sectoral water demand allocation system within the upper Gilgel Gibe sub-basin based on balancing the supply and demand;
3. To predict future water demand of the sub-basin;

1.4 Research questions

The specific research question of the study formulated as follows:

1. How much current surface water potential is available in the upper Gilgel Gibe sub-basin?
2. What is the current sectoral water demand looks like in the upper Gilgel Gibe sub-basin?
3. What will be the future trend of water demand in the sub basin for the selected demand sites?

1.5 Significance of the study

The study was providing clear awareness for governmental and non-governmental bodies working on the area of water resources management, to overcome the complaint raised from the users related to water demand and allocations and also used as an input guide for water resources professionals to further investigation.

1.6 Scope of the study

The scope this study was focused on upper Gilgel Gibe sub-basin located in Oromiya regional state; south-west Ethiopia, where the overall available surface water in quantity manner and allocation of future water demand were the objective. The allocation of the surface water over the most dominant users: agricultural water use, domestic water uses, livestock and environment needed in the sub-basin.

1.7 Structure of the thesis

This thesis is structured into five chapters. Chapter one provides a general overview of the subject matter to be studied, justification, problem of the statements, general and specific objective and how the objectives can be achieved through research questions, significant of the study and scope of the study as well as thesis structure. chapter two discusses surface water resources and demand assessment, Water resource management Models with model selection and process. Chapter three provides Methods and Materials: This chapter gives a brief description of the study area, methods of data collection and analysis, software and materials used in the study, input data preparation for the WEAP model, model calibration parameters and scenario creation for future water prediction. The fourth chapter presents model output results and discussions. The overall thesis output Conclusions and recommendations are included in chapter five.

2. LITERATURE REVIEW

2.1 Surface water resources and demand assessment

Water is an essential ingredient for human security and sustainable development. From growing food and supporting economic growth to ensuring disease is kept at bay, water is a fundamental and irreplaceable resource in all societies. Given its centrality to human life, it is not surprising that water management is complex and that water-related interests are frequently contested (Monzonís *et al*. 2015)

A healthy water management system has always been the vital for sustainable life. The emergence of the ancient civilizations on the banks of great rivers indicates the importance of water as a resource for agricultural, industrial, transportation and domestic needs including social, recreational and aesthetic pleasures. The demand for water resources of sufficient quantity and quality for human consumption, sanitation, agriculture, and industrial uses will continue to intensify as the population increases and global urbanization, industrialization, and commercial development accelerate (Paul and Elango, 2018)

Surface water mostly formed from rainfall and is a mixture of surface run-off, ground water and base flow. It includes larges rivers, ponds and lakes, and the small upland streams which may originate from springs and boreholes. This natural resource plays an essential role in sustaining humankind and other forms of life that includes for public use, industrial, navigation and agricultural supply purposes. Therefore, understanding surface water resources potential and use is a key aspect of water resource assessment, evaluation and development (Boulay *et al*. 2017)

A world-wide water crisis doesn't necessarily mean an overall water shortage compared to the water demand but the problems arise from an uneven regional distribution of water resources. Especially the developing countries have no or only insufficient financial, institutional, personal and technical resources, necessary to build up a functional water supply and demand (Kiniouara *et al*., 2017)

Most countries in the world will experience water scarcity issues by 2025. This is a significant global issue as it affects the water resources as well as the availability of clean drinking water for the population. The ever-increasing population and economic growth put much pressure on the hydrologic cycle and water resources. The water consumption rate, urbanization, and rising living standards have a strong correlation, and these factors are putting more stress on the available water resources (Amin *et al*., 2018). These stresses lead to a decrease in the per capital availability of water in cities. Population growth, economic activities, and the impacts of climate change give rise to the scarcity of water, a condition in which the water demand grows beyond the available water supply because of its physical unavailability and an insufficient water management structure (Berredjem and Hani, 2017).

The challenge is how to improve the management of water resources for present and future generations. This challenge was reduced through the application of Water resources planning and management strategic plan that requires the deep understanding of the special value of water for human life, interaction of human beings and nature, and the social significance of water resources for national economic development. Water resources planning and management tries to meet the water requirements of all the water users (Safavi *et al*., 2015). Since, Growth and economic change has put significant pressure on the existing water resources. The finite water supply is under pressure from an expanding array of uses that include recreation, in-stream flows, wildlife habitat, environmental mitigation, wetlands restoration, and a variety of other socially desired alternatives.

As the water requirement for food production and other human needs grows, quantification of environmental flow requirements (EFRs) is necessary because the number of environmental flows and water science programs continues to grow across the globe, it is critically necessary, to better balance water availability in support of human and ecological needs and to recognize the environment as a genuine user of water. In water-stressed areas, this acknowledgement has resulted in resistance between water users in the public and private sectors. An opportunity exists for practitioners to be on the forefront of the science determining best practices for supporting environmental water regimes (Kennen *et al*., 2018).

A Decision Support System allows decision-makers to combine personal judgment with computer output, in a user- machine interface, to produce meaningful information for support in a decision making process. Such systems are capable of assisting in solution of all problems (structured, semi structured, and unstructured) using all information available on request. They use quantitative models and database elements for problem solving. They are an integral part of the decision maker's approach to problem identification and solution. A DSS must help decision makers at the upper levels, must be flexible and respond to questions quickly, must provide for "what if" scenarios and must consider the specific requirements of the decision makers. Additional important characteristics are accessibility, flexibility, facilitation, learning, interaction and ease of use (Jeuland and Whittington, 2014). The factors that determine the development of water potential in a given geographic area are: the availability of water for residential, commercial, and industrial purposes are a primary indication of prospective growth. Therefore, Governmental bodies at the regional, state and federal levels often need to identify water supply availability to identify growth potential (Wallace, 2001).

2.2 Water Resources Management Models for River Basin Simulation

Water resource management Models are increasingly becoming indispensable tools to assign ex ante probabilities to possible future states of the world in order to identify optimal or near-optimal solutions for planning, design and management of hydrologically related infrastructure (Jeuland and Whittington, 2014).

A model is an imitation of reality that stresses those aspects that are assumed important and omits all properties considered to be unnecessary. A model is a systems methodology approach and helps to define and evaluate numerous alternatives that represent various possible compromises among the conflicting groups, values and management objectives and trade-offs (Ashofteh *et al*., 2014). If assessing water demand in a given basin is essential as discussed but; what available models are there which are capable of modeling water demand and which is best suited to model water demand in the study area (upper Gilgel Gibe sub-basin) is a crucial question any one can ask. There are many models are developed throughout the world with objective of water resource managements and allocation of water to demands in efficient mechanisms. These include WEAP, WARGI-SIM, MODSIM, RIBASIM, MIKEBASIN, CaWAT Model and etc.

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

Water Resources Graphical Interface – Simulation Tool (WARGI-SIM) is the simulation-only module developed by the Water Research Group (WRG) at the Department of Civil and Environmental Engineering (formerly Department of land Engineering) at the University of Cagliari (Italy), within the WARGI user-friendly tool. WARGI-SIM does not require the input of specific operating rules, but more intuitive preferences and priorities. Specifically, the operator can define preferences for each combination of possible transfer between the resource and the demand nodes. 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 (Sulisa *et al*., 2018)

2.2.2 Modular Simulation Model (MODSIM)

Modular Simulation Model (MODSIM) is a generic river basin management decision support system, originally conceived in 1978 at Colorado State University, making it the longest continuously maintained river basin management software package currently available. MODSIM represents a river basin as a network of links and nodes. Unregulated inflows, evaporation and channel losses, reservoir storage rights and exchanges, stream–aquifer modeling components, reservoir operating targets, and consumptive and instream flow demands are considered in MODSIM (Vaghefi *et al*., 2017).

2.2.3 River Basin Simulation Model (RIBASIM)

River Basin Simulation Model (RIBASIM) is a generic model package for simulating the behavior of river basins under various hydrological conditions developed by DELTARES, former DELFT Institute, Delft, The 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 (Monzonís *et al*., 2016).

2.2.4 MIKE BASIN

The Mike Basin model developed by the Danish Hydraulic Institute, has been widely used by water agencies to simulate basin-scale water resources management for multi-purpose, multiple-reservoir systems by specifying associated reservoir operation rule curves and guiding water extraction from several reservoirs in order of priority (Doulgeris *et al*., 2015). Despite their rich modules and user friendly interfaces, the simplified reservoir operation rules and water allocation strategies of these models operated within a “what-if-then” scenario-based framework generally offer poor flexibility if changing hydro-climatic and anthropogenic factors are considered (Hong *et al*., 2016).

2.2.5 The Catchment Water Allocation Tool (CaWAT)

The Catchment Water Allocation Tool (CaWAT) model is a decision support tool to aid water allocations for agriculture and domestic uses in small watersheds of rural areas. It provides options for agricultural planning, irrigation and aquaculture development representing a range of demands. It also incorporates rainfall runoff simulation, storages and diversions infrastructure development representing supply side. It then allows users to intervene the water balance processes through storing, diverting, and allocating water among upstream and downstream units (Cai *et al*. 2014)

2.2.6 Water Evaluation and Planning (WEAP) model

Water Evaluation and Planning (WEAP) model is deterministic, semi-theoretical, semi-distributed and continuous time modeling platform that can provide integrated assessment of climate, hydrology, land use, irrigation facilities, water allocation and water management priorities of the watershed. The WEAP model uses a standard linear programming model to solve water allocation problems at any time step and its target function is to maximize the percentage of supplying demand centers' needs, with regard to supply and demand priority, mass balance and other constraints. All constraints are defined intermittently for each step of time, with regard to the priority of supply and demand (Safavi *et al*, 2015). The WEAP model calculates the mass balance equilibrium of water for each node and branch at either daily or monthly time steps. Using the time series of the climate, the WEAP model calculates the hydrological cycle components by simulating the rainfall–runoff process at the surface of the catchment area. In this study, the soil moisture method of WEAP model was used for modeling hydrological reaction of basins and inter-basins (Ahmadaali *et al*., 2018)

The WEAP model includes two separate systems (Mersha *et al*., 2018). Simulation of natural hydrological processes (e.g., evapotranspiration, runoff and infiltration) to enable assessment of the availability of water within a watershed and Simulation of anthropogenic activities superimposed on the natural system to influence water resources and their allocation (i.e., consumptive and non-consumptive water demands) to enable evaluation of the impact of human water use (Khalil *et al*,. 2018).

The 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 (Kiniouara, *et al*., 2017)

The WEAP model operates on the basic principle of water balance and on a monthly and annual basis. It is designed to show an integrated aspect of a water system (both in its current state and in predicted future scenarios) and has the ability to perform simulations even with limited data (George *et al*. 2018). Flexibility of the tool and its adaptation to the requirements of different data and environment allows the modelling of a basin like Upper Gilgel Gibe Sub- basin, where the data are rare and the conflicts between the various water users are very current (Berredjem and Hani, 2017). The WEAP model provides a set of objects and procedures that can resolve problems faced by water managers using a scenario-based approach, which works on natural watersheds, reservoirs, streams, and canals (Amin *et al*., 2018).

The WEAP is a useful model for the basin level evaluation of the water supply and demand. The loss of water can be comprehensively handled using a simulation model (WEAP), which simulates the current water situation, evaluates the water quality, and manages the water supply and demand issues. Recently, WEAP received a great deal of attention where it is being applied at national and international levels; Capable to build and compare scenarios, Priority–based water allocation system, enable stakeholders to get involved in management procedures through interactive data-driven model. This will increase public awareness and acceptance and enable to assess and evaluate the economic and environmental aspects of the basin, watershed and catchment at different level (Shumet and Mengistu, 2016).

2.3 Model Selection

2.3.1 Problems to be Considered

Hydrological practice would be improved if models were objectively chosen on the basis of making the best use of the information available and following some systematic procedure of selection and verification (Longo *et al*., 2016). The choice of the best model depends to a large extent on the problem. Generally speaking, items that should be considered in the selection process include: The nature of the physical processes involved, The use to be made of the model, The quality of the data available; and The decisions that rest on the outcome of the model's use (Longo *et al*. 2016). Several models may be capable of describing the same process, and to a great extent, selection of the one to be used depends on a comparison of sampled data and model output.

2.3.2 Criteria of Selection

So far the problems to be considered in choosing a suitable model in general have been discussed. In most situations, however, absolute objective methods of choosing the best model for a particular problem have not yet been developed, so this choice remains a part of the art of hydrological modeling. (Ashofteh *et al*., 2014) suggests four criteria that can be used to choose between alternative models, those are; Accuracy of prediction, Simplicity of the model, Consistency of parameter estimate; and Sensitivity of results to change in parameter values.

Accuracy of prediction of system output is clearly very crucial; it is preferred when all other factors being equal, the model with minimum error of variance would be superior. Simplicity refers to the number of parameters that must be estimated and the ease with which the model can be clarified to clients or public bodies. When all other factors are being equal, one should choose the simplest model. Reliability of parameter estimation is an important consideration in developing hydrological models using parameters estimated by optimization techniques. If the optimum values of the parameters are very sensitive to the particular period of the record used, or if they vary widely between similar catchments, the model will probably be unreliable. Finally, models should not be extremely sensitive to input variables that are difficult to measure. Generally, the model to be used in this study is passed through figure (2.1) evaluation process.

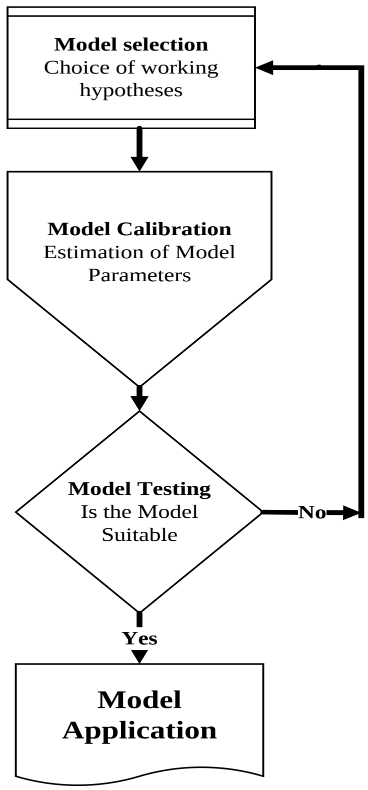


Figure 2.1: Phases of model selection and evaluation (*by Visio 2016*)

2.4 Demand priorities and supply preferences

WEAP uses a linear programming technique to solve the water allocation model; priorities (1 to 99) will have used to classify demands. 1 represents highest priority demand node and 99 represents the lowest priority demand node. A Demand-Priority- and Preference driven Approach used presents a robust solution algorithm to solve the water allocation problem. A standard linear program is used to solve the water allocation problem whose objective is to maximize satisfaction of demand, subject to supply priorities, demand site preferences, mass balances and other constraints (Agarwal *et al*., 2018).

Two user-defined priority systems are used to determine allocations from supplies to demand sites: Demand Priorities and Supply Preferences. Demand Priority determines the demand site's priority for supply. Demand sites with higher priorities are processed first by the WEAP Allocation Algorithm. Reservoir priorities default to 99, meaning that they will fill only if water remains after satisfying all other demands (Amin *et al*., 2018)

Using the demand priorities and supply preferences, WEAP determines the allocation order to follow when allocating the water. The allocation order represents the actual calculation order used by WEAP for allocating water to demand sectors (Agarwal *et al*., 2018).

3. MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Location

The study area, the upper Gilgel Gibe sub-basin, is located in Oromiya regional state, south west Ethiopia at a distance of about 335 km from Addis Ababa. In geographical coordinate system, it lies between 7° 20'0'' and 8° 8'0'' latitude N and 36° 20'0'' and 37° 40'0'' longitude E (Figure 3.1). The sub-basin has an area of about 3970 km².

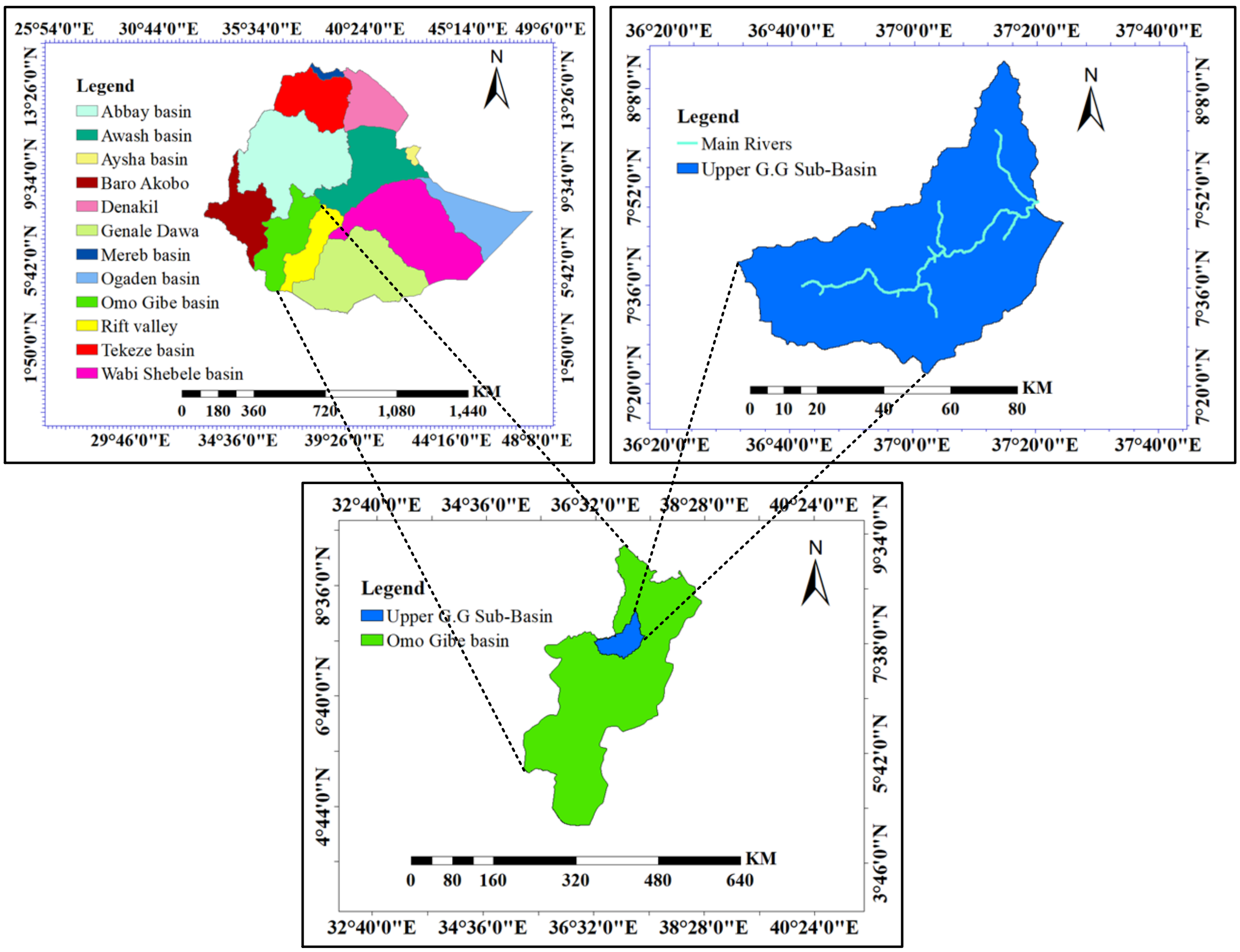


Figure 3.1: Location of the study area

3.1.2 Topography

The catchment is generally characterized by rouged topography with upper plateaus that are cut by deep V-shaped valleys in the flanks and flat river terraces around the upper Gilgel Ghibe River in the center of the catchment with an average elevation of about 1700 m above mean sea level (Takala *et al*., 2016).

3.1.3 Climate

Ethiopia has a two-season tropical climate. The dry winter season occurs between October and April and the rainy season (during the summer months) occurs between May and September. In the study area, the average annual air temperature is 19.2 °C. Figure 3.2 shows monthly mean values of selected meteorological and climatic parameters, recorded at the Jimma station.

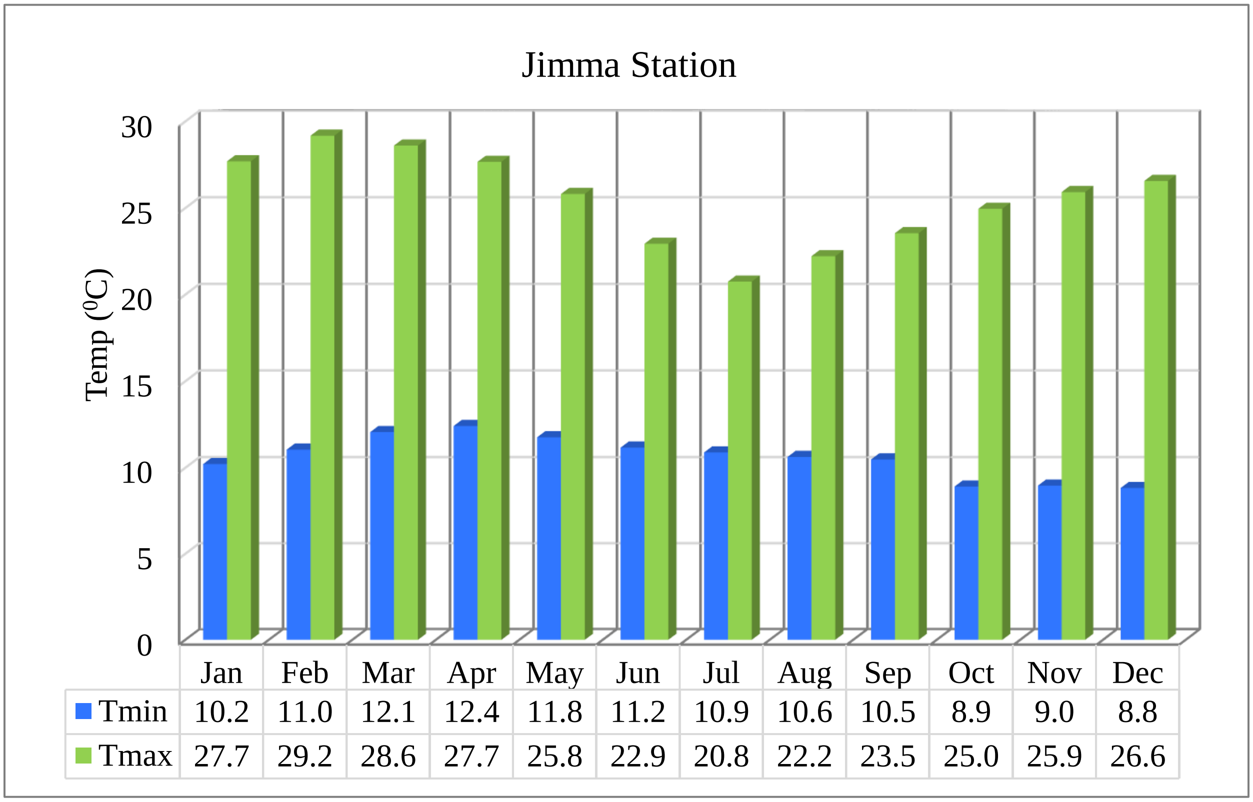
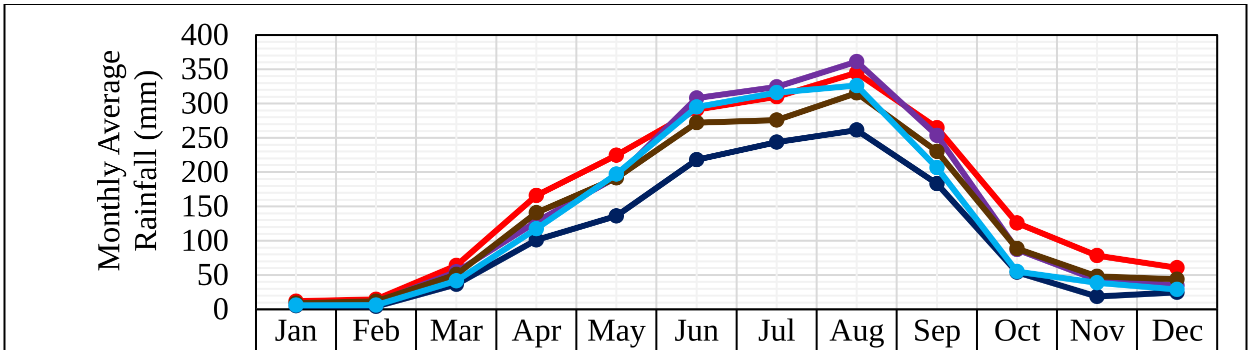


Figure 3.2: Monthly mean value of max & min temperatures of Jimma Station

3.1.4 Rain fall

As shown Figure 3.3, the average annual rainfall of the Gilgel Gibe sub-catchments is 1643 mm. the maximum is about 1956 mm in the Jimma sub-catchment. The minimum rain fall is observed in Dedo sub-catchment. It appears that 70% of the total amount of annual rainfall occurs between May to September, 22% from October to April.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Jimma	12	15	64	166	225	291	310	345	265	126	78	61
Dedo	5	4	36	101	136	218	244	261	183	54	18	25
Kersa	8	10	54	128	192	308	324	361	254	87	43	34
Asendabo	9	12	51	141	191	272	276	315	230	88	48	44
Tiro Afata	6	6	41	118	197	295	316	326	206	55	39	29

Figure 3.3: Average Monthly Rainfall Data (mm/d) (1990-2018)

3.1.5 Land use/ Land cover

As shown Figure 3.4, the sub-basin is largely comprised of cultivated land and the main land use type in the study area is agricultural cropping mainly maize, Soy bean, Potato, barley, sorghum, and with perennial crops like coffee and chat. In addition to this, farmers keep certain plots as grazing land for their livestock. Generally, mixed farming system is common in the study area.

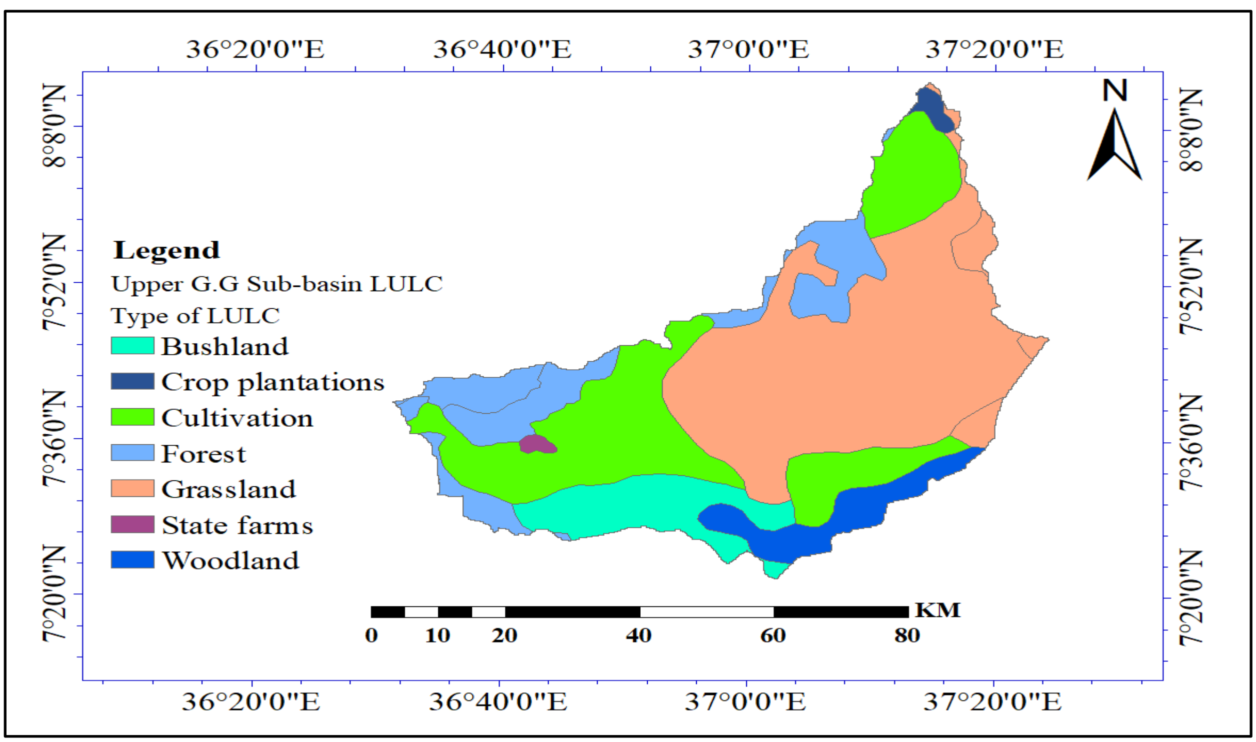


Figure 3.4: Land use land cover of the study area

3.1.6 Geology

The geology of the catchment is related to the uplifting of the East African rift valley in the Upper Eocene. The study area consists of volcanic rocks of the Eocene and Paleocene, Rhyolites, Trachytes, Rhyolitic and Trachytic Tuffs, Ignimbrites agglomerates and Basalts. However, the spatial occurrence of the different geological materials is very complex, heterogeneous and not known in detail (Takala *et al.*, 2016). The geological class of the basin is shown in the Figure 3.5.

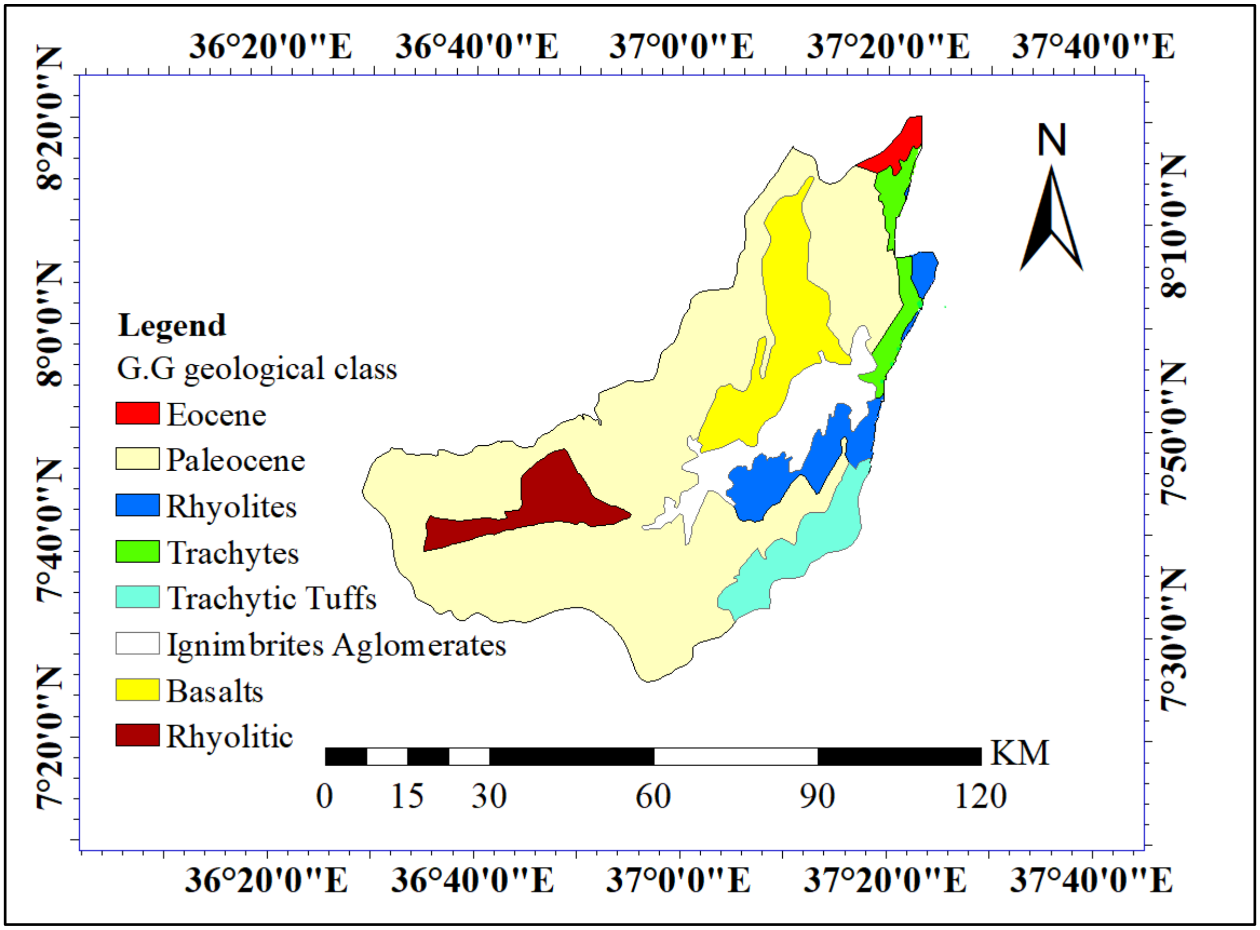


Figure 3.5: Geology of the study area

3.1.7 Soil

The major soil types in the study area were chronic vertisols, dystric fluxisols, dystric Nitisols, eutric Nitisols, orthic Acrisols with the Eutric Fluvisols domination (UNESCO, 1974). The majority of the soils in the sub-basin are deep to very deep, red and reddish brown clay looms over clays. These soils are well drained. They are wide spread over the whole of the northern basin. Soils developed from volcanic parent materials, often with an ash or pumice layer tend to occur on high ground with in the sub-basin. They are moderately deep to deep, well drained, dark brown to dark reddish brown sandy clay loams to clays. Figure 3.6 shows the soil class in the sub-basin.

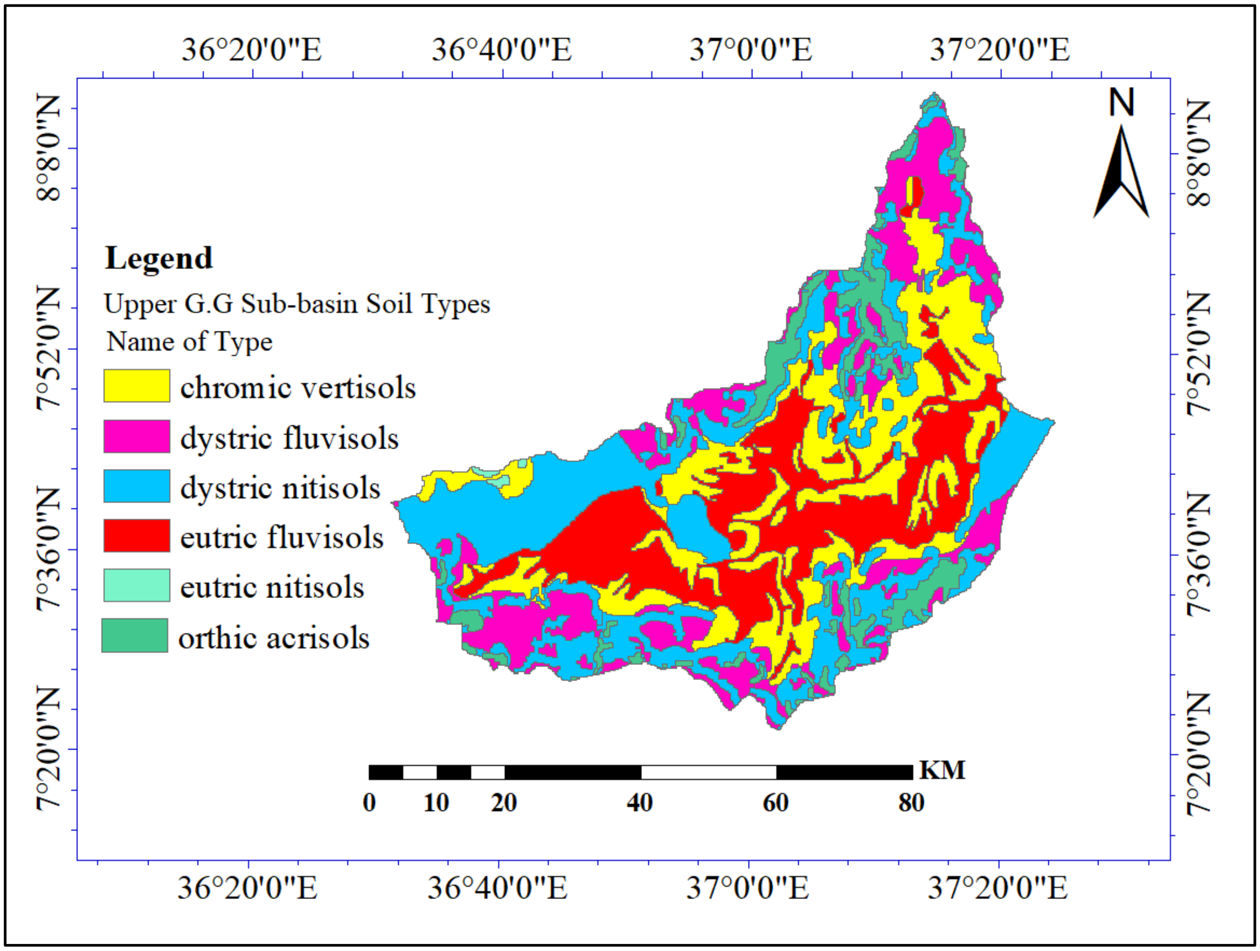


Figure 3.6: The major soil types in Gilgel Gibe sub-basin.

3.1.8 Geomorphology

The understanding of geomorphology is particularly important in a study such as this one, whereby one is trying to establish a relationship between landforms and soils, given that the underlying rock and the macroclimate are the same for the whole landscape. It is indeed through geomorphology that one can explain why different soils can form from the same parent rock. It is of prime importance to understand which soil processes take place on the erosional, stable and depositional positions of the landscape because it is on these positions that different soils can form.

3.2 Data collection and analysis

The necessary data for this study was obtained by visiting responsible government institutions in Ethiopia, in the area of watershed.

Table 3.1: Data collection and sources

Data requirements		Sources
Spatial data	DEM, Soil data and Land cover	Ethiopian Ministry of Water, Irrigation and Electricity, department of GIS and Remote Sensing.
Meteorological	Temperature, Precipitation, solar radiation, relative humidity	Ethiopia National Metrological Agency
Hydrological data	Stream flow	Ethiopian Ministry of Water, Irrigation and Electricity
Water demand data	Population data	Ethiopian Statically Agency and Jimma Zone livestock & fishery development office
	Water use rate	Ethiopian Ministry of Water, Irrigation and Electricity
	Irrigation data	Ethiopian Ministry of Water, Irrigation and Electricity
	The future development plans in industries and other water use sectors	Ethiopian Ministry of Water, Irrigation and Electricity.

3.2.1 Spatial data

3.2.1.1 DEM

Digital Elevation Model (DEM) well define the topography of the area by describing the elevation of any point at a given location and specific spatial resolution as a digital file. It is one of the essential spatial inputs for GIS to delineate the watershed in to a number of sub watersheds or sub basins based on elevation. Drainage pattern, slope, channel width and stream length with in the watershed were processed using DEM. The raw DEM was obtained from Ethiopian Ministry of Water, Irrigation and Electricity at 30x30m resolution and projected using Arc GIS 10.4.1 software package.

3.3 Hydrological data

3.3.1 Filling in missing stream flow data

A number of stations in the basin have incomplete records. Such gaps in the record were filled by developing correlations between the station with missing data and any of the adjacent stations with the same hydrological features and common data periods. Recorded stream flows were less than 10%. Therefore, the arithmetic mean value of the (1990-2018) was used to fill the missed records for all gauge stations.

3.4 Meteorological data

3.4.1 Filling in missing rainfall data

Failure of any rain gauge or absence of observer from a station causes short break in the record of rainfall at the station. These gaps should be filled before using the rainfall data for analysis. The surrounding stations located within the sub-basin help to fill the missing data on the assumption of hydro meteorological similarity of the group of stations. All stations' missing data in the sub-basin were less than 10%. Therefore, the station average method was used for filling missing data in this study. This method is accurate when the total annual rainfall at any of the 'n' region gauges differs from the annual rainfall at the point of interest by less than 10% (Garg, 2005). Equation 3.1 was used to filling missing data (station average method formula).

$$P_M = \frac{P_1 + P_2 + P_3 \ldots + P_n}{n} \tag{3.1}$$

Where, N_1, N_2, N_3 and N_n represent the average annual rain fall at station 1, 2, 3 and n respectively; and P_1, P_2, P_3 and P_n represent their respective precipitation data of the day for which data is missing at station M.

3.4.2 Homogeneity checking of selected rainfall station

Homogeneity analysis is used to identify a change in the statistical properties of the time series data which is caused by either natural or man-made factors. These include alterations to land use and relocation of the observation station. The homogeneity test of time serious may be classified into two groups as "absolute method" and "relative method". In the first method, the test applies to each station separately. In the second method, the neighboring (reference) stations are also used in testing (Tank *et al*., 2003).

According to Benítez (1998), the recommended method to apply homogeneity has been tested with respect to neighboring stations that is supposedly homogeneous. The non-dimensionalizing of the month 's value is carried out as: -

$$P_i = \frac{\overline{P}_i}{\overline{P}} * 100 \qquad 3.2$$

Pi = Non dimensional Value of precipitation for the month i, Pi = all years (1990-2018) averaged monthly precipitation for the station i, P = All year's (1990-2018) average yearly precipitation of the station. The patterns of the Pi (non-dimensional value) for all stations were shown in the Figure 3.7.

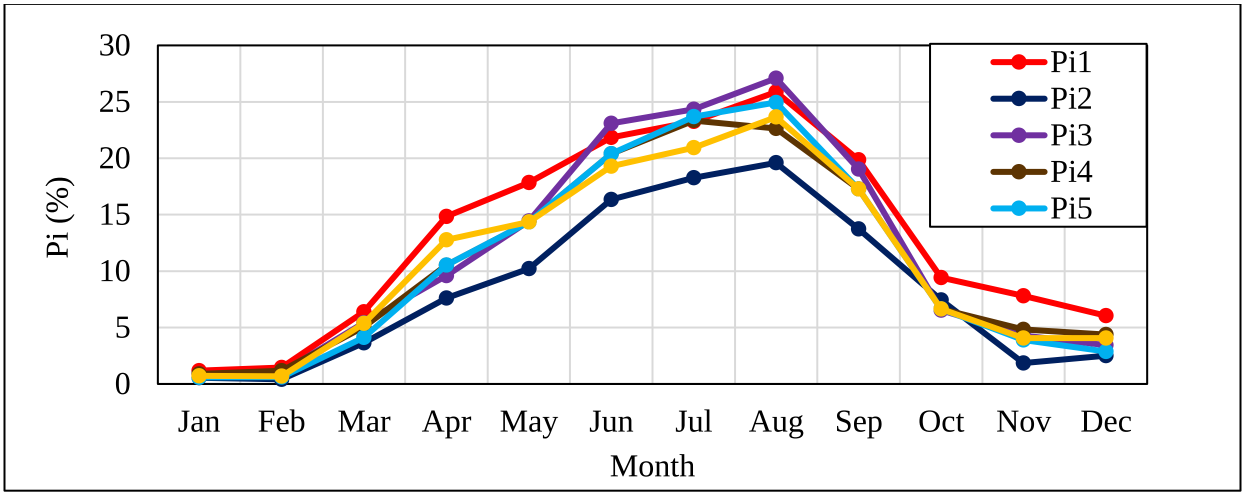


Figure 3.7: Homogeneity Checking of Rain fall for All station by Pi

3.4.3 Consistency checking and of rainfall stations adjustment

The double mass analysis is a commonly used analysis approach for investigating the behaviour of records made of hydrological or meteorological data at a number of locations. It is used to ensure that any trends detected are due to meteorological causes and not changes in gauge location, in exposure or observational methods, as changes due to non-meteorological would be adjusted by the coefficients of the mass curve. Graph of the cumulative data of one variable versus the cumulative data of a related variable is a straight line as long as the relation between the variables is a fixed ratio (Jasim and Awchi, 2017).

For this study, consistency checking of the rain fall station, the double mass curve technique was used to adjust precipitation records to take account of non-representative factors such as change in location or exposure of rain gauge. The accumulated totals of the gauge in question are compared with the corresponding totals for a representative group of nearby gauges. As the Figure 3.8 double mass curves series shows, was consistent. See **Appendix I** for the rest stations in the sub-basin.

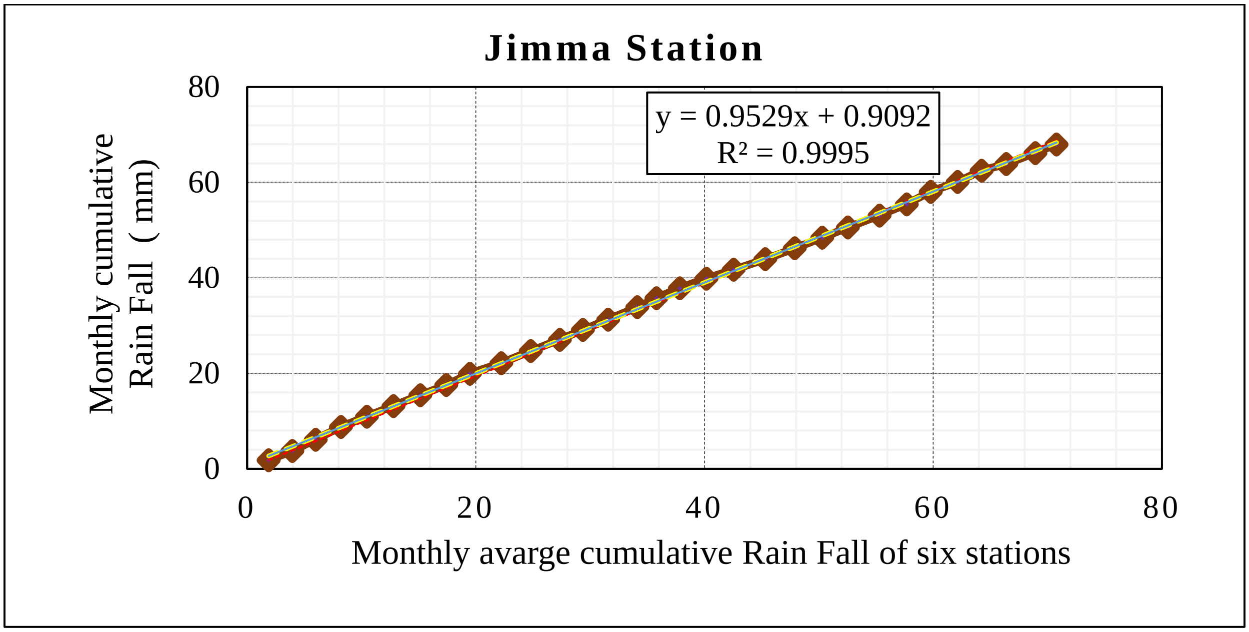


Figure 3.8: The Double Mass Curve for Jimma Station

3.5 Materials

3.5.1 Arc VIEW GIS (software)

For any kind of hydrologic modelling involves delineating streams and river basin, and getting some basic river basin properties such as area, slope, flow length, stream network density, etc. Through the availability of digital elevation models (DEM) and GIS tools, watershed properties can be extracted by using computerized procedures. The processing of DEM to delineate watersheds is referred to as terrain processing. In this study, for mapping and to geo-reference the collected information and generate spatial database, ArcGIS 10.4.1 was used.

3.5.2 Microsoft Excel 2016

Microsoft Excel is a general-purpose electronic spreadsheet used to organize, calculate, and analyze data. This software is part of the Microsoft Office suite and is compatible with other applications in the Office suite. Excel has the same basic features as all spreadsheet applications, which use a collection of cells arranged into rows and columns to organize and manipulate data. They can also display data as charts, histograms and line graphs. In this study, it is used to import and export necessary data to and from WEAP model.

3.5.3 CROPWAT model

The crop water requirement (CWR) is defined by the amount of water required to compensate the evapotranspiration loss (ET) from the cropped field. The CWR depends on the local climate and the crops growing in the fields. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rain fed conditions or deficit irrigation (Doulgeris *et al*. 2015)

3.5.3.1 Input data for CROPWAT model

For the estimation crop water requirements (CWR) the model requires:

- ❖ Rainfall data (daily/decade/monthly data); monthly rainfall is divided into a number of rainstorm each month;
- ❖ A Cropping Pattern consisting of the planting date, crop coefficient data files (including Kc values, stage days, root depth, depletion fraction) and the area planted (0-100% of the total area); a set of typical crop coefficient data files are provided in the program.

3.5.3.2 CROPWAT model output

CROPWAT is automatically calculates the results as tables or plotted in graphs. The time step of the results can be any convenient time step: daily, weekly, decade or monthly. Jimma station CROPWAT model output parameters used for WEAP model is shown in Table 3.2. For the rest stations see **Appendix II** (a), (b), (c), and (d).

Table 3.2: Jimma station CROPWAT8 result used for WEAP model

Month	Tmin (°C)	Tmax (°C)	RH (%)	Wind (km/d)	Sun (hr)	S. Rad MJ/m²/d	ETo mm/d	Eff RF (mm)	Kc (Coeff)
Jan	10.2	27.7	58	1	8.1	19.7	3.2	0.3	1
Feb	11.1	29.2	54	1	8.6	21.7	3.6	0.4	0.7
Mar	12.1	28.6	65	1	8.5	22.5	4	1.7	0.8
Apr	12.4	27.7	75	1	8.5	22.6	4.1	4.4	0
May	11.8	25.8	81	1	8.3	21.6	3.9	6	0
Jun	11.2	22.9	89	1	6.9	19.1	3.4	7.8	0
Jul	10.9	20.8	91	1	5.7	17.5	3	8.3	0
Aug	10.6	22.2	90	1	6.8	19.6	3.4	9.2	0
Sep	10.5	23.6	88	1	8.4	22.2	3.8	7.1	0
Oct	8.9	25	78	1	9.1	22.6	3.8	3.4	0
Nov	9	25.9	70	1	8.7	20.9	3.4	2.1	0
Dec	8.8	26.6	65	1	8.3	19.6	3.1	1.6	0
Ave	10.6	25.5	75	1	8	20.8	3.6	4.4	0.2

3.6 WEAP21 model background

3.6.1 Overview

WEAP program structure consists of five main views: Schematic, Data, Notes, Results, and Scenario Explorer. WEAP21 solve the water allocation problems by using a linear programming technique. Linear programming technique (LPT) is mathematical modeling techniques useful for the allocation of the scarce or limited resource on the basis of a given criteria of optimality. Figure 3.9 shows WEAP screen views, menu bar schematic view of the study sub-basin

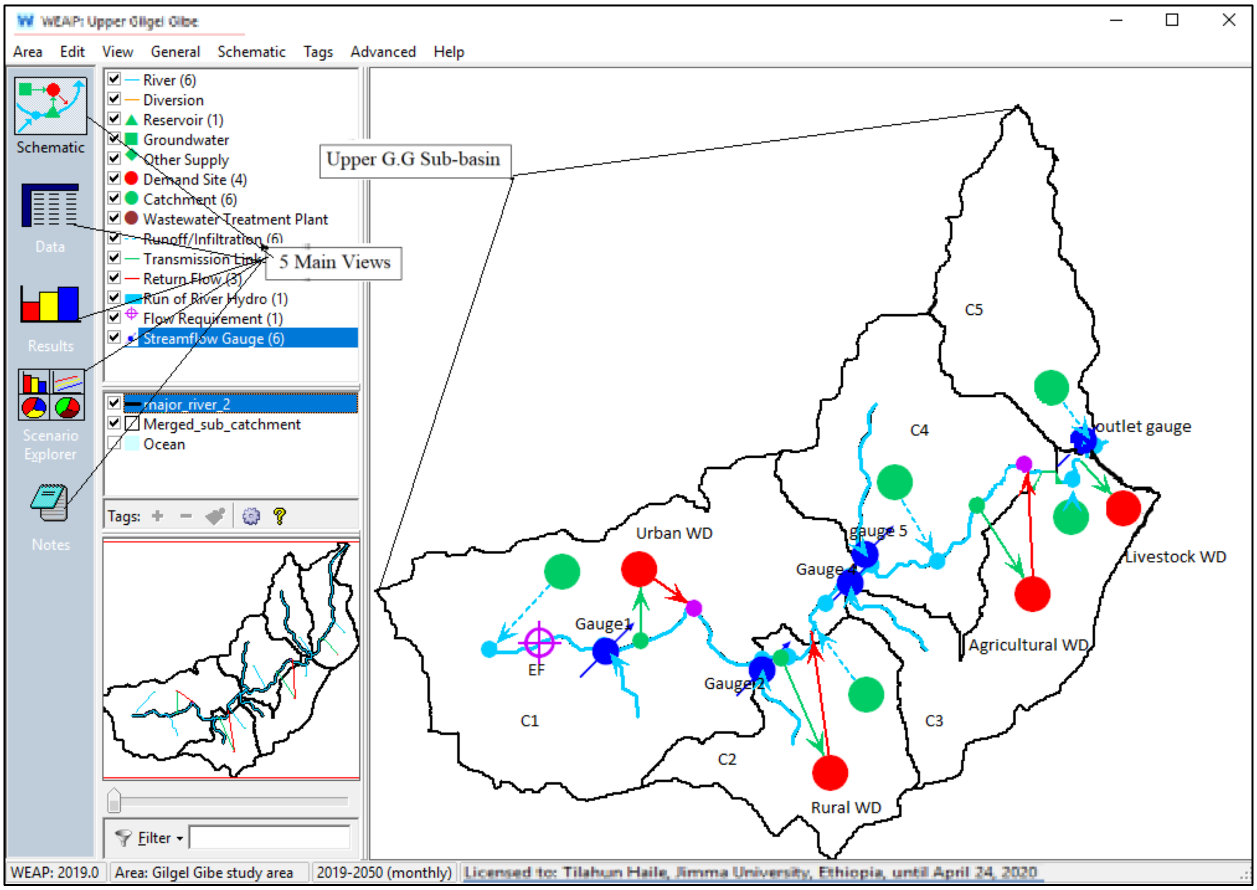


Figure 3.9: WEAP screen views, menu bar schematic view in the study sub-basin

3.7 Input Data Preparation for WEAP Model

3.7.1 Population Projection

Population projection treaties with computations of future projection size and characteristics based on assumptions about future developments in fertility, mortality and migration. Meanwhile, it is not possible to predict the future developments in fertility, mortality and migration, it is also difficult to predict the future size and characteristics of a population accurately. Projections are simply intelligent exercise as to what would happen to current population under specified assumptions of fertility, mortality and migration in the future years. Town Planning requires a fair idea of future for which planning needs to be done. For this purpose, planners use various methods and tools for "predicting" the future which generally involves population data and population projection. Generally, Projections are an extrapolation of historical data (population versus time) into the future (Khalil *et al*., 2018).

The accuracy of population projections is generally considered directly proportional to the size of the existing population and the historical rate of growth, and inversely proportional to the length of the time projection. Therefore, population prediction is a very important aspect in environmental engineering that helps in determination of certain factors that helps in the future planning and for accurate determination of the certain requirement in the future (Khalil *et al*., 2018). The common methods by which the Population Projection will be done are: Geometric increase method, Incremental increase method, Decrease rate method, Simple graphical method, Master plan curve method, Logistic curve method and Ration and correlation method.

Geometric increase method is based on the assumption that the percentage increase in population remains constant and it is applicable for growing towns and rural having vast scope of expansion. Since study are categorized under growing towns and rural having vast scope of expansion, it was used for this study area. The equation for the Geometric growth method in (3.3).

$$P = P_o x(1 + P)^{(T-T_o)} \qquad 3.3$$

Where; P= Projected population in number, P_o=Baseline population in number**,** T= Projected year, T_o=Baseline year

The Expression Builder is a "Growth Form" function built into the WEAP model that helps project the population of the reference period (2019-2050). It is a general purpose tool to construct WEAP expressions by dragging and dropping the functions and WEAP branches into an editing box (SEI, 2015). The input data in Growth Form field within WEAP for projecting the population for reference period are: Year of last census, Population at Current and Estimated growth rates.

In this study the base line (2019) population projection was done 3.5% for Rural and 6.2 for Urban population and for reference Scenario (2020-2050) increasing in population growth which is 2.9% for Urban and 1.2% for Rural and used linear population increase based on Central statistics agency of Ethiopia report (2007). Table 3.4 illustrates the projected rural and urban population for the year 2019.

Table 3.3: Population Growth Rate in Ethiopia

Year	Growth rates (%)	
	Rural	Urban
1990-2000	3.5	6.2
2000-2010	2.8	5.5
2010-2020	2.2	6.2
2020-2030	1.6	5.2
2030-2040	1.0	4.2
2040-2050	0.6	3.5

Table 3.4: Population projection for the year 2019

S.No.	Study area Districts and Town	Population at 2017		Projected Population for 2019	
		Rural	Urban	Rural (3.5%)	Urban (6.2%)
1	Tiro Afata	253,710	20,544	263,960	23,170
	Kersa	296,609	20,735	308,592	23,386
	Omo Nada	352,507	26,560	366,749	29,955
	Dedo	411,964	16,135	428,608	18,198
	Seka Chekorsa	308,125	18,192	320,574	20,518
	Sub-total	1,622,915	102,166	1,688,483	115,227
2	Jimma town	-	195,225	-	220,640
Total		1,622,915	297,391	1,688,483	335,867

3.7.2 Livestock Population Projection

Valid sources of information and appropriate methods of forecasting data from the sources are crucial to both public and private sectors. Reliable information and estimates are necessary for organizations in public sector to develop, implement and monitor policies. Therefore, use of application of mathematical theories, methods and models can be utilized to assess the substantial consideration circumstances and produce effective and efficient solutions. This study was applying logistics growth technique for forecasting each livestock species: donkey, horse, cattle, sheep and goat. Logistic forecasting is used to estimate future values based on a time series of historical data.

The new values are predicted using an approximate fit of a logistic function by linear regression (Michale *et al*,.2017). A logistic function takes the general form of equation (3.4):

$$y = A + \frac{B - A}{1 + e^{(-aX + b)}} \quad \textbf{3.4}$$

Where: The Y terms corresponds to the variable to be forecasted and the X term is years. A, B, a, b are constants and e is the base of the natural logarithm (2.718). A logistic forecast is most appropriate when a variable is expected to show an "S "shaped curve over time. This makes it useful for forecasting shares, populations and other variables that are expected to grow slowly at first, then rapidly and finally more slowly, approaching some final value (the "B" term in the equation (3.4). For this study, the projected livestock population was 2617139 in the year 2019. Table 3.5 shows collected data of livestock population in the year 2016. See more in **Appendix IV** (a) and (b).

Table 3.5: Livestock Population data in the year 2016

District	2016					
	Cattle	Goat	Horse	Donkey	sheep	Mule
Tiro Afata	281,861	38,868	3128	11,136	62,062	8,505
Kersa	304,830	27,081	7,240	7,716	62,760	10,637
Omo Nada	292,778	122,164	7,417	35,373	158,637	9,021
Dedo	424,674	404,515	36926	34,670	105,499	30,678
Seka Chekorsa	243,199	44,070	10,026	12,259	153,966	14,958
Sub total	1547342	636698	64737	101154	542924	73799
Total	2966654					

3.7.3 Sectoral water demand

Water demand is defined as the volume of water requested by users to satisfy their needs. In a simplified way it is often considered equal to water consumption. Sectoral information of data will be collected from different sources in order to evaluate and fully understand the current and future water demands in relation with the available supply of Gilgel Gibe sub-basin. But Ministry of Water, Irrigation and Energy guideline (2002) has put for the domestic water demand, commercial and institutional water demand, industrial water demand, livestock water demand categories and additional climatic factors which affect consumption variation in the specific river basin (Gilgel Gibe river basin) under their master plan study based on the practical situation and life style of the basin population.

- Domestic Water Demand

The domestic water demand is the demand for domestic house hold use; the water consumption per capita per day (lpcd). The per capita demand of the basin is generally based on the newly revised water demand standard of second Growth and Transformation Plan of Ethiopia (GTP II – which goes from 2015 - 2020). Based on the newly revised water demand standard of GTP II, it ranges from 40 – 100 lpcd depending on the population size for urban and 25 lpcd for rural up to the year 2020. For this study, the water demand is forecasted up to the year 2050 which is assumed 60 liters per capita per day for Urban and 25 l/c/day for Rural for this study.

- Commercial and Institutional Water Demand (CIWD)

In addition to those of household consumers, the water requirements of towns include the needs of such commercial and institutional consumers as public schools, clinics, hospitals, offices, shops, bars, restaurants, and hotels. CIWD is usually linked directly to population size. For small- and medium-sized towns, it was estimated at 5 per cent of the DWD. For larger towns, the CIWD estimate was 10 per cent of DWD. Those allowances were applied to all towns. 5% allowances were made for CIWD from rural communities. In this sub-basin no larger towns are exist. Therefore, 5% of DWD were considered for this study.

Commercial and Institutional Water Demand (CIWD) for Urban = 5% DWD = 0.05 x 0.06= 0.003m^3/c/d,
Commercial and Institutional Water Demand (CIWD) for Rural = 5% DWD = 0.05 x 0.025= 0.00125m^3/c/d,

- Industrial Water Demand (IWD)

Industrial water demand which is consumed by industries is not usually linked directly to population and currently the study area was not well developed. But for the purpose of planning, it is assumed to use 10% of domestic water demand for all towns in the sub-basin and rural communities.

Industrial Water Demand (IWD) for Urban = 10% DWD = 0.06 x 0.10 = 0.006 m^3/c/d,
Industrial Water Demand (IWD) for Rural = 10% DWD = 0.025 x 0.10 = 0.0025 m^3/c/d,

❖ Livestock Water Demand (LWD)

For this study in order to estimate livestock water demand, it is assumed an average of 1 Livestock Unit (LU) per person for the sub-basin. The average water demand for livestock is taken as 25 liters per LU per day.

Livestock Water Demand (LWD) = 1 x 25 l/day = 25 l/c/d = 0.025 m^3 /c/d,

The current (2019) livestock population in the study is 2617139 which was estimated with logistic curve method.

❖ System losses (SL)

In estimating water losses in the water supply system a percentage of 25% of the total of domestic, commercial, institutional and industrial demands is assumed in the basin.

System Losses (SL) for Urban = 25% (DWD + CIWD + IWD) = 0.25(0.06+0.003+0.0025) = 0.0164 m^3/c/d,

System Losses (SL) for rural = 25% (DWD + CIWD + IWD) = 0.25(0.025+0.00125+0.0025) = 0.0072 m^3/c/d,

❖ Average Daily Demand (ADD)

The average daily demand is taken to be the combined total of the domestic, commercial, institutional, industrial and livestock demands and the system losses. Average Daily Demand = Demands for Domestic + Commercial & Institutional + Industrial + Livestock + Losses

Average Daily Demand (ADD) for Urban =0.06+0.003+0.0025+0.025+0.0164=0.1069 m^3 /c/d,

Average Daily Demand (ADD) for Rural =0.025+0.00125+0.0025+0.025+0.0072=0.0826 m^3 /c/d,

❖ Maximum Daily Demand (MDD)

The daily water consumption in a town varies depending on time of day, the season and climatic conditions. Therefore, the Maximum Daily Demand (MDD) has been taken as 1.15 times the Maximum Daily Demand (MDD) for all towns in the basin. = 1.15 ADD.

Maximum Daily Demand (MDD) for Urban = 1.15 ADD=1.15x0.1069=0.1229 m^3 /c/d,

Maximum Daily Demand (MDD) for Rural = 1.15 ADD=1.15x0.0826 =0.095 m^3 /c/d,

❖ Annual Water Use Rate for Urban

Hence, the WEAP model needs annual water use rate as an input calculating maximum yearly water demand is very important.

Maximum Demand per person per year for Urban = MDD*365 = 0.1229 x 365 m^3=44.86 m^3/year**.**

Maximum Demand per person per year for Urban = MDD*365 = 0.095 x 365 m^3=34.68 m^3/year**.**

Therefore, take annual water use rate per person in the basin as 44.86 m^3/year and 34.68 m^3/year which is the input for WEAP model.

3.7.4 Agricultural water demand

Agricultural demand throughout the catchment was delineated according to irrigation districts. For each district, water demand was calculated according to irrigation requirements based on crop areas and climate. Irrigation requirements of crops was estimated using the Penman-Monteith approach based on climate and crop culture. See **Appendix III** for monthly average Crop water requirement.

The upper Gilgel Gibe sub-basin comprises total suitable surface irrigable land of 239,115 ha, 46,623 ha was studied potential land by Jimma zone Agriculture office (JZAOR, 2018). and among this potential study only 17,560 ha was developed. This study applied the WEAP tool based on the objective of allocating limited available water among competing crops during the critical production period in a manner that would maximize the economic returns to the producer with environmental consideration.

3.7.5 Environmental flow requirement

Environmental water requirements (EWR) for freshwater ecosystems are used as a proxy to represent ecosystem demand. It evaluates minimum water requirements as a fraction of the available flow to maintain freshwater ecosystems in by fair conditions, with respect to pristine flow (i.e., flow with no human influence), and whereby fair refers to an ecological state of the river between poor and good conditions (Lara *et al*. 2018). The basic flow requirements for rural communities and other unregulated use must be considered in terms of meeting these demands as well as ensuring that the hydrological impacts on these are acceptable. Similarly, minimum flow requirements for environmental or aesthetic needs are also important. Sustainability (Kennen *et al*., 2018)

The environmental or instream flow requirement is often defined as how much of the original flow regime of a river should continue to flow down it in order to maintain the riverine ecosystem in a prescribed state (e.g. pristine, good, satisfactory). However, an environmental instream flow often fulfils a number of different functions. In addition to the ecology of a water course there may be a need to recommend instream flow requirements for the following reasons:

- ❖ Protection of the rights of other abstractors,
- ❖ Navigation;

- Prevention of saline intrusion;
- Dilution of effluent;
- Maintenance of the flood carrying capacity of the channel;
- Cultural and social reasons;
- Prevention of invasive plant species; and
- Maintenance of the channel diversity.

In this study, minimum flow requirements for environmental was used by using flow duration curve estimation method.

3.8 WEAP21 Modelling process

WEAP model applied by simulating recent base year account, for the water availability and demand will determined. This information obtained from different institutions in the sub-basin. The 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. (Ahmadaali et al., 2018).

The modeling of a watershed using the WEAP consists defining of the study area and time frame. The setting up of the time frame includes the last year of scenario creation (last year of the analysis) and the initial year of application. Secondly, Create 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. Thirdly, Create the 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 from running the model. The scenarios are used to address a lot of what if situations, like what if reservoirs operating rules are altered, what if groundwater supplies are fully exploited, what if there is a population increase. Scenario creation can take into consideration factors that change with time. Finally, Evaluate the scenarios about 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 was the core of this study.

3.9 WEAP Model Setup

For Investigating the Existing Surface Water Potential and Allocation of Future Water Demands: The Case of Gibe Sub Basin, water supplying and demand water for different agricultural, Livestock, domestic and industrial supply process the framework chosen to undertake this assessment was shown in figure (3.10).

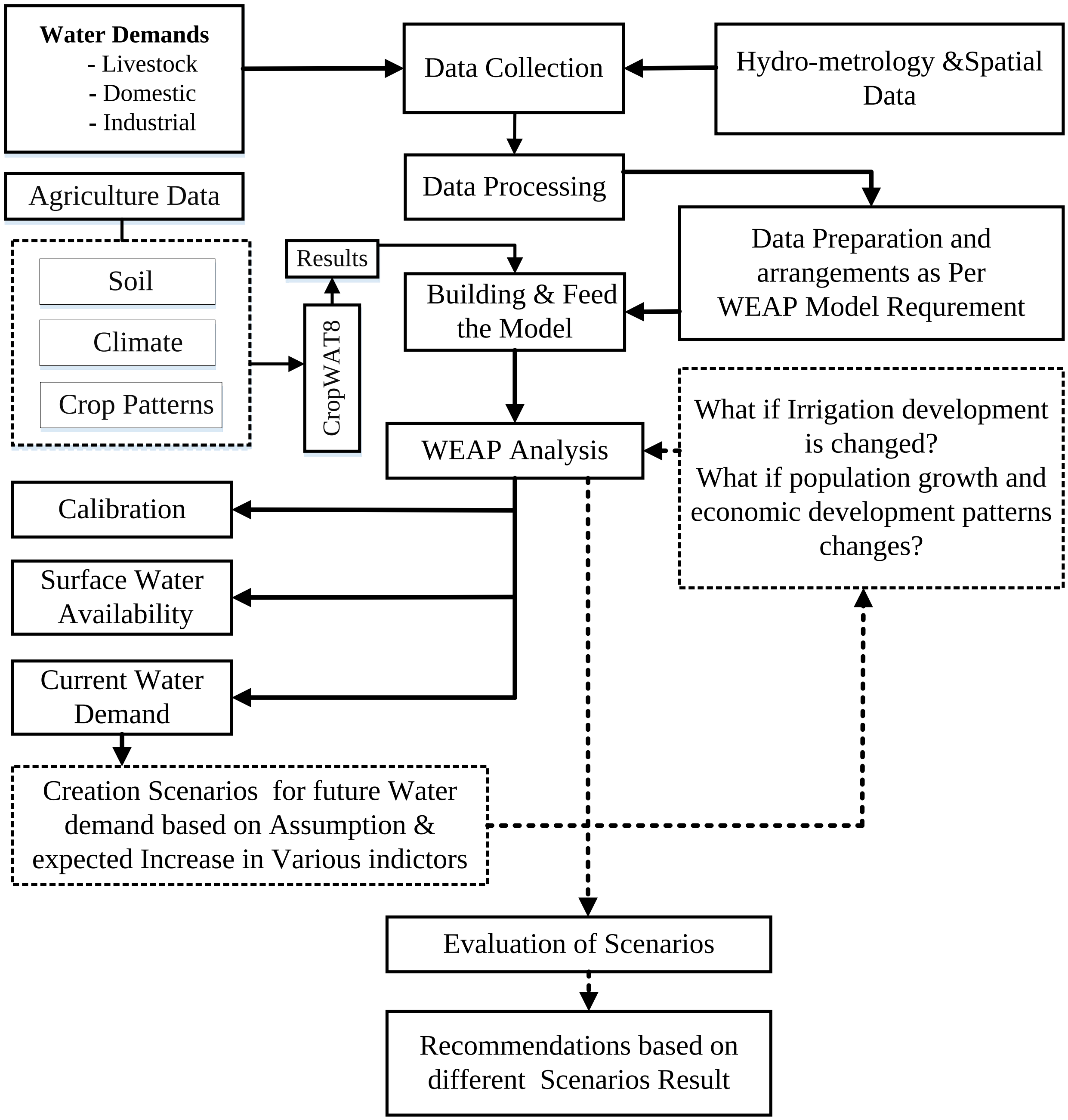


Figure 3.10: The general frame work of the study

3.10 Calibration of WEAP Model

All the input and parameter information were available, the calibration location and periods of record to use were selected. Calibration is the process of choosing parameter values to determine how the model behaves, then to compare the model's prediction (Amin *et al*., 2018). WEAP has calibrations 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 (SEI, 2015). Was used PEST to help calibrate one or more variables in WEAP model which can be particularly useful when using the rainfall runoff method (simplified coefficient method)

The complexity of water allocation models and the fact that they are required to simulate demand behavior (to reflect changes in demand) in addition to WEAP model processes means that model calibration and validation is extremely difficult and has often been neglected in the past (Kiniouara, Hanib and KapelaN, 2017). in this study of calibration, the WEAP model involves the comparison of simulated and observed flows. Accordingly observed stream flow data at gauging station in the sub-basin was used for calibration. Naturalized stream flows from the selected station were compared to the simulated results of the model. NSE is commonly used for measuring the goodness of fit in hydrological modeling. It defines the relative magnitude of the residual variance (noise) compared to the observed data variance. The NSE combines the correlation of observed and simulated data, and also averages and standard deviations, which is calculated as given by Equation (3.5). The NSE coefficient ranges between -∞ and 1.0. Values of NSE is between 0.0 and 1.0 indicates that the performance of the method is at an acceptable level. However, if it is lower than 0, it indicates that the simulated value is worse than the mean observed value, so model performance cannot be accepted (Yaykiran *et al*., 2019,)

$$\mathrm{NSE} = 1 - \left[\frac{\sum(\mathrm{Q_{obs}} - \mathrm{Q_{sim}})^2}{\sum(\mathrm{Q_{obs}} - \mathrm{Q_{obs}})^2}\right] \qquad 3.5$$

While NSE is a useful one-value indicator of model performance, it is biased by high flows. Additionally, it only captures certain aspects of the model flow deviations from observed. To fully understand and evaluate model performance, NSE must be used in conjunction with other metrics that consider seasonal variation, flow duration curves, and annual totals of the modeled and observed flows. To this end, often consider the ratio of the root mean squared error to the standard deviation (RSR) as a measure of how much the simulated flows deviated from the observed hydrographs. In general, the model can be judged as satisfactory if the NSE ≥ 0.5, Percent of Bias (PBIAS) ±25% and RSR ≤ 0.7, (Bank, 2017). The equations used for model calibration is as follows:

$$\mathrm{RSR} = \frac{\mathrm{RMSE}}{\mathrm{STDEV_{obs}}} = \frac{\left[\sqrt{\sum(\mathrm{Q_{obs}} - \mathrm{Q_{sim}})^2}\right]}{\left[\sqrt{\sum(\mathrm{Q_{obs}} - \bar{\mathrm{Q}}_{\mathrm{obs}})^2}\right]} \qquad 3.6$$

$$SDR = \frac{STDEV_{sim}}{STDEV_{obs}} = \frac{\left[\sqrt{\sum(Q_{sim} - \bar{Q}_{sim})^2}\right]}{\sqrt{\sum(Q_{obs} - \bar{Q}_{obs})^2}} \quad 3.7$$

$$PBIAS = 100 * \left[\frac{\sum(Q_{obs} - Q_{sim})}{\sum(Q_{obs})}\right] \quad 3.8$$

where: Q_{obs} = Observed Flow Rates, Q_{sim} =Flow Rate Model Results and $\bar{Q}$ =Average Flow Rate Values.

3.11 Creation of scenarios

3.11.1 Current accounts year

The Current Accounts represent the basic definition of the water system as it currently exists, and forms the foundation of all scenarios analysis. In this study, the current account of the model was developed using the demand data of the 2019.

3.11.2 Reference scenario

The reference scenario was developed from the current account to simulate the likely evolution of the system without intervention; it only increasing in population growth. In this study, the reference scenario was created from 2020 to 2050.

3.11.3 High population growth scenario

Policy scenarios can be established from the reference scenario with alternative assumptions about future development. These scenarios can address a broad range of "what if" questions, such as: what if population growth pattern changes?

3.11.4 Current irrigation potential scenario

This scenario shows the impact of additional identified irrigation areas full development. This scenario is implemented in the model by increasing the irrigation area. In Gilgel Gibe sub-basin many irrigation areas are identified suitable for irrigation yet not developed because of financial and other factors so this scenario shows the impact in water demand ''what if"' this identified irrigation areas are fully developed.

3.11.5 Irrigation projection scenario

This scenario was created; the sub-basin is not fully developed in terms of irrigation; there are potential areas suitable for irrigation. Hence this scenario shows what if the impact of irrigation development increased four times the current account (from 17560 ha to 59232 ha)? What will be the effect in water demand in projection in irrigation scenario?

4. RESULTS AND DISCUSSIONS

4.1 Surface water potential

Twenty-eight years' data were taken to estimate the river flow at outlet gauge station and simulated runoff from the entire sub basin. The river system was schematized from an ArcView GIS layer. The runoff from the sub-watershed nodes in WEAP21 represented the head flow of the streams. There are five methods to simulated the catchment. These are: Rainfall Runoff Method (Simplified Coefficient Method), Irrigation Demands Only Method (Simplified Coefficient Method), Rainfall Runoff Method (Soil Moisture Method), MABIA Method (FAO 56, Dual Kc, Daily) and Plant Growth Method (PGM). In this study to calculate the runoff the rainfall-runoff method was used to simulate watershed processes (runoff). This method defines land use by crop coefficients, Kc, sub watershed area and effective precipitation while the climate is defined by precipitation and reference evapotranspiration, ETo. The Rainfall Runoff method also determines evapotranspiration for irrigated and rain fed crops using crop coefficients. The total annual river flow of the upper Gilgel Gibe sub-basin at outlet (Asendabo) gauge station has been estimated to be 1276 MCM. Out of the mean annual surface runoff of the sub-basin, 84.3% the mean annual surface runoff of the sub-basin is produced from the heavy rainy months (i.e. August, and September). Average monthly surface runoff of the sub- basin is shown in Figure 4.1.

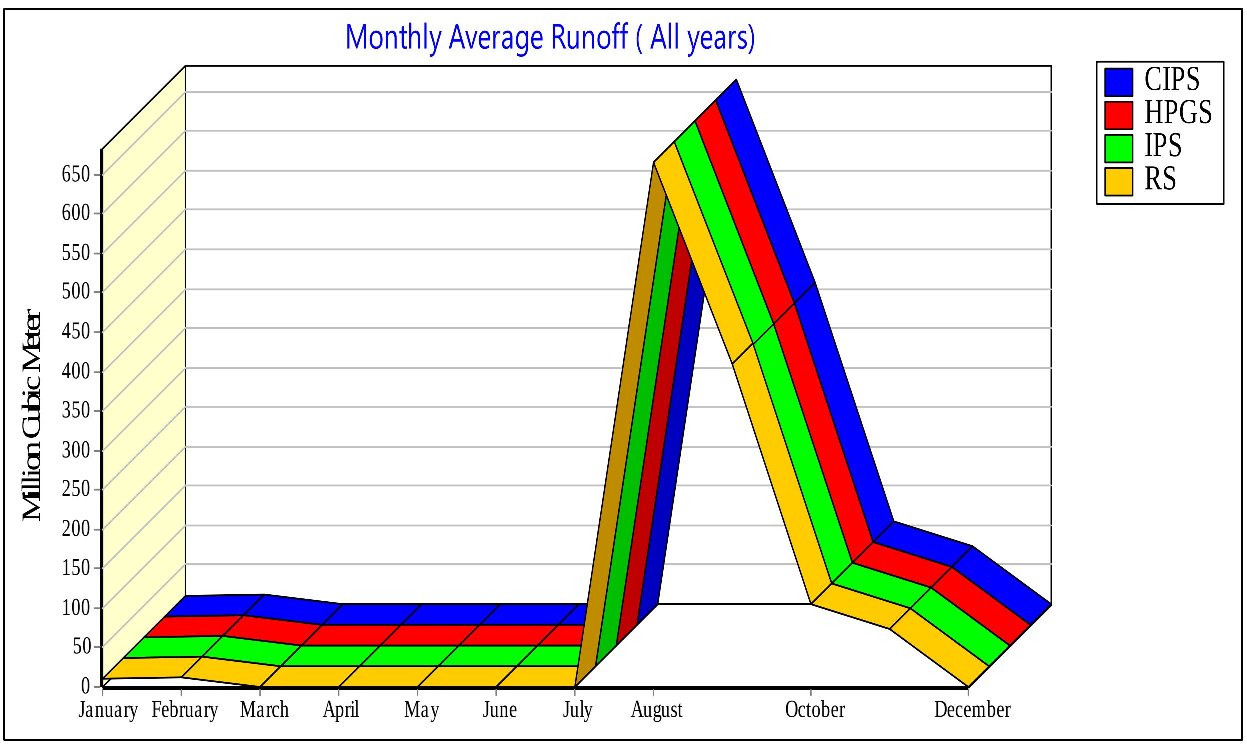


Figure 4.1: Monthly Average simulated flow up to 2050.

4.2 Model calibration result

Calibration of the model means adjusting some parameters in such that there is good match between the simulated and observed data at selected stations (SEI, 2015). Observed data is required for calibration of the model and sufficiently long continuous observed data is available for all sub catchments in the sub-basin. Calibration of the WEAP model was based on the flow at the Asendabo gauging stations was done for the period 1990-2018,

The accuracy of the model was assessed by simulated and observed stream flow, results from Figure 4.2, it was estimated that the simulated and observed flows were comparable in Gilgel Gibe main river, there was good match between monthly average stream flow of the outlet gauge (Asendabo) and runoff from the respective sub catchment values, and as shown in the Figure 4.3, the mean R-squared value is 0.9986. Nash-Sutcliffe Efficiency (NSE), Percent of Bias (PBIAS), Ratio of Standard Deviation of Simulated Versus Observed (SDR) and Ratio of the Root Mean Squared Error to the Standard Deviation (RSR). Comparable result is shown in Table 4.1. Therefore, the model performance is perfect and provides a good estimate.

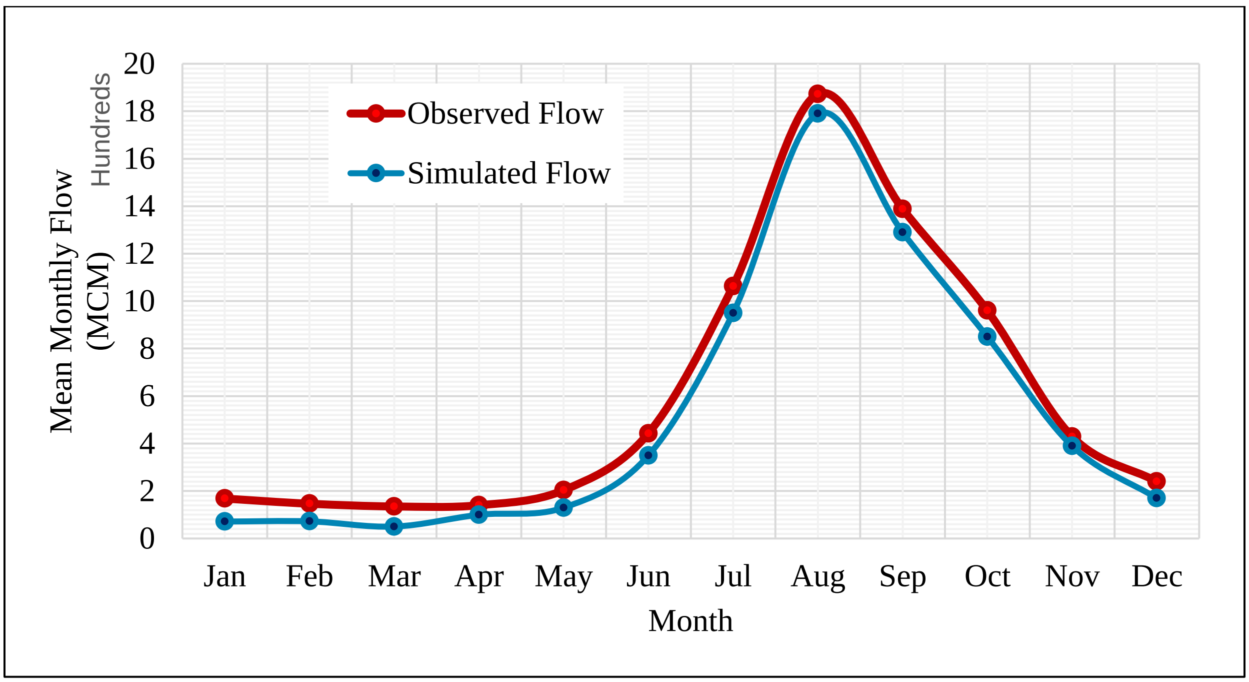


Figure 4.2: Mean Monthly OSF Vs SSF pattern at outlet gauge station (1990-2018).

Table 4.1: Continuous Statistical Analysis Values of the Model Performance

Standard Statistical Parameters Range	Statistical Analysis Values	Remark
NSE ≥ 0.5	NSE = 0.976	Ok!
PBIAS ±25%	PBIAS = -14%	Ok!
RSR ≤ 0.7	RSR = 0.141	Ok!
0.9 ≤ SDR ≤ 1.1	SDR =1.0	Ok!

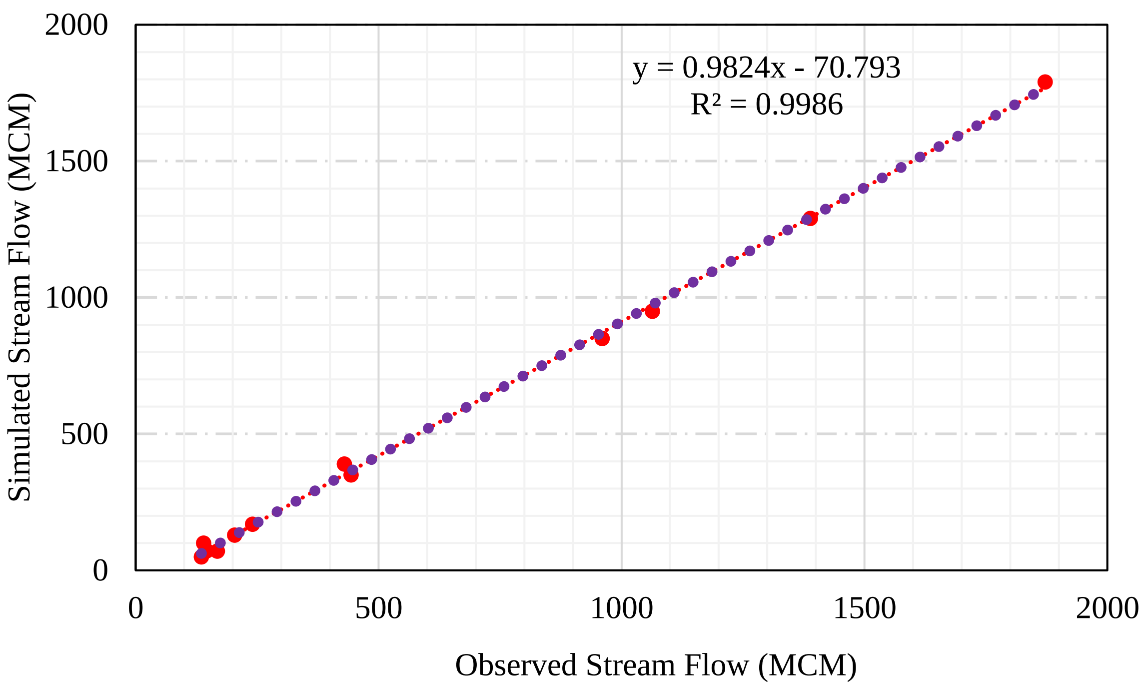


Figure 4.3: Mean monthly observed and simulated stream flow

4.3 Current account (2019) water demand

The Current Accounts represent the basic definition of the water system as it currently exists, and forms the foundation of all scenarios analysis. In this study, the current account of the model was developed using the demand data of the year 2019. The WEAP model was setup for the 2019 current account water demand under the condition of annual water use rate for domestic and livestock demand site data. The total agricultural water demand was estimated using CROPWAT8 output result. Generally, in current account year the basin major demands i.e. Domestic (Urban and Rural), Agriculture, Livestock annual water demand and unmet demand were estimated. The current total water consumption for all consumers (domestic (Urban and Rural), agriculture and livestock water demands within the sub-basin was estimated to be 146.29 MCM. From this result agriculture and rural sites consumed the highest demand share which is 43.91 MCM and 56.56 MCM respectively. Livestock and Urban nodes consumes 28.66 MCM and 15.07 MCM respectively.

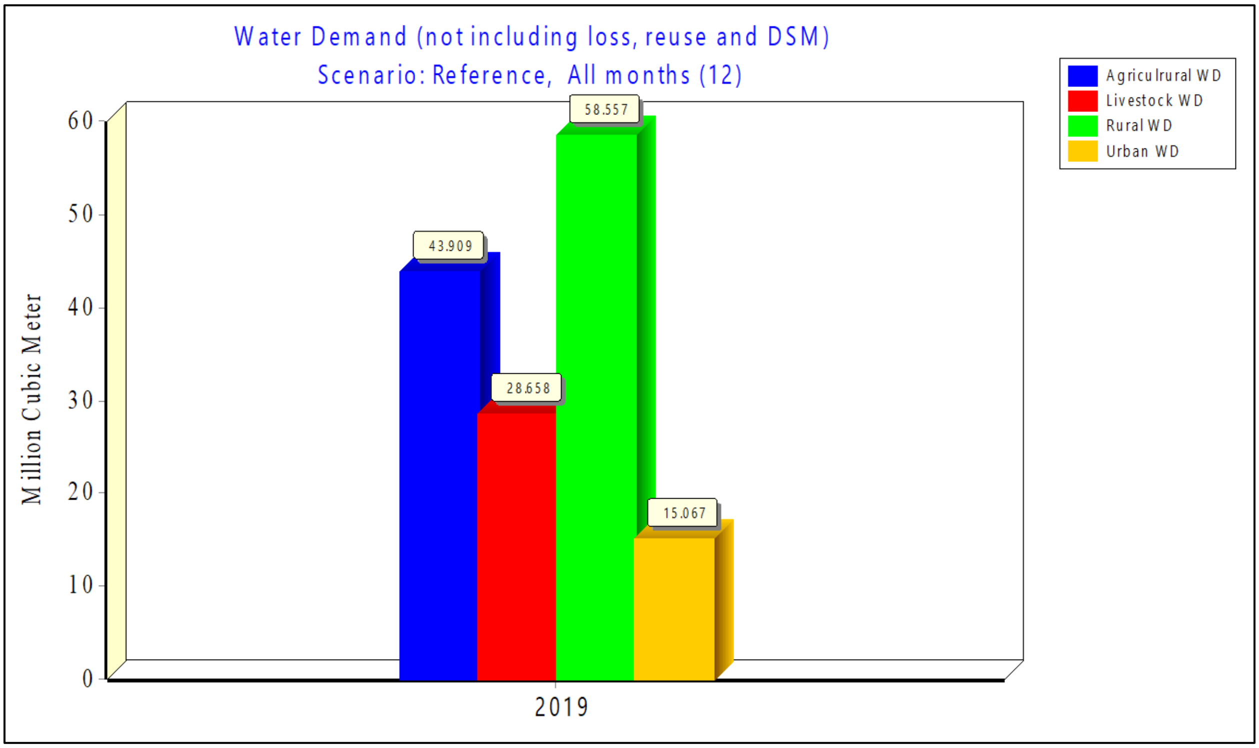


Figure 4.4: Current account annual water demand for demand Site (MCM)

Under current account (2019), total 1.11 MCM water shortage seen on rural and urban. which is very small percentage share compared to total available water potential. The overall result indicates that all the demand sites have not faced to water shortage in the year 2019. Table 4.2 summarizes the result of the model for the current account water consumption, demand share and Unmet demand for all demand sites.

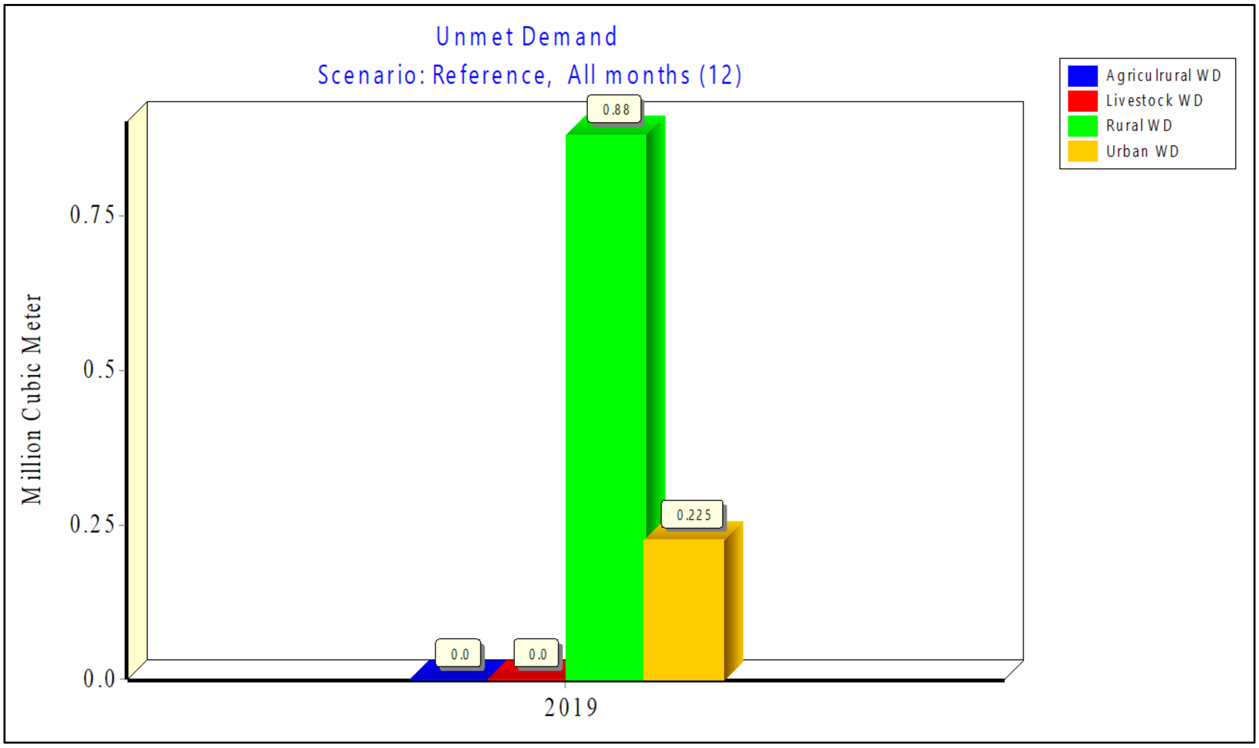


Figure 4.5: Current account annual unmet water demand for demand site (MCM)

4.4 Environmental flow requirement

For Upper Gilgel Gibe sub-basin 20.8% of total annual runoff was allocated to the environment. This was estimated from the available 28-year river flow; the flow duration curve is one of the common methods which was used in determining environmental flows using the 90% flow as the minimum environmental flow. In this study, as shown in the Figure 4.6, 90% exceeded flow result 265.83 MCM was used to estimate the minimum flow which is exceeded 90% of the time. The basic time unit used in preparing a flow duration curve was determined by sorting average monthly discharges for period of record from the largest value to the smallest, involving a total of n values. The sorted daily discharge values are assigned a rank (M) starting with 1 for the largest and the probability of exceedance (P) calculated using Equation 4.1.

$$P = 100 * [M / (n + 1) \qquad 4.1$$

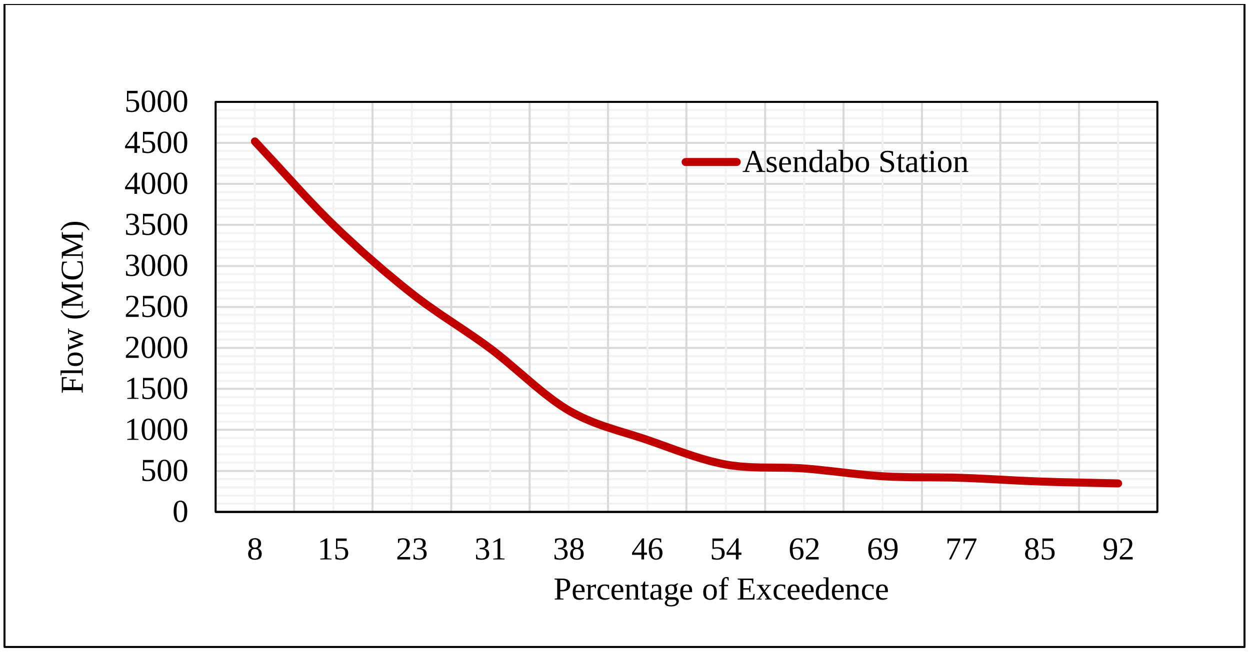


Figure 4.6: Flow duration curve for estimating EFR.

4.5 Future water demand

4.5.1 Reference scenario

The reference scenario (2020-2050) is the scenario in which the changes that are likely to occur in the future without intervention new policy measures; it only increasing in population growth which was 2.9% for urban and 1.2% for rural and used linear population increase based on Central statistics agency of Ethiopia report. agricultural demand and hydrological condition was assumed unchanged into the future in this scenario and assuming that similar trends of the stream flow situation will exist in future. Generally, reference scenario shows high population growth, current irrigation potential and irrigation projection. Data to be entered is combination of measured and assumptions concerning water abstractions, natural flow and water management rules. Finally, "what-if" scenarios can be created to alter the "Reference Scenario" and evaluate the effects of changes in policies and/or technologies. Figure 4.7 indicates annual monthly water demand for reference scenario.

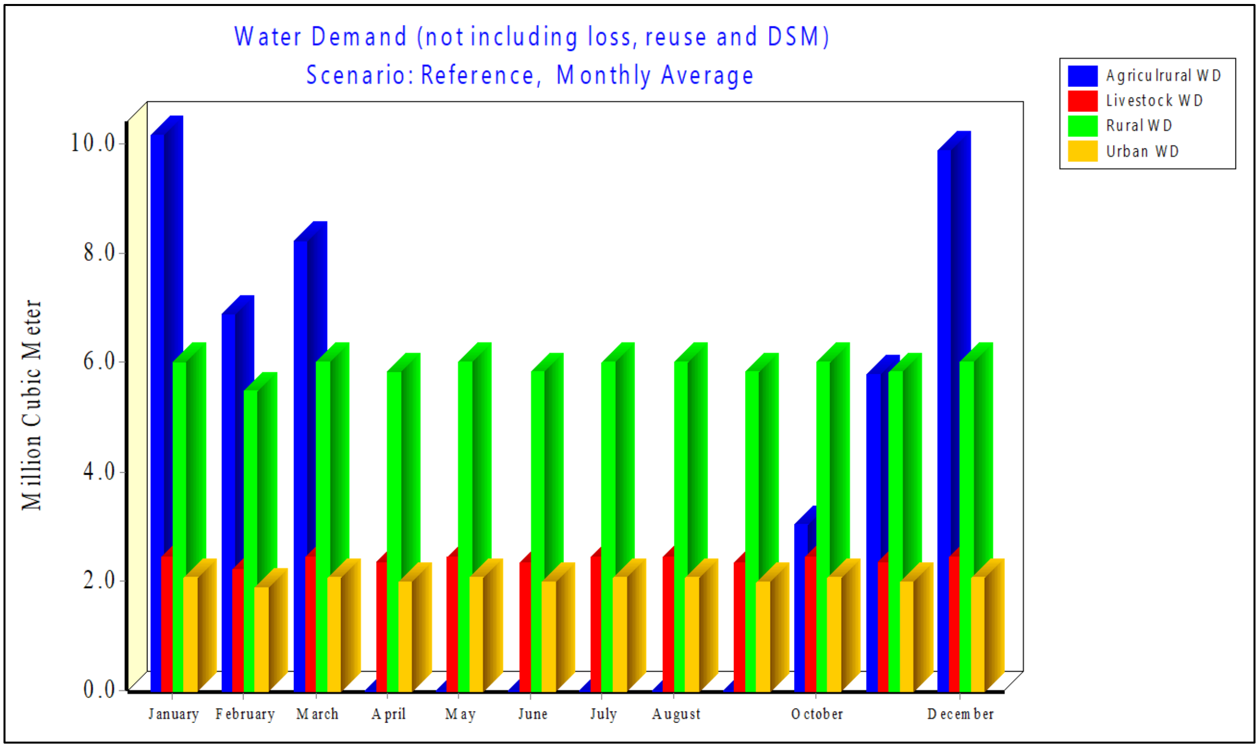


Figure 4.7: Annual monthly water demand under reference scenario

Under this Scenario, As Figure 4.7 shows, from monthly annual water demand, agricultural water demand site has got higher water demand in the month October to march. Livestock, rural and urban demand sites uses water all months. In this scenario Annual Water Demand is increased 146.29 MCM to 167.72 MCM which increased by 14.65% from base year (2019). From this demand, agriculture and rural demand sites consumed higher demand share which is 43.91 MCM and 70.88 MCM. Livestock and urban demand sites took the remaining 28.64 MCM and 24 MCM share respectively as shown in the Figure 4.8. For each month annual water demand share under this scenario, see **Appendix V**.

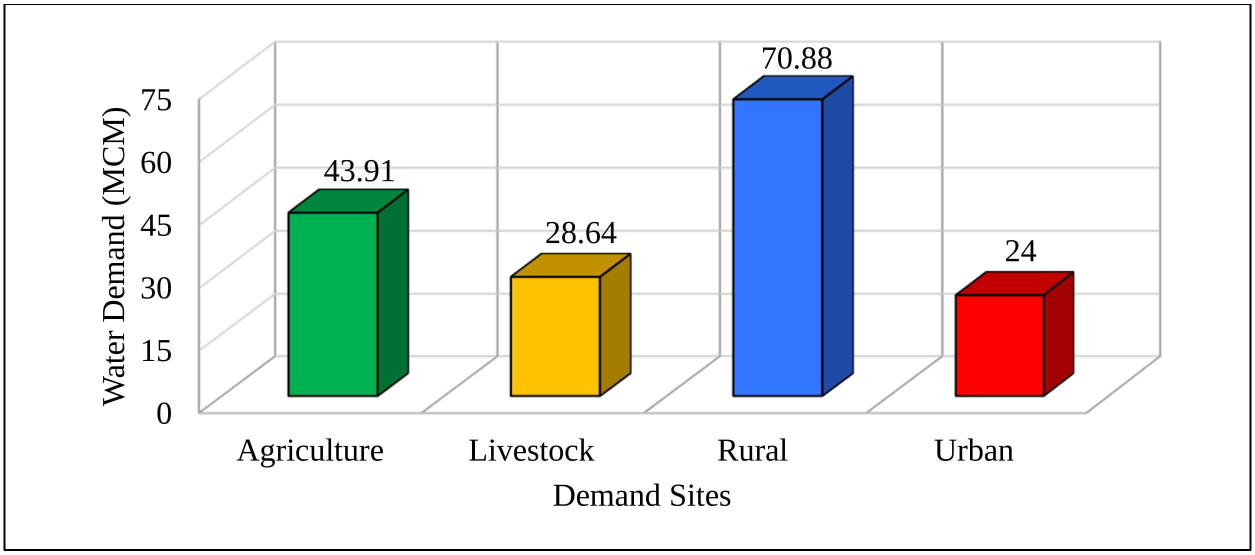


Figure 4.8: Annual water demand for all demand site under reference scenario

As shown in Figure 4.9, from annual monthly unmet demand, rural and urban demand sectors have got scarcity the months between November to march. Agricultural unmet demand seen on month march. Livestock has got fully coverage. Under this scenario, the annual unmet water demand was estimated to be 13.99 MCM. Among this unmet demand, 0.27 MCM, 8.33 MCM, and 604 MCM water shortage faced under agriculture, rural and urban demand sites respectively and livestock demand site has not faced to unmet demand (full coverage). Sectoral each month's annual unmet water demand is summarized on **Appendix VI**.

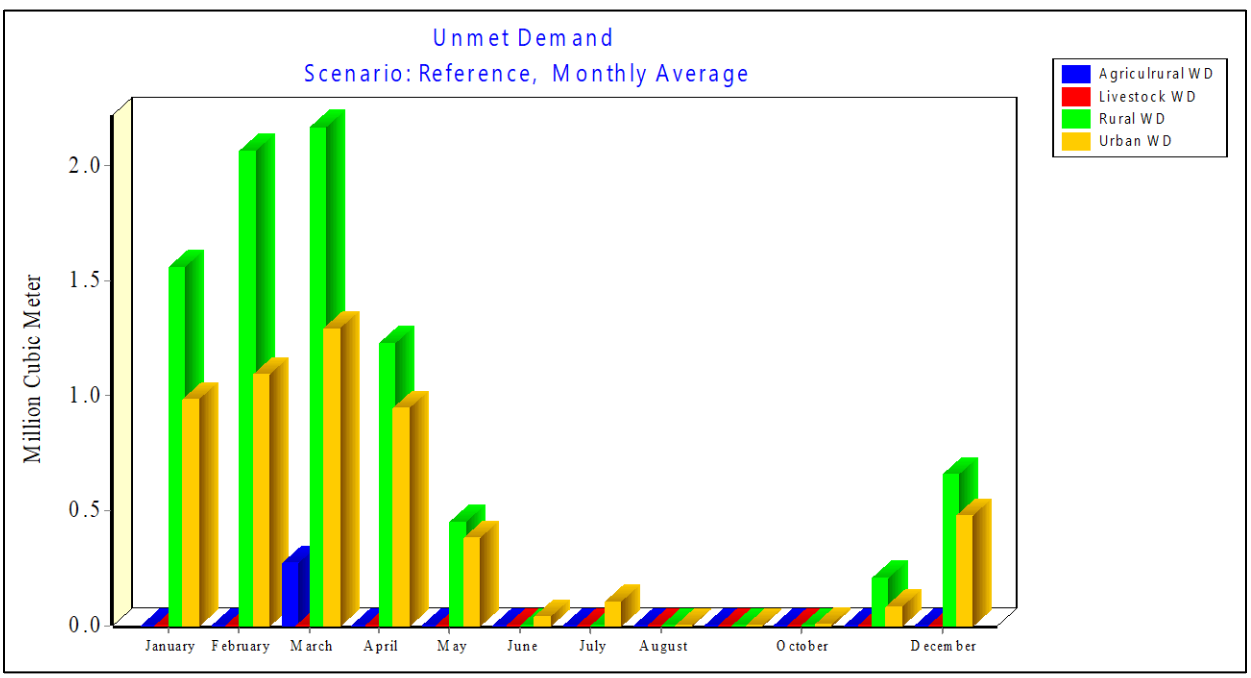


Figure 4.9: Annual monthly unmet demand (MCM) for all demand site under RS.

4.5.2 Scenario 1. High population growth

This scenario shows what will happen if the population growth rate is set to greater growth rate than the reference scenario population growth rate?

In this scenario, the population growth rate was raised to 5% for Urban and 2% for rural to simulate the water supply demand in the future. In this Scenario, as the result in Figure 4.10 shows, the monthly annual water demand shares of all demand sites. For detail of monthly annual water demand see **Appendix VII**.

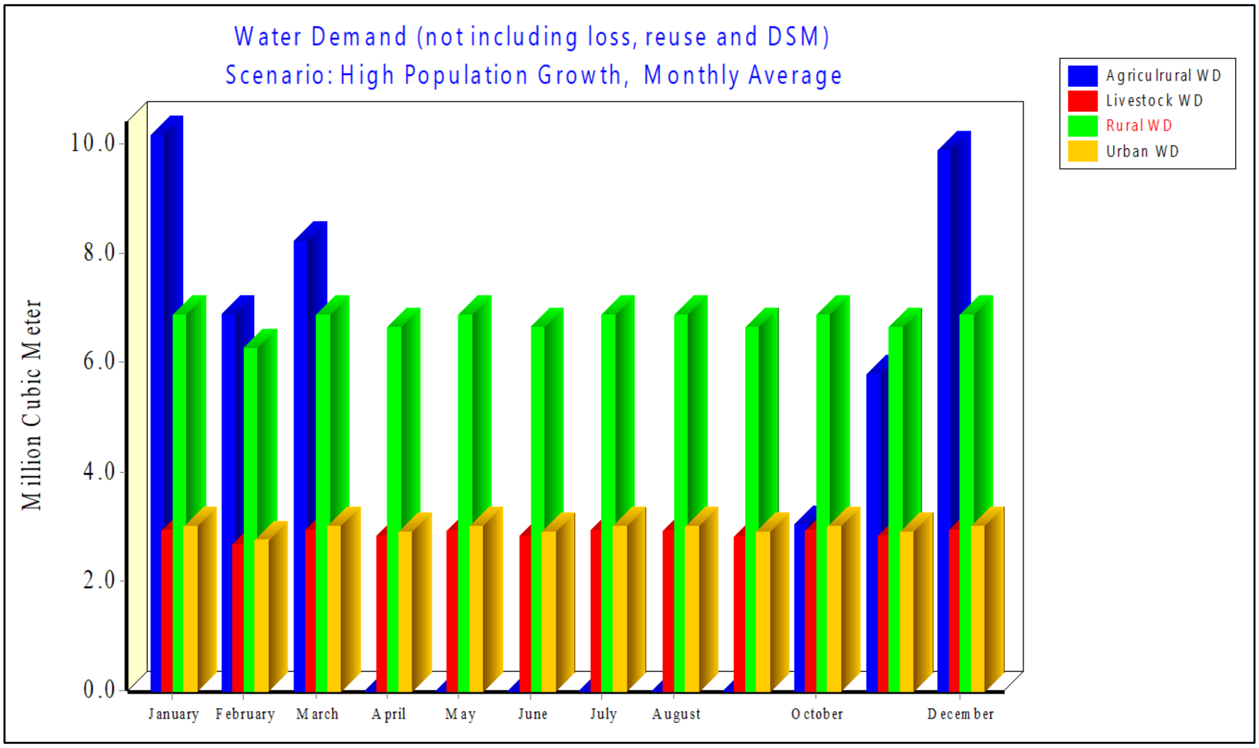


Figure 4.10: Annual monthly water demand for high population growth scenario.

On the other hand, as the Figure 4.11 Shown, the overall water demand for all demand consumers was increased from 167.72 MCM to 194.7 MCM compared to reference scenario. Among this demand, rural demand site took the highest demand share which is 80.93 MCM. Agriculture livestock and urban demand sites were consuming 43.91 (MCM), 34.41 MCM and 35.45 MCM demand share respectively.

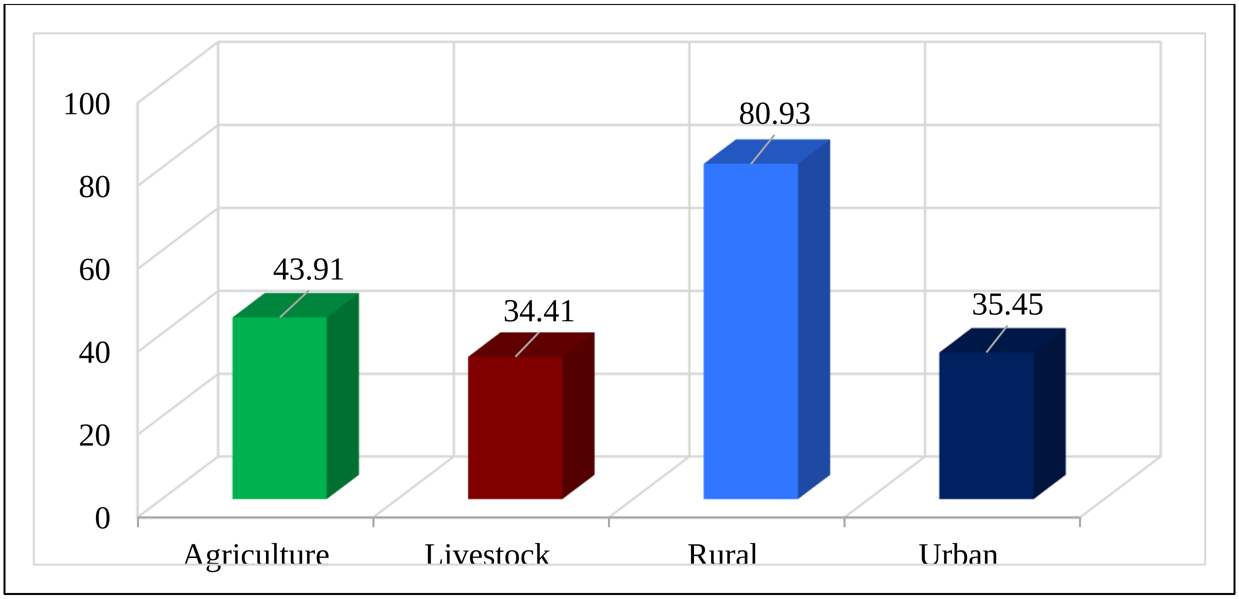


Figure 4.11: Annual water demand for demand site under HPGS.

Figure 4.12 result shows that the annual monthly unmet water demand for high population growth scenario is higher than the annual unmet demand under the reference scenario for all water supply demand sites. The result of reference scenario is 13.99 MCM which increased to 1621 MCM under High population growth scenario. For detail of monthly annual unmet water demand see **Appendix VIII**.

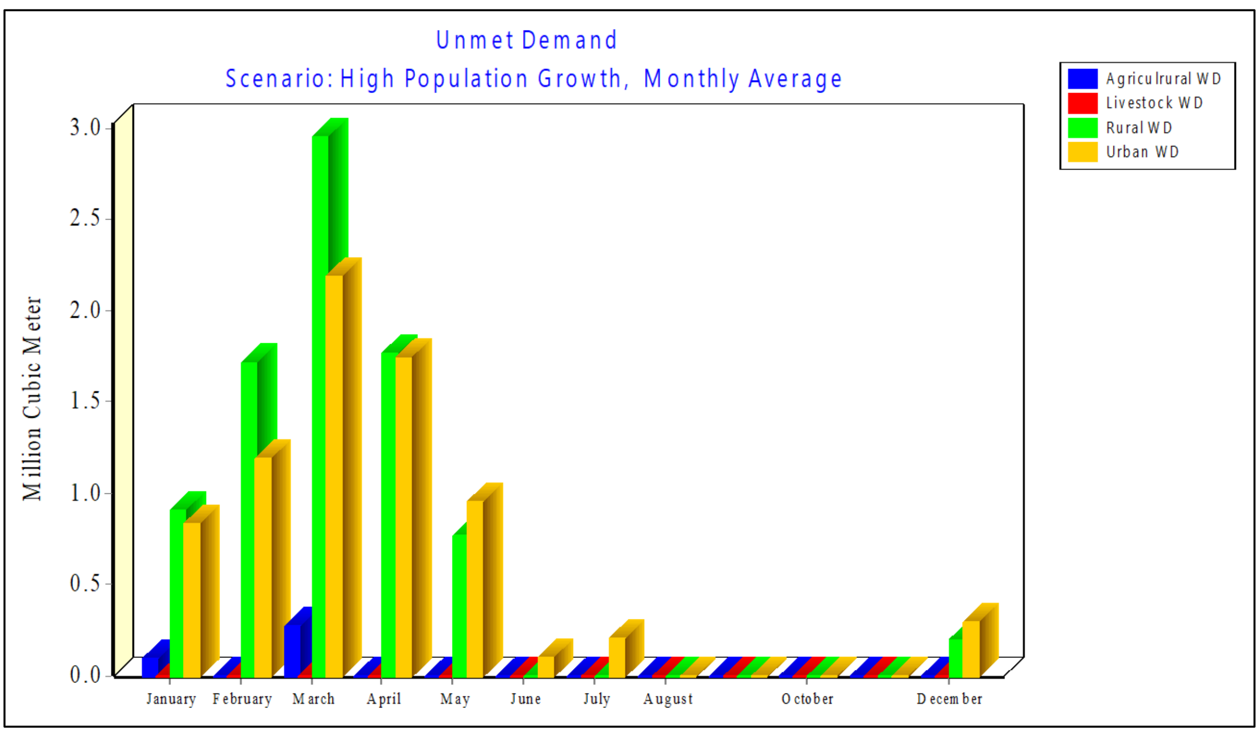


Figure 4.12: Annual monthly unmet water demand for demand site under HPGS.

4.5.3 Scenario 2. Current irrigation potential

This scenario shows the impact of additional identified irrigation areas full development. This scenario is implemented in the model by increasing the irrigation area. In upper Gilgel Gibe sub-basin many irrigation areas are identified suitable for irrigation yet not developed because of financial and other factors so this scenario shows the impact in water demand if this identified irrigation areas are fully developed. For this scenario, increasing irrigation land to studied potential of 46,623 ha which is increased 2.66 times the current irrigable land 17,560 ha. As illustrated in Figure 4.13 the annual monthly water demand share under this scenario agriculture demand has increased in the month October to march. This comprises that, the annual water demand was increased from 43.91 to 74.61MCM compared to reference scenario.

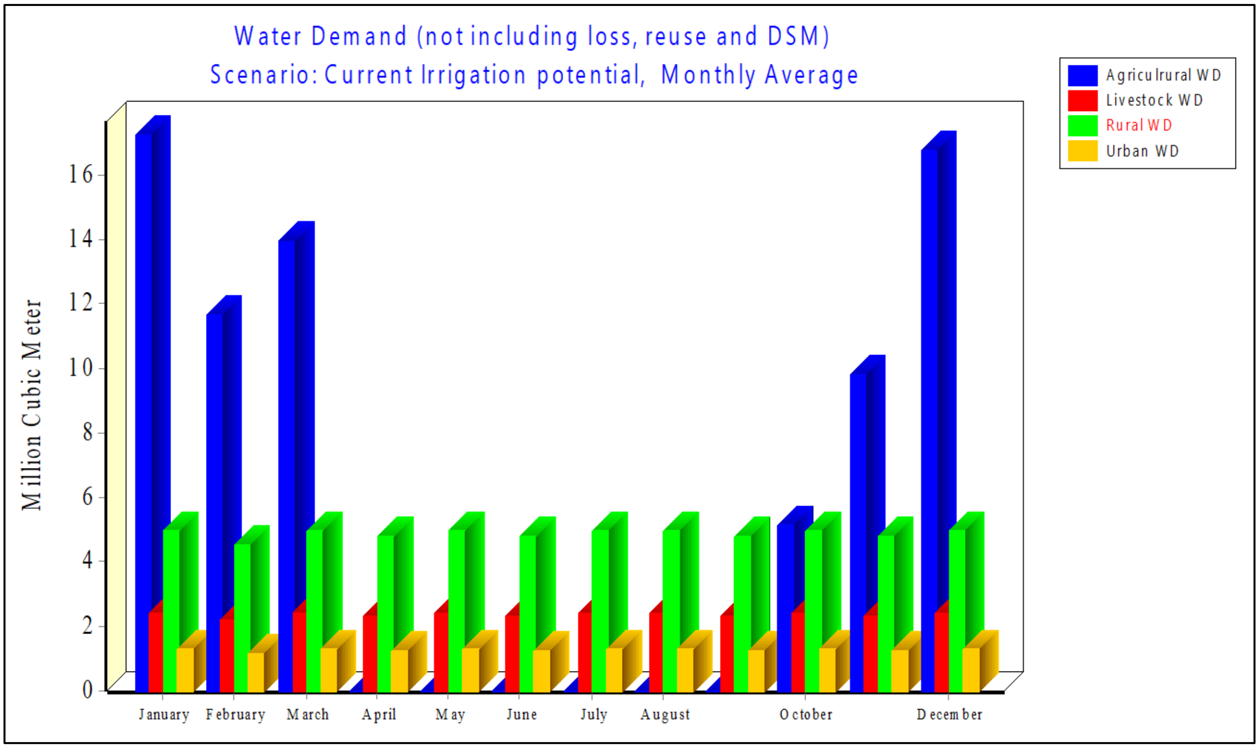


Figure 4.13: Annual monthly water demand under CIPS.

As in Figure 4.14 illustrates, regarding to sectoral aspect of water demand, agriculture demand site is dominating under this scenario which share 74.61 MCM. Livestock, rural and urban consumes the remaining demand share 28.66 MCM, 58.56 MCM and 15.07 MCM respectively from the annual water demand 176.89 MCM. Annual each month's water demand under current irrigation potential scenario is presented on **Appendix IX**.

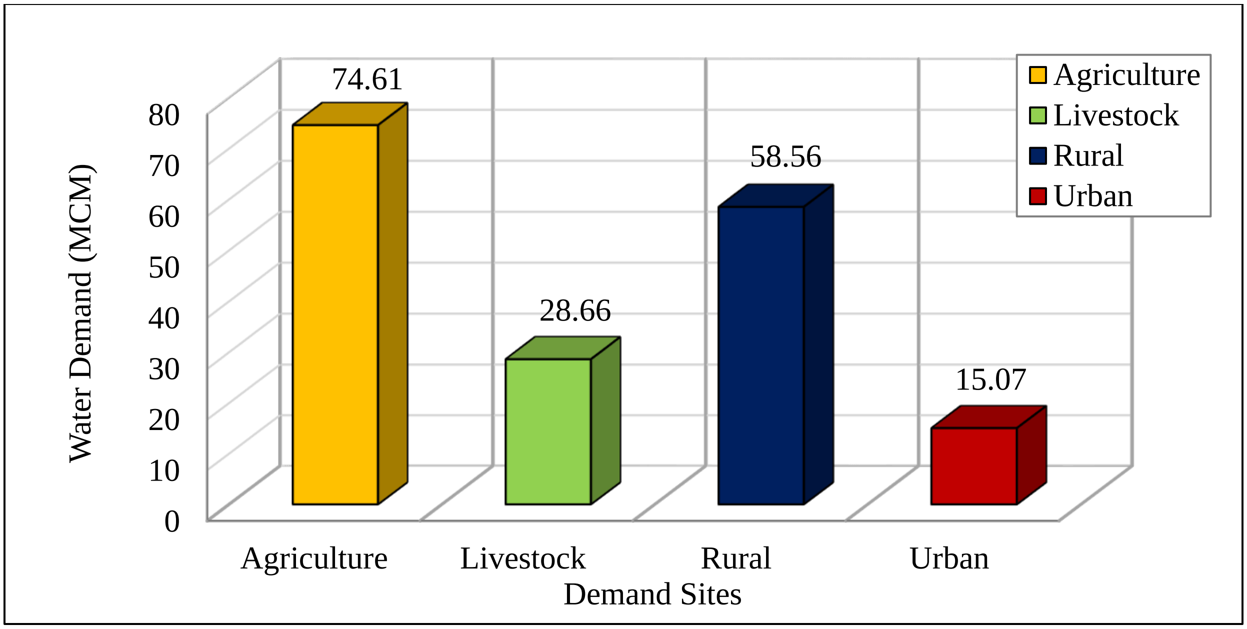


Figure 4.14: Annual water demand for demand site under CIPS.

Under this scenario the overall unmet demand is 7 MCM. Among this result as shown in figure 4.15, agriculture, rural, and urban (1.87 MCM, 3.59 MCM and 1.54 MCM) faced to unmet demand respectively. Livestock demand site got full coverage also in this scenario. **Appendix X** summarizes the unmet water demand of each month for all demand consumers.

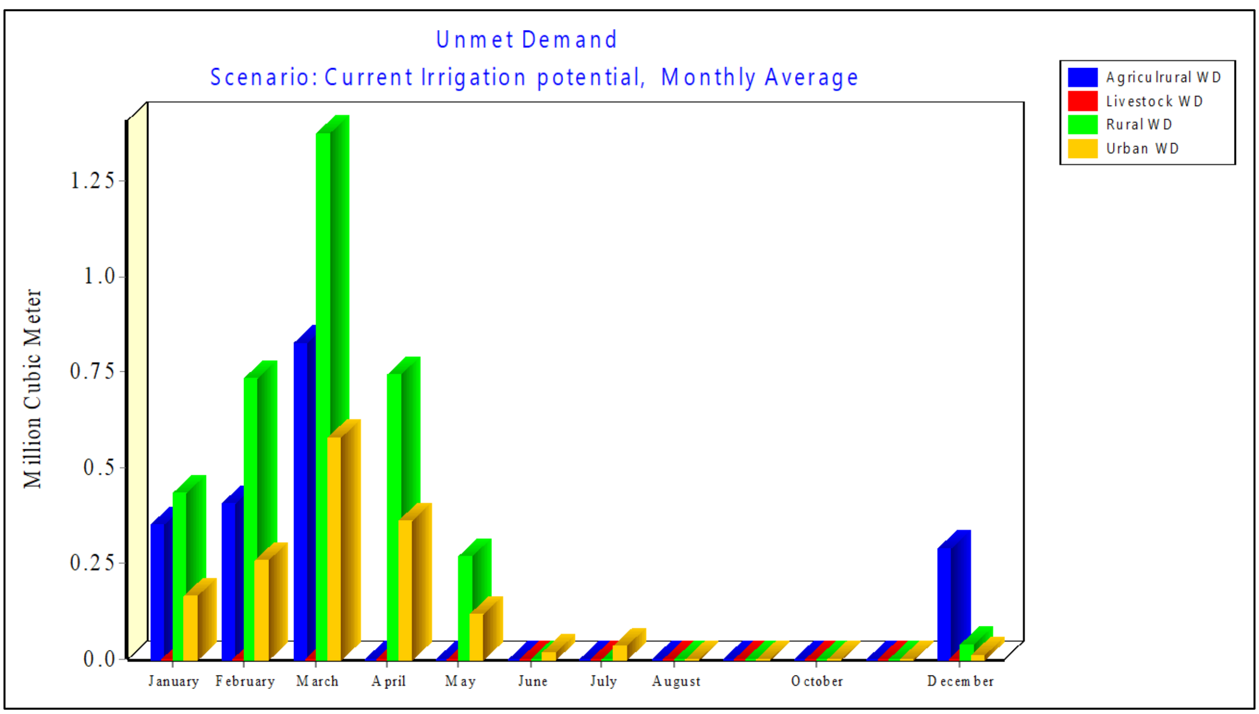


Figure 4.15: Annual monthly unmet demand for demand site under CIPS.

4.5.4 Scenario 3. Irrigation projection

The sub-basin is not fully developed in terms of irrigation; there are potential areas suitable for irrigation. According to Jimma zone agriculture office report (2018), additional irrigation projects are under study by different institutions and in the sub-basin, yet the developed irrigation projects are quite small. Hence this scenario shows what if the impact of irrigation development is increased from the current account 17,560 ha to 59,232 ha? What will be the effect in water demand in projection in irrigation scenario. As the figure 4.16 shown, under irrigation projection scenario annual monthly water demand is increased by 20.6 MCM compared to reference scenario and 11.43 MCM from current irrigation potential scenario.

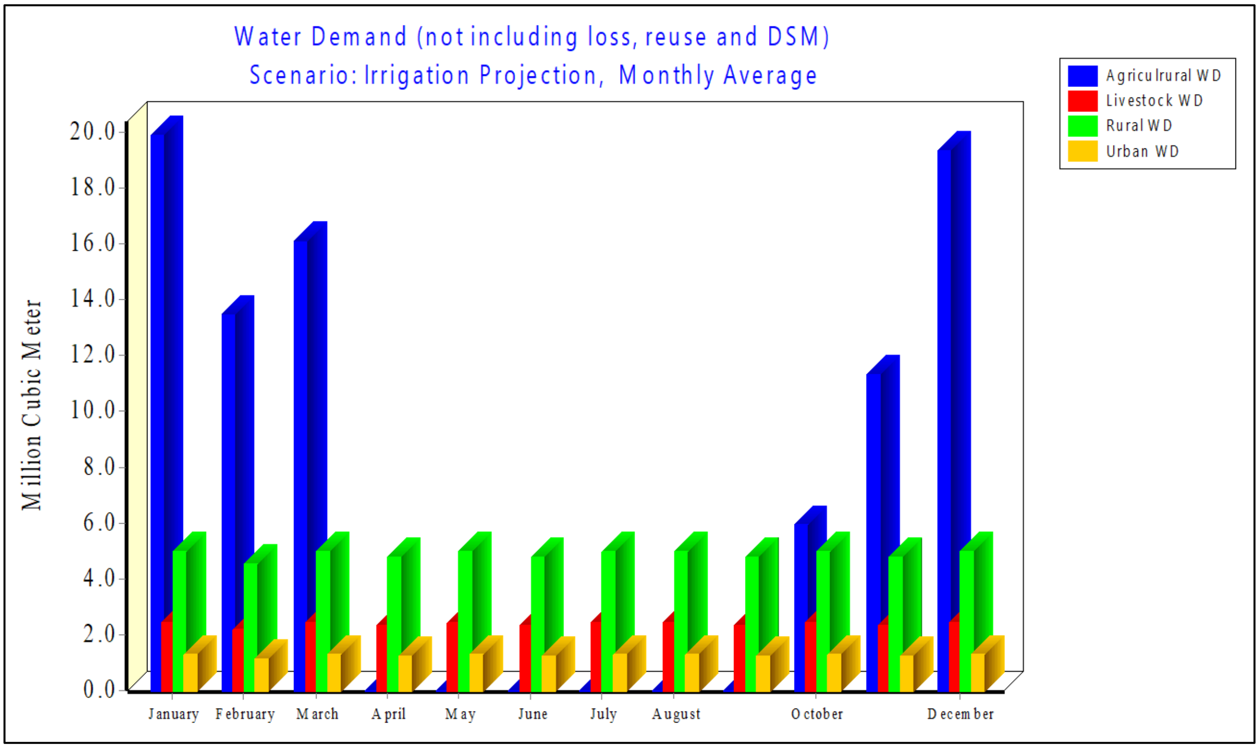


Figure 4.16: Annual monthly water demand pattern under IPS.

The annual Sectoral water demand under this scenario as shown in figure 4.17, agriculture demand site shared the largest demand 86.04 MCM. Rural, urban and livestock shared 28.66 MCM, 58.56 MCM and 15.07 MCM respectively from total water demand 188.32 MCM. The annual each month water demand under irrigation projection scenario is shown in **Appendix XI**.

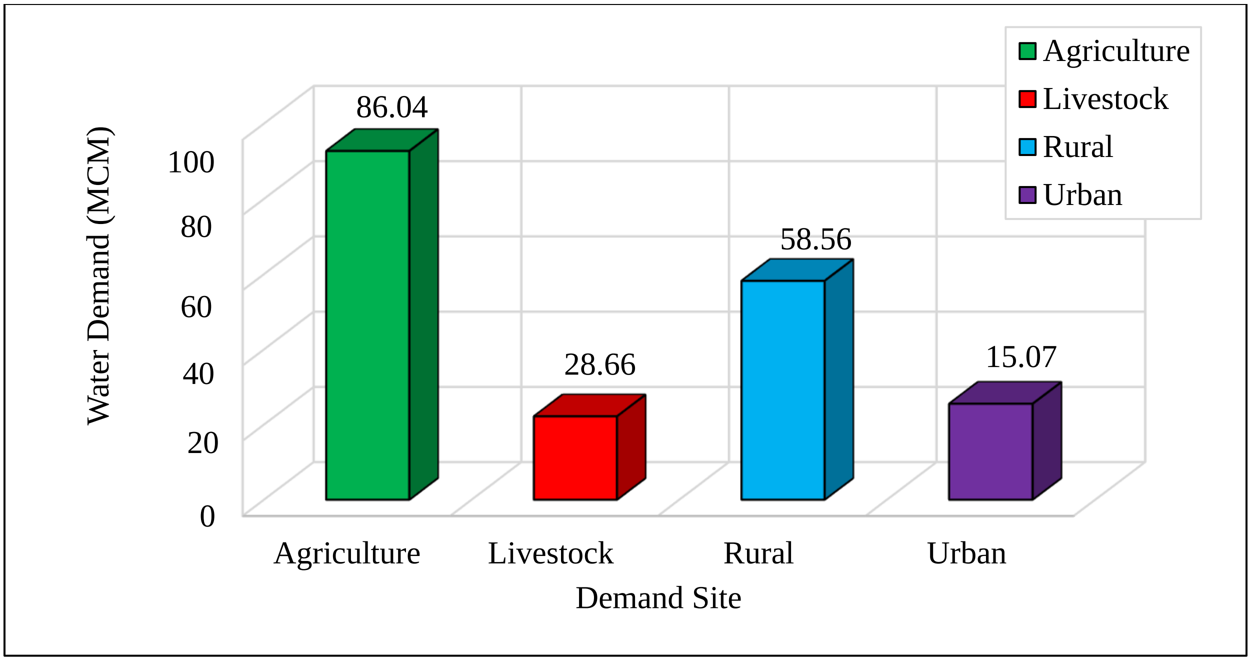


Figure 4.17: Annual water demand for all demand site under IP.

The annual unmet water demand under this scenario is 8.6 MCM which is increased by 1.6 MCM from current irrigation potential scenario. Among this value as shown in the Figure 4.18, agriculture 3.47 MCM, rural 3.59 MCM and urban 1.54 MCM. Livestock demand site got full coverage (no unmet demand). **Appendix XII** summarizes annual each month sectoral unmet water demand under irrigation projection scenario.

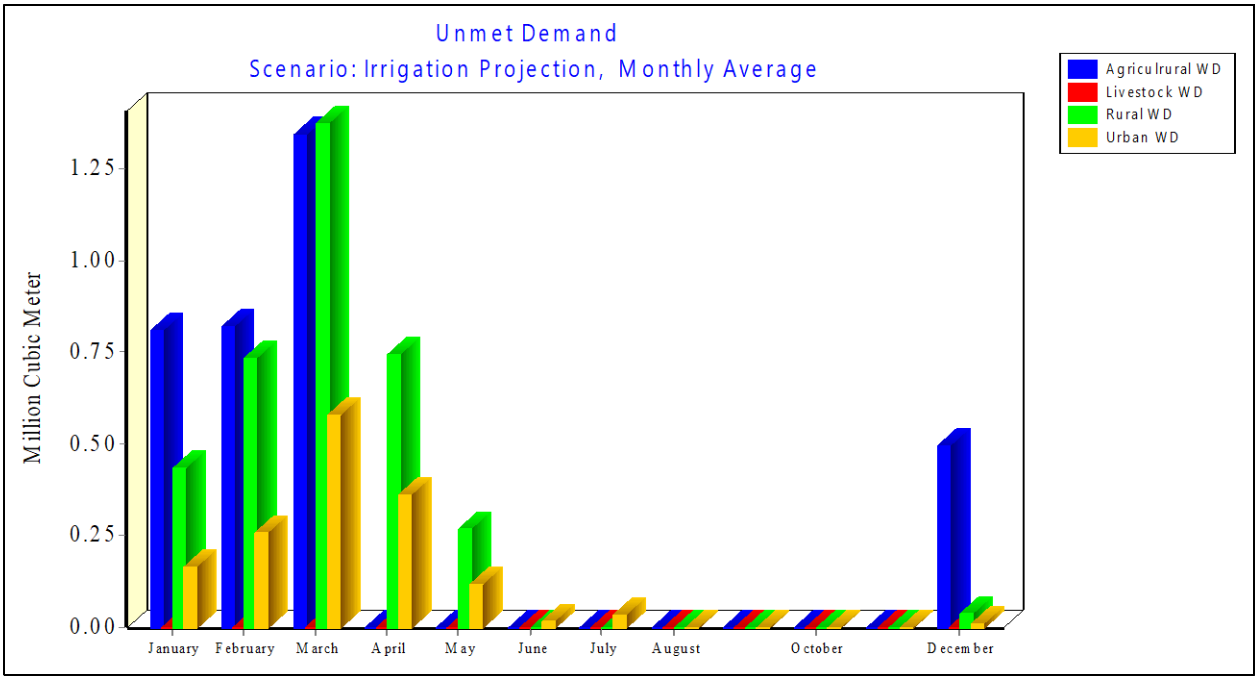


Figure 4.18: Annual monthly unmet demand for all demand site under IPS.

4.6 Comparison of water demand and unmet demand among all scenarios

After analyzing the 2019 baseline data and the impact of the river flow, the WEAP model was configured for the reference, high population growth, current irrigation potential and irrigation projection scenarios. As shown Figure 4.19, high population growth scenario leads all the other scenarios which results 194.7 MCM and 167.72 MCM increment compared to reference scenario. Irrigation projection scenario took the second demand place 188.32 MCM.

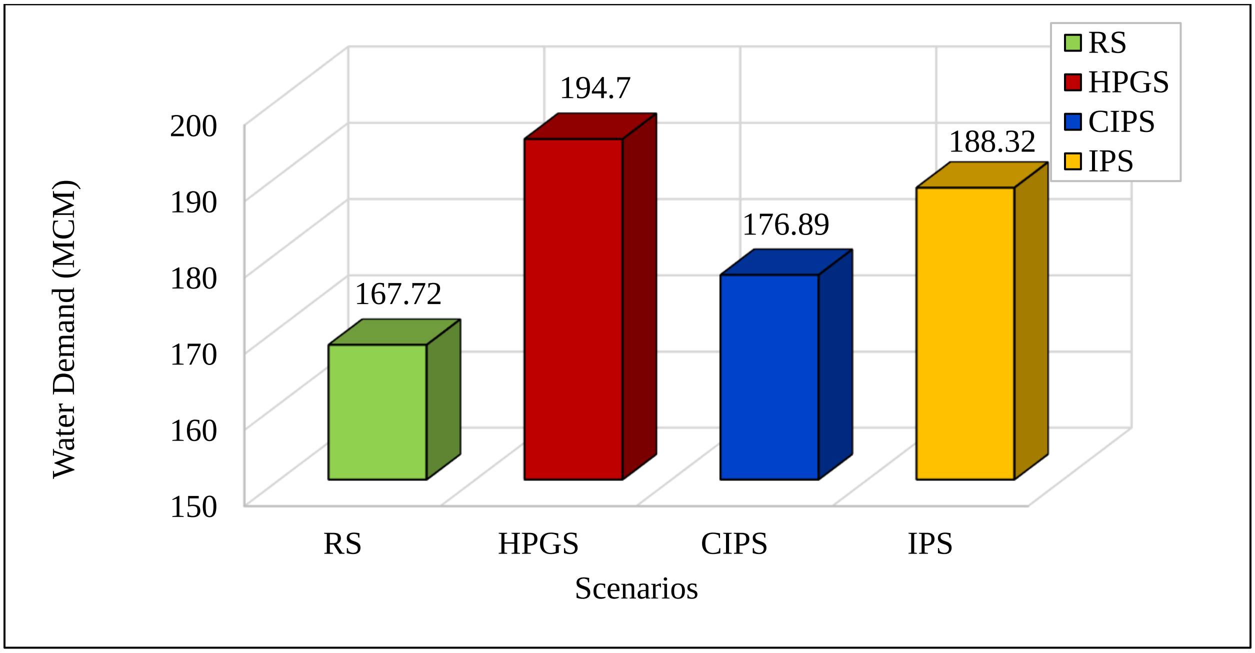


Figure 4.19: Comparison of annual water demand among all scenarios (MCM).

Comparison by demand site under all scenario, as illustrated under figure 4.20, agriculture demand site was consuming higher demand value under CIPS and IPS which results 74.61 MCM and 86.04 MCM respectively. Whereas livestock, rural and urban demand sites consume the highest demand under HPGS shared 34.41 MCM, 80.93 MCM and 35.45 MCM respectively. Summarized annual each month water demand comparison under each scenario is shown in **Appendix XIII**.

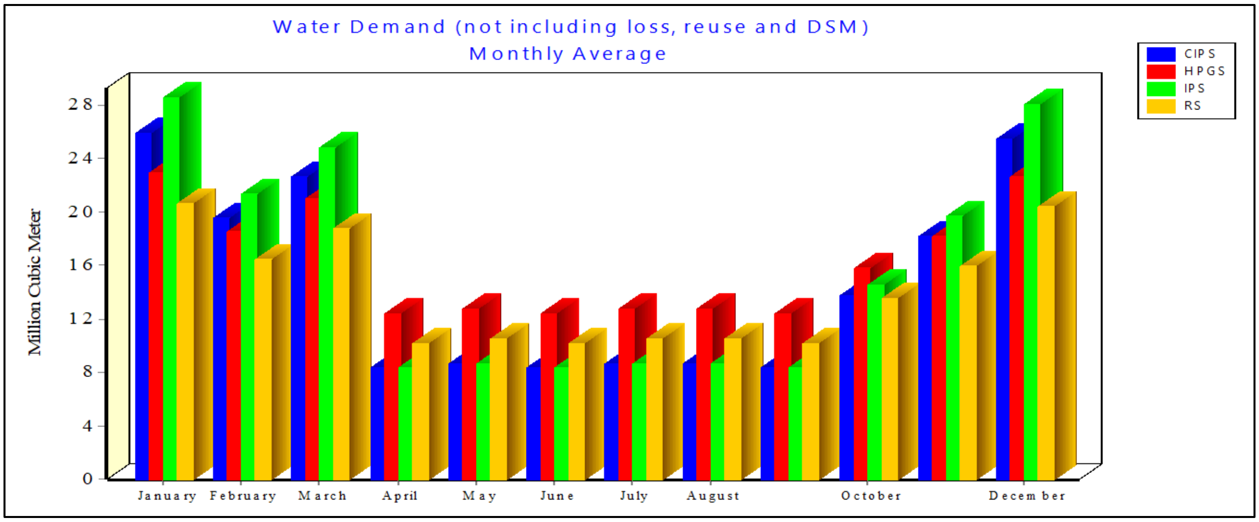


Figure 4.20: Annual WD comparison among demand site for all scenario (MCM)

As illustrated in the Figure 4.21, among annual monthly unmet water demand of each scenario, all scenarios are faced to water scarcity on the month between December to May. Comparison by sectoral demand sites, unmet water demand under each scenario, agriculture demand site was face to high unmet demand under current irrigation scenario and irrigation projection scenario which results 1.87 MCM and 3.47 MCM respectively. Unmet demand for rural 8.31 MCM and urban 7.52 MCM demand sites was more increased under high population growth scenario and remain constant under current irrigation scenario and irrigation projection scenario. On the hand, Livestock demand site got full coverage under all scenarios. Summarized annual each month unmet water demand comparison under each scenario is shown in **Appendix XIV**.

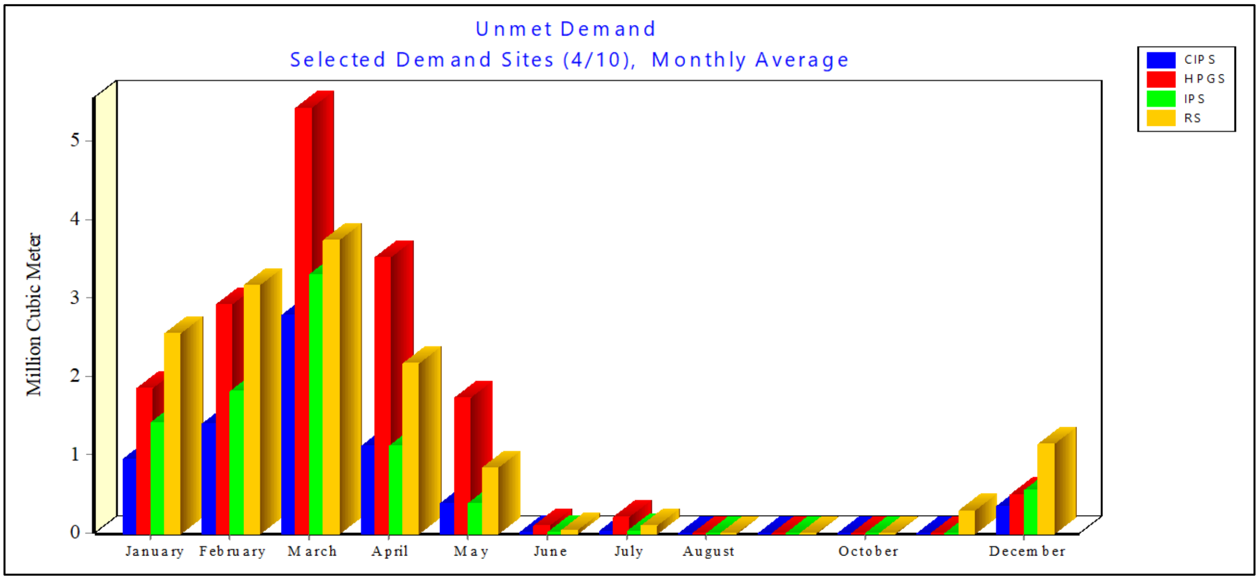


Figure 4.21: Annual monthly unmet demand among all scenario.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study was undertaken to Investigate the existing of surface water potential and future water demand analysis implication for enhancing water resource planning in upper Gilgel Gibe-basin using the WEAP (Water Evaluation Assessment & Planning) tool approach.

The finding of study shows that, the Surface water potential of upper Gilgel Gibe-basin was 1276 MMC, but in dry season of the year, about 9.5% lowest runoff was seen from January to June during all months of the year. Under the year 2019, the water demand situation for rural was 70.88 MCM followed by agriculture which consumed 43.91 MCM. livestock and urban water demand was also 28.64 MCM and 24 MCM respectively. Currently the total annual water demand within the sub-basin make up to 2.8% of water potential which was sufficient to cover all water demand coverage. The study estimates that, the environmental flow requirement was 265.83 MCM (20.8 %) of the mean annual flow to maintain the basic ecological functioning of the downstream.

To predict future water demands, four scenarios (reference, high population growth, current irrigation potential and irrigation projection) were used. The model annual water demand result by considering all demand site under four scenarios were estimated 167.72 MCM, 194.7 MCM, 176.89 MCM and 188.32 MCM for reference, high population growth, current irrigation potential and irrigation projection scenarios respectively. Although under all scenarios comparison, agriculture site was the highest water utilized sector in CIPS and IPS which results 74.61 MCM and 86.04 MCM respectively. On the other hand, livestock, rural and urban consumed, about 34.41 MCM, 80.93 MCM and 35.45 MCM respectively in HPGS. When comparing the annual unmet water demand, agriculture demand site faced highest unmet demand under CIPS and IPS which accounted 1.87 MCM and 3.47 MCM respectively. under HPGS the unmet demand for Rural and urban were estimated 8.31 MCM and 7.52 MCM respectively. But under all scenarios livestock demand site could not face water shortage problem.

5.2 Recommendation

Based on the results obtained from the analysis, the study recommended that: -

1. Additional investigation required on groundwater potential on its extent, location, recharges rates, safe yields, and current amounts of abstraction; basic quality and purpose of sectoral shares.
2. To support water potential of the sub-basin during dry season of the year small dams and other river diversions should be built to regulate constant flow throughout the year.
3. To support water potential of the sub-basin, increasing water recycling and reuse, creating alternative water supply sources from storm water/rain water, providing water quality to end user needs, and implementing multipurpose and multi-benefit infrastructure to achieve environmental goals.
4. The study results of water scarcity indicated that, it needs immediate solutions by water planners, decision makers and local authorities to balance the supply and demand which avoid water based conflicts among multiple water users in the sub-basin. Especially, for agricultural activities adaptation on revision of the cropping patterns and their water requirement should be addressed, and also the most efficient irrigation methods must be introduced to the local communities as well as to the irrigation institute to solve the water demand coverage issues

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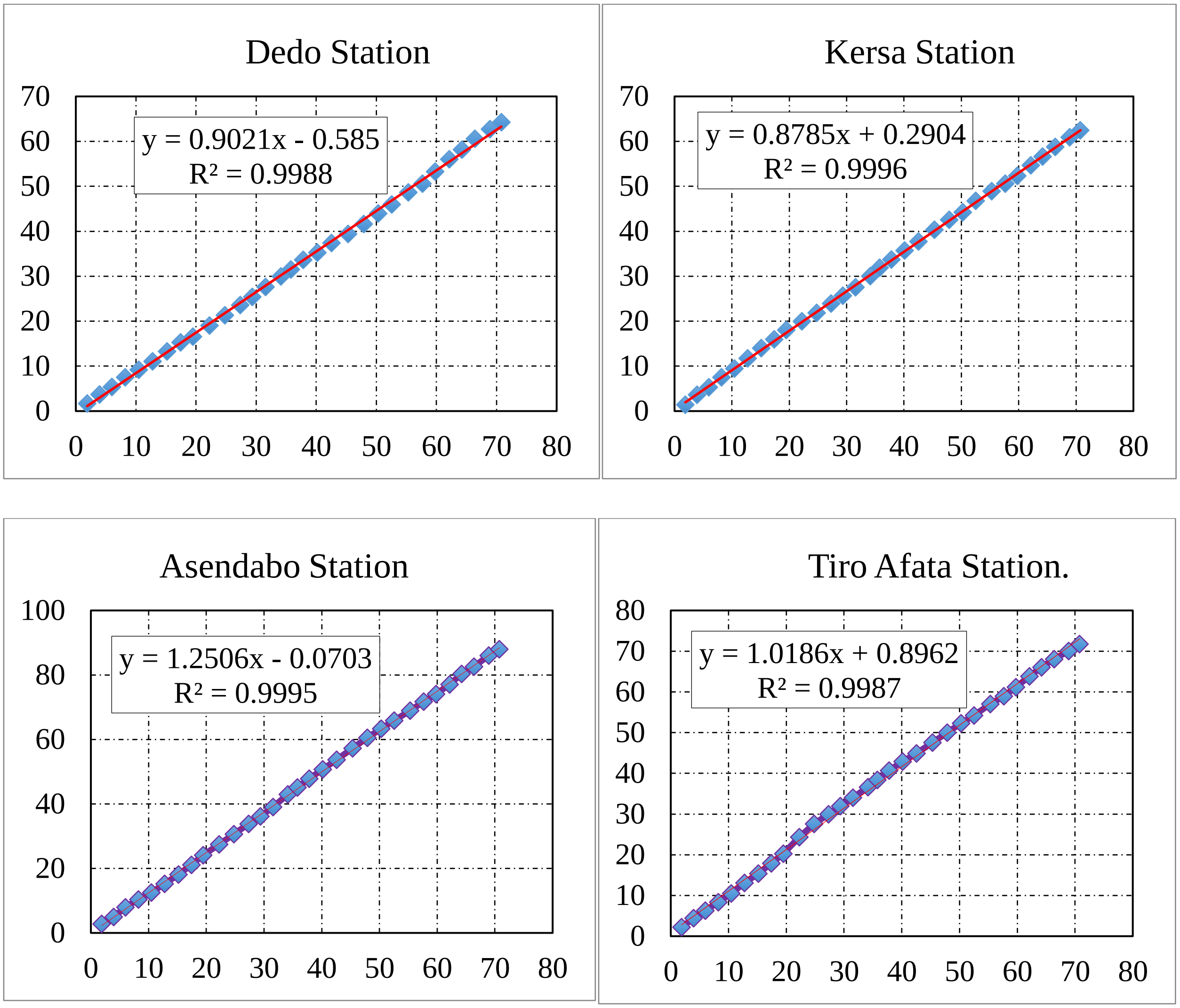
APPENDIX

APPENDIX I: Double mass curve for the sub-basin stations (mm).



APPENDIX II: CROPWAT8 result used for WEAP model

(a) Kersa station

Month	Tmin	Tmax	RH	Wind	Sun	S. Rad	ETo	Eff RF	Kc
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day	mm	Coeff.
Jan	12.4	28.4	53	1	8	19.7	3.22	0.2	1
Feb	13.1	29.9	50	1	8.6	21.7	3.7	0.3	0.7
Mar	13.6	29.4	61	1	8.4	22.3	4.05	1.4	0.8
Apr	13.6	28.5	72	1	8.4	22.5	4.2	3.7	0
May	12.8	26.7	80	1	8.2	21.5	3.99	5.1	0
Jun	12.2	23.6	87	1	6.8	18.9	3.46	7.3	0
Jul	11.7	21.4	90	1	5.7	17.4	3.1	7.4	0
Aug	11.8	22.4	89	1	6.7	19.5	3.42	8.4	0
Sep	12.1	24.1	84	1	8.3	22.1	3.88	6.1	0
Oct	11.1	26.2	70	1	9	22.5	3.82	2.4	0
Nov	11.3	27	59	1	8.6	20.6	3.38	1.3	0
Dec	11.2	27.4	53	1	8.2	19.5	3.1	1.2	0
Ave	12.2	26.3	71	1	7.9	20.7	3.61	3.7	0.2

(b) Dedo Station

Month	Tmin	Tmax	RH	Wind	Sun	S. Rad	ETo	Eff RF	Kc
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day	mm	Coeff.
Jan	12.9	29.8	46	2	8.7	20.5	3.36	0.1	1
Feb	13.7	31.3	43	2	9.3	22.7	3.85	0.1	0.7
Mar	14.3	31.7	51	2	9.2	23.5	4.28	1	0.8
Apr	14.1	30.8	60	2	9.2	23.6	4.45	2.7	0
May	13.1	29	69	2	9	22.8	4.29	3.6	0
Jun	12.4	24.8	82	1	7.7	20.3	3.77	5.8	0
Jul	11.7	22.1	86	1	6.7	18.9	3.38	6.5	0
Aug	11.7	23.6	85	1	7.6	20.9	3.7	7	0
Sep	12.2	26	78	1	9.2	23.4	4.17	4.9	0
Oct	11.4	28	61	2	9.5	23.1	3.97	1.4	0
Nov	11.6	28.6	51	2	9	21.2	3.5	0.5	0
Dec	11.8	28.5	46	2	8.7	20.1	3.2	0.7	0
Ave	12.6	27.9	63	2	8.6	21.8	3.83	2.9	0.2

(c) Tiro Afata station

Month	Tmin	Tmax	RH	Wind	Sun	S. Rad	ETo	Eff RF	Kc
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day	mm	Coeff.
Jan	10.1	29	58	1	8.8	20.8	3.36	0.2	1
Feb	11.3	30.6	53	1	9.5	23	3.86	0.2	0.7
Mar	12.4	30.5	61	2	9.4	23.8	4.27	1.1	0.8
Apr	12.8	29.9	69	2	9.4	24	4.43	3.1	0
May	12.3	28.2	77	1	9.2	23.1	4.26	5.2	0
Jun	11.5	25.1	86	1	8	20.8	3.78	7.9	0
Jul	10.9	22.4	90	1	6.8	19.1	3.36	8.4	0
Aug	10.8	23.6	90	1	7.8	21.2	3.7	8.7	0
Sep	10.6	24.9	86	1	9.3	23.6	4.11	5.5	0
Oct	8.9	26	77	1	9.6	23.3	3.92	1.5	0
Nov	8.8	26.9	69	1	9.1	21.4	3.48	1	0
Dec	8.7	27.6	63	1	8.8	20.3	3.22	0.8	0
Ave	10.8	27.1	73	1	8.8	22	3.81	3.6	0.2

(d) Omo Nada

Month	Tmin	Tmax	RH	Wind	Sun	S. Rad	ETo	Eff EF	Kc
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day	mm	Coeff.
Jan	12.6	28.7	49	2	8.1	19.8	3.13	0.2	1
Feb	13.3	30.3	47	2	8.6	21.7	3.59	0.3	0.7
Mar	13.8	30.3	57	2	8.4	22.4	3.96	1.4	0.8
Apr	13.6	29.2	68	1	8.4	22.5	4.11	3.4	0
May	12.8	26.1	77	1	8.3	21.6	3.87	5.1	0
Jun	12.3	22.6	86	1	6.8	19	3.32	8.2	0
Jul	11.9	21	89	1	5.7	17.4	2.98	8.7	0
Aug	12.1	22.5	88	1	6.8	19.7	3.35	9.6	0
Sep	12.2	24.6	81	1	8.4	22.2	3.78	6.8	0
Oct	11.2	27.5	64	2	8.9	22.4	3.71	2.3	0
Nov	11.4	28	52	2	8.7	20.8	3.28	1.1	0
Dec	11.6	27.8	46	2	8.3	19.6	2.98	0.9	0
Ave	12.4	26.6	67	2	8	20.7	3.5	4	0.2

APPENDIX III: Monthly average Crop Water Requirement

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
Maize	107.3	31.1	0	0	0	0	0	0	0	17	59.2	110.4
Potato	108.1	46.8	0	0	0	0	0	0	0	38.2	74.6	108.4
Soybean	84.2	0	0	0	0	0	0	0	0	0	43.4	107.6
Cabbage Crucifers	98.9	103.9	109.2	0	0	0	0	0	0	42	69	78.9
Sorghum	95.4	94.3	48.1	0	0	0	0	0	0	0	14.7	50.3
Net scheme irr.req.												
in mm/day	3.2	1.8	0.8	0	0	0	0	0	0	0.6	1.8	3.1
in mm/month	100.1	50.5	25.8	0	0	0	0	0	0	19.9	54.4	95.1
in l/s/h	0.37	0.21	0.1	0	0	0	0	0	0	0.07	0.21	0.36
Irrigated area (% of total area)	100	82	32	0	0	0	0	0	0	67	100	100
Irr.req. for actual area(l/s/h)	0.37	0.25	0.3	0	0	0	0	0	0	0.11	0.21	0.36

APPENDIX IV:

(a) Livestock Population in the year 2017.

District	2017					
	Cattle	Goat	Horse	Donkey	sheep	Mule
Tiro Afata	192987	66517	4381	8290	68525	5985
Kersa	209670	63736	5584	7525	86736	5428
Omo Nada	248856	36170	6809	24601	113691	7231
Dedo	312350	59423	31378	16403	375190	22042
Seka Chekorsa	208533	59083	8269	8922	103336	12137
Sub total	1172398	284928	56423	65743	747476	52822
Total	2379790					

(b) Livestock Population in the year 2018.

District	2018					
	Cattle	Goat	Horse	Donkey	sheep	Mule
Tiro Afata	204987	67717	4501	8409	71524	29945
Kersa	221669	64936	5703	7645	89736	5748
Omo Nada	260856	37370	6929	25621	116690	7551
Dedo	324349	60623	31498	17523	387190	23262
Seka Chekorsa	220636	61309	10291	9874	108329	12554
Sub total	1232498	291954	58923	69074	773467	79058
Total	2504974					

APPENDIX V: The annual each month Water demand under Reference Scenario

Month	Agricultural WD	Livestock WD	Rural WD	Urban WD	Sum
Jan	10.15	2.43	6.02	2.06	20.66
Feb	6.86	2.22	5.48	1.88	16.44
Mar	8.23	2.43	6.02	2.06	18.74
Apr	0.00	2.35	5.82	2.00	10.17
May	0.00	2.43	6.02	2.06	10.51
Jun	0.00	2.35	5.82	2.00	10.17
Jul	0.00	2.43	6.02	2.06	10.51
Aug	0.00	2.43	6.02	2.06	10.51
Sep	0.00	2.35	5.82	2.00	10.17
Oct	3.02	2.43	6.02	2.06	13.53
Nov	5.76	2.35	5.82	2.00	15.93
Dec	9.88	2.43	6.02	2.06	20.39
Sum	43.91	28.64	70.88	24.29	167.72

APPENDIX VI: The annual each month unmet Water demand under Reference Scenario

Month	Agricultural WD	Livestock WD	Rural WD	Urban WD	Sum
Jan	0.00	0.00	1.56	0.98	2.54
Feb	0.00	0.00	2.06	1.09	3.15
Mar	0.27	0.00	2.17	1.29	3.73
Apr	0.00	0.00	1.23	0.94	2.17
May	0.00	0.00	0.45	0.38	0.83
Jun	0.00	0.00	0.00	0.04	0.04
Jul	0.00	0.00	0.00	0.10	0.10
Aug	0.00	0.00	0.00	0.00	0.00
Sep	0.00	0.00	0.00	0.00	0.00
Oct	0.00	0.00	0.00	0.00	0.00
Nov	0.00	0.00	0.21	0.08	0.29
Dec	0.00	0.00	0.66	0.48	1.14
Sum	0.27	0.00	8.33	5.39	13.99

APPENDIX VII: The annual each month Water demand under High population growth.

Month	Agricultural WD	Livestock WD	Rural WD	Urban WD	Sum
Jan	10.15	2.92	6.87	3.01	22.95
Feb	6.86	2.66	6.26	2.74	18.52
Mar	8.23	2.92	6.87	3.01	21.03
Apr	0.00	2.83	6.65	2.91	12.39
May	0.00	2.92	6.87	3.01	12.80
Jun	0.00	2.83	6.65	2.91	12.39
Jul	0.00	2.92	6.87	3.01	12.80
Aug	0.00	2.92	6.87	3.01	12.80
Sep	0.00	2.83	6.65	2.91	12.39
Oct	3.02	2.92	6.87	3.01	15.82
Nov	5.76	2.83	6.65	2.91	18.15
Dec	9.88	2.92	6.87	3.01	22.68
Sum	43.91	34.41	80.93	35.45	194.70

APPENDIX VIII: The annual each month unmet Water demand under High population growth.

Month	Agricultural WD	Livestock WD	Rural WD	Urban WD	Sum
Jan	0.10	0.00	0.91	0.84	1.84
Feb	0.00	0.00	1.71	1.19	2.91
Mar	0.27	0.00	2.95	2.19	5.42
Apr	0.00	0.00	1.77	1.74	3.51
May	0.00	0.00	0.77	0.96	1.72
Jun	0.00	0.00	0.00	0.10	0.10
Jul	0.00	0.00	0.00	0.20	0.20
Aug	0.00	0.00	0.00	0.00	0.00
Sep	0.00	0.00	0.00	0.00	0.00
Oct	0.00	0.00	0.00	0.00	0.00
Nov	0.00	0.00	0.00	0.00	0.00
Dec	0.00	0.00	0.20	0.30	0.50
Sum	0.37	0.00	8.31	7.52	16.21

APPENDIX IX: The annual each month Water demand under current irrigation potential (MCM).

Month	Agricultural WD	Livestock WD	Rural WD	Urban WD	Sum
Jan	17.25	2.43	4.97	1.28	25.93
Feb	11.66	2.22	4.53	1.17	19.57
Mar	13.99	2.43	4.97	1.28	22.67
Apr	0.00	2.35	4.81	1.24	8.40
May	0.00	2.43	4.97	1.28	8.68
Jun	0.00	2.35	4.81	1.24	8.40
Jul	0.00	2.43	4.97	1.28	8.68
Aug	0.00	2.43	4.97	1.28	8.68
Sep	0.00	2.35	4.81	1.24	8.40
Oct	5.13	2.43	4.97	1.28	13.81
Nov	9.79	2.35	4.81	1.24	18.20
Dec	16.78	2.43	4.97	1.28	25.46
Sum	74.61	28.66	58.56	15.07	176.89

APPENDIX X: The annual each month unmet Water demand under current irrigation potential (MCM).

Month	Agricultural WD	Livestock WD	Rural WD	Urban WD	Sum
Jan	0.35	0.00	0.43	0.17	0.95
Feb	0.41	0.00	0.73	0.26	1.40
Mar	0.82	0.00	1.37	0.58	2.78
Apr	0.00	0.00	0.74	0.36	1.10
May	0.00	0.00	0.27	0.12	0.39
Jun	0.00	0.00	0.00	0.02	0.02
Jul	0.00	0.00	0.00	0.03	0.03
Aug	0.00	0.00	0.00	0.00	0.00
Sep	0.00	0.00	0.00	0.00	0.00
Oct	0.00	0.00	0.00	0.00	0.00
Nov	0.00	0.00	0.00	0.00	0.00
Dec	0.29	0.00	0.04	0.01	0.34
Sum	1.87	0.00	3.59	1.54	7.00

APPENDIX XI: The annual each month Water demand under irrigation projection (MCM).

Month	Agricultural WD	Livestock WD	Rural WD	Urban WD	Sum
Jan	19.90	2.43	4.97	1.28	28.58
Feb	13.44	2.22	4.53	1.17	21.36
Mar	16.13	2.43	4.97	1.28	24.81
Apr	0.00	2.35	4.81	1.24	8.40
May	0.00	2.43	4.97	1.28	8.68
Jun	0.00	2.35	4.81	1.24	8.40
Jul	0.00	2.43	4.97	1.28	8.68
Aug	0.00	2.43	4.97	1.28	8.68
Sep	0.00	2.35	4.81	1.24	8.40
Oct	5.92	2.43	4.97	1.28	14.60
Nov	11.29	2.35	4.81	1.24	19.70
Dec	19.35	2.43	4.97	1.28	28.04
Sum	86.04	28.66	58.56	15.07	188.32

APPENDIX XII: The annual each month unmet Water demand under irrigation projection (MCM).

Month	Agricultural WD	Livestock WD	Rural WD	Urban WD	Sum
Jan	0.81	0.00	0.43	0.17	1.41
Feb	0.82	0.00	0.73	0.26	1.81
Mar	1.34	0.00	1.37	0.58	3.30
Apr	0.00	0.00	0.74	0.36	1.10
May	0.00	0.00	0.27	0.12	0.39
Jun	0.00	0.00	0.00	0.02	0.02
Jul	0.00	0.00	0.00	0.03	0.03
Aug	0.00	0.00	0.00	0.00	0.00
Sep	0.00	0.00	0.00	0.00	0.00
Oct	0.00	0.00	0.00	0.00	0.00
Nov	0.00	0.00	0.00	0.00	0.00
Dec	0.50	0.00	0.04	0.01	0.54
Sum	3.47	0.00	3.59	1.54	8.60

APPENDIX XIII: Annual each month water demand comparison among all scenarios (MCM).

Month	RS	HPGS	CIPS	IPS
Jan	20.66	22.95	25.93	28.58
Feb	16.44	18.52	19.57	21.36
Mar	18.74	21.03	22.67	24.81
Apr	10.17	12.39	8.40	8.40
May	10.51	12.80	8.68	8.68
Jun	10.17	12.39	8.40	8.40
Jul	10.51	12.80	8.68	8.68
Aug	10.51	12.80	8.68	8.68
Sep	10.17	12.39	8.40	8.40
Oct	13.53	15.82	13.81	14.60
Nov	15.93	18.15	18.20	19.70
Dec	20.39	22.68	25.46	28.04
Sum	167.72	194.70	176.89	188.32

APPENDIX XIV: Annual each month unmet water demand comparison among all scenarios (MCM).

Month	RS	HPGS	CIPS	IPS
Jan	0.95	1.84	1.41	2.54
Feb	1.40	2.91	1.81	3.15
Mar	2.78	5.42	3.30	3.73
Apr	1.10	3.51	1.10	2.17
May	0.39	1.72	0.39	0.83
Jun	0.02	0.10	0.02	0.04
Jul	0.03	0.20	0.03	0.10
Aug	0.00	0.00	0.00	0.00
Sep	0.00	0.00	0.00	0.00
Oct	0.00	0.00	0.00	0.00
Nov	0.00	0.00	0.00	0.29
Dec	0.34	0.50	0.54	1.14
Sum	7.00	16.21	8.60	13.99