JIMMA UNIVERSITY

SCHOOL OF POSTGRADUATE STUDY

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIROMENTAL ENGINEERING

HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR

Assessment of Surface Water Availability and Demand Analysis for Water Resource Planning: The Case of Borkena River Watershed, Awash River Basin, Ethiopia.

By: Hasen Hussien Hamid

A Thesis submitted to Jimma University, Jimma Institute of Technology, Faculty of Civil and Environmental Engineering, Hydrology and Hydraulic Engineering Chair, in partial fulfillment of the requirements for the degree of Master Science in Hydraulic Engineering

February, 2020

Jimma, Ethiopia

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Main Advisor: Dr. Zerihun Asmelash (PhD, Ass. Professor)
Co-Advisor: Mr. Andualem Shigute (MSc)

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Jimma, Ethiopia

DECLARATION

I under signed, declare that this thesis entitled "Assessment of Surface Water Availability and Demand Analysis for Water Resource Planning at Awash Kombolcha Sub-Basin: The Case of Borkena River Watershed, ANRS, Ethiopia." is my original work, and has not been presented or published by any others person for un award of a degree in Jimma University or other Universities. I have acknowledged and quoted all materials in this Thesis which is not my own work through appropriate referencing and acknowledgements.

Hasen Hussien Hamid

Signature__________________ Date __________________

APPROVAL SHEET

We certify that the Thesis entitled "Assessment of the Surface Water Availability and Demand Analysis for Water Resource Planning at Borkena River Watershed, Awash River Basin" is the work of Hasen Hussien 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, Ass. Professor) ____________________ _______________

(Main Advisor) Signature Date

Mr. Andualem Shigute (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 Hasen Hussien 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.

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ABSTRACT

Water is a basic necessity for sustaining life and development of society with the Increasing of population and socio- economic activities demand for water has increased rapidly over the years the aim of this study is to understand the association of surface water availability and water demand for water competition scenarios with surface water variability in the Borkena *watershed to assess the current surface water availability of river Borkena in terms of demand and supply potential, the current (2019) data were used into the entire time horizon in which no changes are imposed and serves as a point of comparison for the other scenarios like: medium growth and high growth in which changes are made in the system data furthermore to predict the future scenarios of water resource of Borkena watershed, Unmet, demand and demand Coverage in (%) were considered to evaluate the impact of possible surface water demand on the water resources of Borkena watershed by 2030, the General work was carry out by collecting secondary data obtaining from different data sources, the Analysis of raw data was made for data quality checking and filling of missing records the data source were Ministry of Water Irrigation & Energy Ethiopian Mapping Agency National Meteorological service Agency, Central Static Agency of Ethiopia and literatures, to evaluate water Demands for various needs in the study including domestic livestock agriculture industrial commercial and environmental are identifying, materials used in the study are Arc GIS 10.4.1 CropWat8 model and WEAP (Water Evaluation and Planning) the watershed receives the amount of rainfall estimated around 54.4 MCM annually will be by year (2020-2030) the total annual surface runoff from a given precipitation in the study area estimated to be 15.1 (MCM) by (2020-2030) the total surface water availability in the area has been estimated to be 4.1 BCM by 2020-2030 but for the current account surface water availability has estimated to be 544.5Mm^3 at the study period in 2019 the result from WEAP Model indicated that demand coverage (%) and supply potential in the study for all scenarios over the year is satisfied during the* month *(July to September) since the rain fall of the area is characterized by mini modal types of rain fall pattern generally in the case of water consumption between reference ,medium growth and high growth scenarios are 37%,45% and 48% the available surface water will use by year of (2030.*

Keywords: *Surface water availability, Demand analysis, Borkena watershed, WEAP Model, Crpwat8 Model.*

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Lastly, I thank my wife: Sara Ghezu and our kids Yonatal Hasen and Fasika Hasen for being with me throughout my year of education both morally and lovely. This victory is crown to us all and may God bless us to achieve more in life.

TABLE OF CONTENT PAGE

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

ABA	Awash basin authority
ANRS	Amhara national regional state
AWD	Agricultural water demand
AWRDB	Amhara Water Resource Development Bureau
BCM	Billion cubic meters
CIWD	Commercial and institutional water demand
DMS	Demand Management System
EFR	Environmental flow requirement
ETH-DEM	Ethiopia digital Elevation Model
EWD	Environmental water demand
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GTP	Growth Transformation Plan
GWP	Global Water Partnership
HG	High growth scenario
IOPConf	International of post Graduation conference
IWD	Industrial water demand
IWRM	Integrated Water Resources Management
LWD	Livestock water demand
MG	Medium growth scenario
NSE	Nash-Sutcliffe model efficiency
PBIAS	Percent bias
RWD	Rural water demand
SEI	Stockholm Environment Institute
UNDP	United nation development program
UTM	Universal Transverse Mercator
UWD	Urban water demand
WEAP	Water Evaluation and Planning System
WMO	World Meteorological Organization

1. INTRODUCTION

1.1. Background of the Study

Water is necessary for all forms of human, animal and plant life. It is essential for overall human well-being and supports all aspects of human livelihoods. Furthermore, water plays an important role in supporting productive human activities such as agricultural, energy and industrial production, sanitation, transportation services, fishing and tourism (UNDP, 2009). The global water demand will primarily grow due to population and economic growth, rapid urbanization and the increasing demand for food and energy (GWP, 2009). Therefore, assessing water resource availability of relevant spatial and temporal scales is of importance (Junguo , 2017). as well as an ability to assess the availability of freshwater resources has been an issue of importance in most countries for many decades (WMO, 2012).

Water is a basic necessity for sustaining life and development of society, with the Increasing of population including urbanization, economic growth, industrial production, agricultural and livestock production, demand for water has increased rapidly over the years (GWP, 2000). Population growth and economic development put constant pressure on the eco-systems of water resources (Junguo, 2017). There is also a strong positive relation between water demand and urbanization or population growth.

There are twelve major river basins in Ethiopia of which nine of them have run-off, with the exception of Awash River basin, Rift Valley Lakes and Omo-Ghibe, all the other rivers are trans-boundary and flow to the North-western, Western and South-eastern areas of the country (Tegenu, 2012). The Awash River rises on the high plateau to the West of Addis Ababa near Ginchi in the central highlands of Ethiopia at an altitude of about 3000m. in order to assess surface water availability and demand scenario analysis implication for enhancing the water resources planning, and monitoring, the Awash Basin is sub divided into six planning areas, namely, Awash Upstream Koka, Awash Awash, Awash Halidebi, Awash Adaitu, Awash Terminal and Eastern sub basin (Tegenu, 2012). Awash Koka sub basin comprises Awash Kuntre River, Mojo River and Akaka River. Awash at Awash sub basin includes Keleta-Werenso Rivers and Awash Arba 1 and 2 Rivers. Awash Halidebi sub basin contains Kesem-Kebena Rivers, Ankober River, Negeso-Gera River, Awadi River and Gedebasa Swamp.

Awash Adaitu sub-basin includes Ataye River, Borkena River, Cheleleka River and Adaitu River. Awash Terminal sub-basin includes Mile River and Logia River (Tegenu, 2012).

Borkena watershed is one of the rivers found in the middle part of Awash Basin which found between high water utilizing sectors and facing challenges of land degradation, high population density, natural water degradation and wetland degradation. Already desertification has started at lower and Middle part of Awash River Basin. In the upper part deforestation and sedimentation has increased in the past three decades. As more water is drawn from the river there could be drastic climate and ecological changes which endanger Borkena watershed habitat and human livelihood. Increase in water demand will reduced surface water availability among users during dry seasons and has as well in the future water conflicts will increase in the basin. Unless properly managed water resource.

Particularly in the Borkena River watershed, in the North-central part of Ethiopia has been exposed to in a relatively greater number of large-scale manufacturing plants which is all plant found along the two main tributary of Borkena River. Textiles, meat processing (ELFORA), a tannery, brewery (BGI), steel factory, and Loyale Irrigated Land are near Loyale River and worka Irrigated land is near Worka River (Eskinder,2011). On top of this, the town has now been selected to be the main industrial corridor of northern Ethiopia. Thus, it is obvious that the associated surface water availability and pollution risk will increase in the future to meet the demand.

The existing industries have been discharging their wastes into the rivers. According to the local district office in Kombolcha town report, more than 25 000 farmers are diverting the effluent-contaminated river water to irrigate about 2700 ha of farmland to grow different crops including cereals, vegetables and fruits, in addition, the report also explains that many farmers and enterprises have been using this river for irrigation for a long time (Eskinder, 2011). As a result, no study has been conducted on the topic of assessment of surface water availability and water demand analysis to enhance water resource planning and livelihood of the study area in the level of watershed.

The watershed of Borkena demonstrates severe soil degradation problems. The problem has been long aged and deep rooted, as the watershed is one of the aged agricultural areas. The major form of land degradation in the watershed is soil erosion by water. The common type of erosion is water erosion exhibited with all forms of erosion such as sheet and rills, gully, river embankments and land sliding on very steep slope areas. Borkena cascade dams constructed in the Dergue regime are considered as an example of largest check dam in east Africa (Eskinder, 2011). The soil erosion in the watershed is not due to natural causes but primarily to human activities that progressively ever grown since centuries (Eskinder, 2011). The long aged agricultural activities resulted in progressive depletion on resources through deforestation, overgrazing and over cultivation and hence sever soil erosion and land degradation (Eskinder, 2011).. Presently, these resources, including water resources, are exceedingly depleted resulting in environmental, socio-economic and ecological losses. The resources depletion has created to progressively lowered land productivity to the rural people.

1.2. Statement of the Problem

Recent studies showed that climate change, socioeconomic activities, population growth, water pollution and the huge water abstraction are the main challenges that altered the natural hydrologic regime of the Borkena River (Eskinder, 2011). As a result no study has been conducted on the topic of surface water availability and water demand analysis to enhance water resource planning and livelihood of the study area. As Ethiopia is under significant influence of global surface water variability then prediction of the future demand will have tremendous importance for better awareness and preparedness to mitigate the subsequent surface water scarcity associated.

The question arise is that what will be the future demand and supply imbalance impact on the hydrology of the Borkena watershed because there is no research that has been attempt on this topic in this area that is the other goal of this Research paper to focus on this topic.

The aim of this study is to understand the association of surface water availability and water demand for water competition scenarios with surface water variability in the central highlands of Ethiopia, Particularly in Borkena watershed in the north-central part of Ethiopia. The high-water use for industrial, domestic and agricultural sectors in this Area due to the lack of hydrological knowledge, unimplemented water rights and ignorance of the environmental water demands leads to decrease water quantity and quality, hence it affect the water resource of the area.

1.3. Research questions

1. What is the current surface water availability of river Borkena in terms of demand and supply potential?
2. What are the scenarios of water resource of Borkena watershed?
3. What will be the impact of possible surface water demand on the water resources of Borkena watershed by 2030?

1.4. Objective of the Study

1.4.1 General Objective

The aim of this study is to assess the current surface water availability and demand analysis within Borkena watershed and project the implication based on current and future scenarios.

1.4.2. Specific objectives

1. To assess the current surface water availability of river Borkena in terms of demand and supply potential;
2. To predict the future scenarios of water resource of Borkena watershed; and
3. To evaluate the impact of possible surface water demand on the water resources Borkena River watershed by 2030.

1.5. Scope and Limitations of the Study

This study was carrying out in Borkena river watershed. This is covers the local uses of water resources to the domestic, livestock, environment and agriculture to build future scenarios in order to identify the possible future impact of surface water availability in the study area. The assessment of current surface water availability in river Borkena in terms of demand and supply was in quantity manner, to predict the future scenarios for the sack of evaluating the impact of possible surface demand and allocation were the goal. The allocation of the surface water over the selected scenarios was for enhancing surface water resource planning and management in the study area.

In this thesis, based on a limited set of data in order to account Climate change scenarios and their impact on surface water resources in this study are hardly to be taken into account due to limitation of deep information about these scenarios of the study area and demands, allowing for reliable descriptions of the water system under different conditions. In addition to this the assumption made, this study has been done within a framework of few information on water demand since was not available in detail. The thesis does not involve the following: The ground water resources and climate change that can lead to reliable information of the watershed parameters in the study area. The main problems include: (i) lack of sufficient studies in the area and (ii) lack of sufficient data in watershed level.

1.6. Significance of the study

This research help to understand what does mean by surface water with a better economic development and better plan in order to balance the predictable amount of demand and supply. yet, the study on this issue is scanty in this area, so this thesis use to address this gap and Provide sufficient information on water demand as well as the supply potential of the study area which are important for decision makers engages in water related sector. WEAP modeling has an important role to play in evaluating the possible impacts of different development options and scenarios.

Furthermore, the result from the analysis use to propose the alternative suitable technical and non-technical means to shape up water demand and supply, particularly in Borkena watershed, in the study area The Scenarios that conducted in this studies were as a useful contribution to greater understanding of what will happen in the Borkena river watershed, having implication to development, in the future by year 2030.

2. LITERATURE REVIEW

2.1. Introduction of surface water

Surface water is water that is open to the atmosphere and fed by runoff from the surface, such as in a stream, river, lake, or reservoir. Water discharged into a river is the runoff from the watershed drained by the river (Taffa, 2002, Durrans, 2003, Malual, 2015). Surface water is a valuable resource that can use for public, industrial, navigation and agricultural supply purposes, etc. Therefore, understanding surface water resources potential and use is a key aspect of water resource assessment, evaluation and development. The assessment of water availability at watershed level is realized by quantifying runoff generated in the watershed (Daniel *et al,* 2011, Malual, 2015). Water resources assessment relies on a full understanding of all the water flows and storages in the river basin or catchment under consideration.

Various literatures have been done on global and regional studies level about surface water availability assessment in watershed, basin and sub-basin level.

According to Teka (2012), investigated relationships between rainfall variability and crop and livestock production in eastern Tigray, Northern Ethiopia. They found a positive correlation between livestock holding size and crop yield with rainfall amount. Another study was the work of (Rosell and Holmer, 2007) on implications of rainfall change for *Belg* harvest in South Wollo, north-central Ethiopia. They found significant effect of rainfall variability on food security of communities and changes in farming situation in the past 40 years. This indicates that there is no implementation of water use policies in order to enhance Water Resources planning and improving livelihood in the sub-basin. Decrease in rainfall, increases agricultural, industrial, livestock's environmental need and domestic water abstraction, poor water management aggravates the problem with more intensity during the recent time because of lack of proper water resources management plan. However, no effort has been made to assess the water supply and demand situation of the study Area and identify the major challenges of water resource planning.

2.2. Overview of Surface Water Assessment

The eradication of poverty and hunger in rural areas is closely related to a fair and equitable access for the most vulnerable people to basic livelihood assets (including land and water) for most domestic and productive uses (UN, 2006). Therefore, water resource management is one of the most important challenges the world is facing today. In order to meet the demands of different users, efforts should be intensified on the efficient use of all water resources (surface water, ground water, and rainfall) and also on water allocation plans that maximize the resultant economic returns to limited water resources and, at the same time, protect the fragile ecosystem (Adeboye *et al.,*2008).

Surface water is water that is on the Earth's surface, such as in a stream, river, lake, or reservoir. Surface water is a valuable resource which can be used for public, industrial and agricultural supply purposes. Surface water courses also provide important natural habitats and environmental and leisure resources. Therefore, understanding surface water resources is a key aspect of water resource assessment and evaluation (Tadesse, 2006). If it is important to quantify the surface water potential in Borkena river basin in terms of surface runoff; one can ask what hydrologic models are available to simulate the surface runoff and which one is the most suitable in the study area solve this problem? Really critical question that has to be answered, off course there are different types of hydrologic models capable of simulating surface runoff in a given catchment.

There is wide variability in their characteristics and potential applications, for example, spatial and temporal scale, processes modeled and the basis of relationships and algorithm used. With this increasing number of availability, wide ranging characteristics and potential applications of the models, it is becoming challenging job for the potential model users to choose a particular model best suited for the given problem. In addition, modifications are made to existing models and new models are available each year. Therefore, updated, consistent and comprehensive evaluations of hydrological models are a continuous need (Dhami and Pandey, 2013). In this study WEAP model is comparably suited to simulate Catchment Run-off in Borkena Watershed.

2.3. Overview of Water Demand Assessment

The factors that determine development potential in a given geographic area, the availability of water for residential, commercial, and industrial purposes is a primary indication of prospective growth. Governmental bodies at the regional, state and federal levels often need to identify water supply availability in order to identify growth potential (Wallace, 2001). According to Flint (2004) 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.

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

2.4. Global surface Water Scarcity in Agriculture

60 years ago, the common perception was that water was an infinite resource. At that time, there were fewer than half the current numbers of people on the planet. Affluence was not as high; individuals consumed fewer calories and ate less meat, so less water was needed to produce their food (Chartres and Varma, 2010). They required a third of the volume of water we presently take from rivers. Today, the competition for water resources is much more intense (Chartres and Varma, 2010). This is because there are now nearly eight billion people on the planet; their consumption of meat and vegetables is rising (Chartres and Varma, 2010). Competition for water from industry, urbanization and bio-fuel crops is rising congruently (Chartres and Varma, 2010). To avoid a global water crisis, farmers will have to make use Technology to increase their productivity to cover food demand, while industry and cities find ways to use water more efficiently (Chartres and Varma, 2010).

and transport (AWRDB, 2016). Economically livestock and livestock products constitute significant part on the farmers' life (AWRDB, 2016). They are the only insurance at the time of crop failure. Cattle, sheep, goat, horse and donkey are more importantly Share resource within the sub-basin.in the study area (AWRDB, 2016).

Processing (ELFORA), a tannery, brewery (BGI), steel factory, and Loyale Irrigated Land are near Loyale River and worka Irrigated land is near Worka River (Eskinder, 2011).

2.5. Water resource Planning and management

Water resources planning and management is generally an exercise based on engineering considerations in the past. Nowadays, it increasingly occurs as a part of complex, multidisciplinary analysis that brings together a wide range of individuals and organizations with different interests, technical skills, and options (Yates et al, 2005 and Malual, 2015). Successful planning and management of water resources requires application of effective integrated water resources management (IWRM) models that can solve the encountering complex problems in these multi-disciplinary investigations (Laín, 2008).

2.6. Available Water Resource

Identifying which portion of the freshwater resource is available for human use is always a complex issue, because water is not a static resource, but exists in very dynamic cycles of rain, runoff, and evaporation (Frank and Rijsberman, 2006). Therefore, to describe "available water resource," we need to draw a system boundary. For blue water, most studies define available blue water resource as "renewable surface water" such as runoff and stream flow, with groundwater recharge as an optional component. Spatially, "renewable surface water" resources defined in previous studies may include runoff generated within the watershed only, or more commonly with inflows from upstream watersheds (Hui and May, 2017). Because river discharge will be reduced by upstream water consumption, upstream input is the "unused" part of blue water accumulated along the river network. This "unused upstream input" is subject to changes in upstream consumption. This is not a problem for describing the current demand-to-supply relationship, but the problem interdependency can be a challenge for future scenario analysis, since any change in an upstream watershed will affect upstream input of all downstream watersheds. For green water analysis, interdependency is not a concern, since soil moisture can only be utilized locally for plant growth.

2.7. Scenario analysis with WEAP model

WEAP model allows for the analysis of various global change and water management scenarios (Ahamed, 2015). Scenarios are self-consistent story-lines of how a future system might evolve over time. These can address a broad range of "what if" questions like what if population increases? What if ecosystem requirements are loosen? WEAP is a new generation of water planning and management software, and the powerful capability of today's personal computers can easily use it everywhere to access to the appropriate tools (Ahamed, 2015).

2.8. CropWat Software and Applications

CROPWAT is a decision support system developed by the Land and Water Development Division of FAO for planning and management of irrigation. It is a practical tool that will use to carry out standard calculations for reference evapo-transpiration, crop water requirements and irrigation requirements. CROPWAT uses the recommended FAO PenmanMonteith method for estimating crop evapo-transpiration. This model has been used in several studies to determine crop water requirements, (Mtshali,2001) applied CROPWAT to determine crop water requirement for sugarcane in Swaziland and acknowledged that estimates from the model were more realistic than the estimates derived from pan evaporation and pan factor coefficients.

For this study, CropWat 8.0 was used to calculate crop water requirements and irrigation requirements from existing or new climatic and crop data. Furthermore, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

Geographically the Borkena watershed is located between 1154573.2 meters to 1249931.1 meters North and 558396.7 meters to 603952.6 meters East in UTM coordinates with an altitude range of 1394 meters up to 3513 meters above sea level with total spatial area coverage of 1258.4 km^2. Borkena watershed is named by the name of Kombolcha town which is located in the north-central part of Ethiopia immediately South-east of Dessie town in the Amhara Nation Regional State.

The Borkena River crosses Kombolcha town in the watershed, emerging from the east and running to the west. In its way through the town, it receives effluents indirectly through its tributaries like Worka and Leyole. Most of the factories are found close together in the middle of the town near these tributary rivers (AWRDB, 2016).

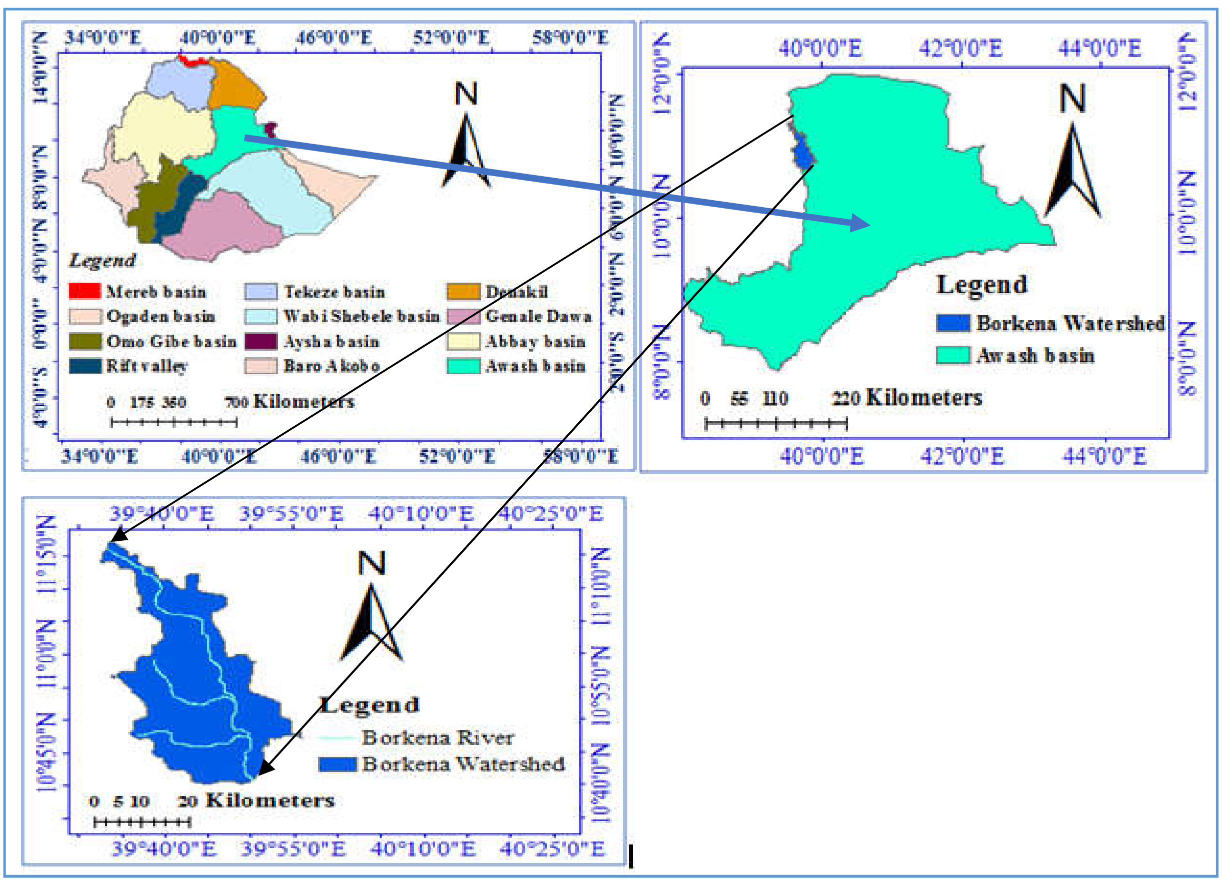


Figure 1: Location of the Study Area

3.2. Topography

The rocky terrain and steep slopes accelerate land degradation. The rocky and steep land has influence not only lowering infiltration of rainwater but also the water holding capacity of soils this increase loss of surface water resource in the sub-basin of Borkena river watershed (AWRDB, 2016). It also has negative impacts on surface water harvesting activities in the study area. In this area there are different terrains including flat plain followed by another large Boru meda plain. The right side is a very steep ridge including Tossa mountain chains. This chain extends to Addis Ababa forming the main Rift Valley of Ethiopia (AWRDB, 2016). The topographic feature becomes steep mountain ridges on both sides after Dessie town (Zonal capital of South Wollo) (AWRDB, 2016). After Dessie, the topographic feature again becomes a very flat plain along the main river courses starting from Harbu /kalu up to Kemiessie (AWRDB, 2016).

3.2.1. Slope

Borkena river Watershed has marked topographic variation. All types of slopes are present. Especially the mountainous part is very steep with the slope range up to 24.4 %. The dominant slope class is moderately steep (15-30%) which covers 21.83 % of the total area followed Sloping (30-50 %) which is 21.38 %. Gentle slope (3-8%) covers 16.33%. Mountainous area, Very steeply (>50%)covers about 16.06 % , undulating slope (8-15%), covers about 12.93% and Flat or almost flat (0-3%) accounts about 11.47%, respectively (AWRDB, 2016).

3.2.2. Soil Type

There is strong relation between landform and soil characteristics. The study Area has various land form. As per the variety of landforms within the Study Area, the soil characteristics are different for most of the mapping units. There are five different soil types' chromic Vertisols EutricCambisoils, EutricRegosoils, leptosoils and swamp Figure4: Dominant soil is EutricCambisoils (51.14%) followed by swamp (31%) Table 1: the depth of soil in the area ranges from shallow in hills and mountains to very deep in plains (AWRDB, 2016).

Table 1: Soil Type and its Coverage (%)

S/No	Soil Type	Dominancy in (%)
1	leptosoils	0.48%
2	chromicVertisols	3.91%
3	EutricRegosoils	13.47%
4	swamp	31%
5	EutricCambisoils	51.14%

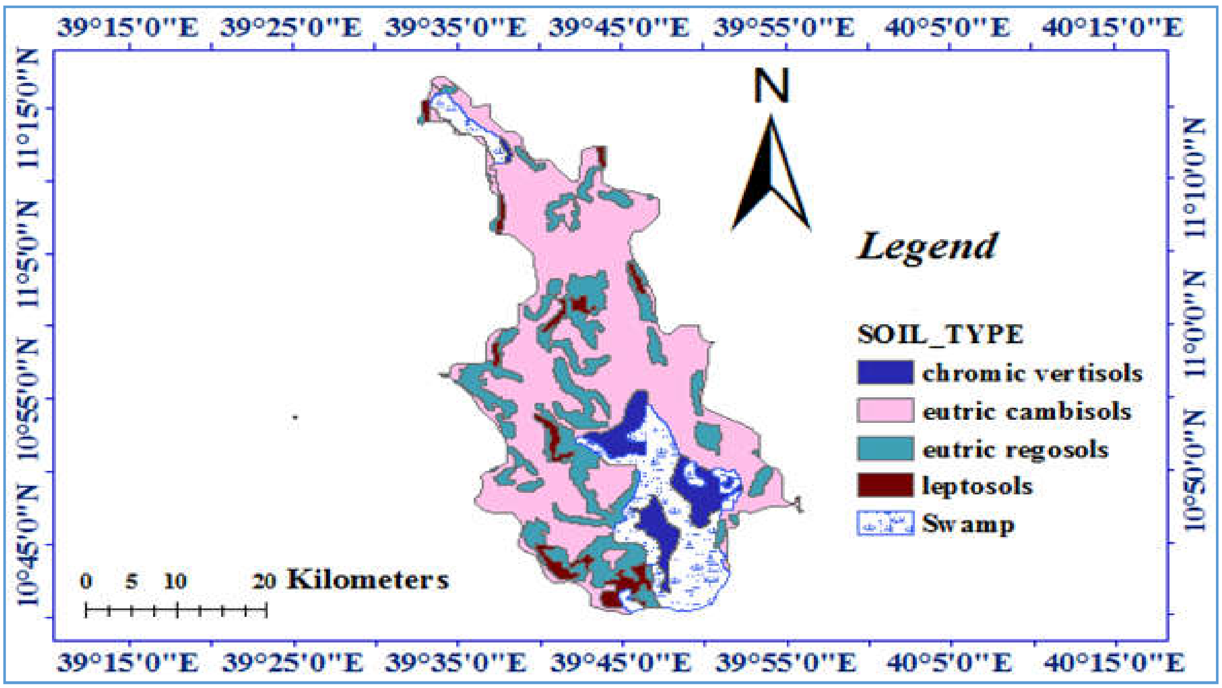


Figure 2: Soil Map of the Area

3.2.3. Hydro-Geology

According to Sileshi (2012), in the study area Borkena River has three Hydro-Geological valley Dessie valley to the North, which is mountainous and volcanic, the other is Kombolcha valley, which is a half graven with fault scarp in the east and a volcanic mountain in the west. In case of Kombolcha valley, in the North -central part of Ethiopia has been exposed to in a relatively greater number of large-scale manufacturing plants near by the main tributaries of Borkena River (Eskinder, 2011). This indicates that in the future surface water availability and demand imbalance will crash the hydrology of the watershed in the study area and the last one is the southern Chefa valley is a graven bounded by fault scarps in the east and west.

Almost all ground and surface waters in the area are fit for domestic and irrigation purposes. However, some aquifers, especially in Dessie and Kombolcha towns, are vulnerable to pollution.

3.3. Conceptual frame works for the Study

The overall procedure that adopted for this study is described by the following flow chart.

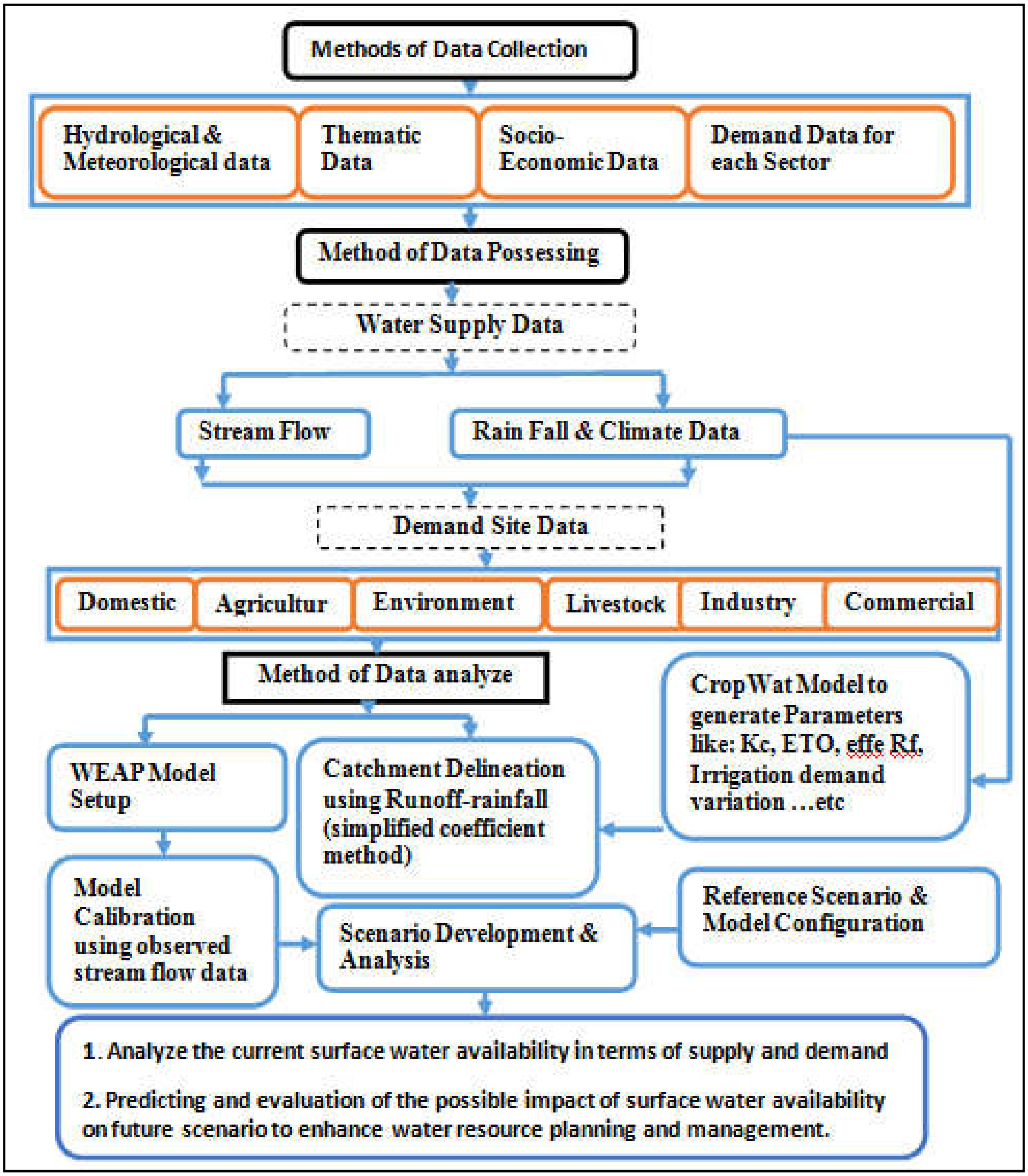


Figure 3: The flow chart of research design

3.3.1. Data Collection

General work was carry out by collecting secondary data and validate by comparing the data obtaining from different data sources. Because the reliability of the collected raw meteorological and hydrological data was significantly affects the quality of the model input data. Long-term data are required for any meaningful analysis of the flow regime in area of high variability flow. Absence of recorded long time stream flow data all over the area requires determination of surface water availability from rainfall.

Analysis of raw data was made for data quality checking and filling of missing records. The hydrology of Borkena watershed was characterized by slope, land use, rainfall, temperature, Evapo-transpiration and runoff. The data source were Ministry of Water, Irrigation & Energy, Ethiopian Mapping Agency, National Meteorological service Agency, Central Static Agency of Ethiopia and literature Table2.

Table 2: Summary of secondary data sets for the modeling work in this thesis:-

S/No	Data type	Source of data
1	Hydrological data, Stream flow data	Ministry of Water, Irrigation & Energy
2	Thematic data, Dem, Shape file	Ethiopian Mapping Agency
3	Metrological data, rain fall -max & min temperature, relative humidity -sunshine hour and Wind speed	National Meteorological service Agency
4	Population data(2017) -Urban population &Rural population	Central Stastic Agency of Ethiopia
5	Water demand data -Annual activity level -Annual water use rate (lit/p/c/day)	Awash Basin master plan study of water sector development program main report volume II(2002) based on (GTP review)
6	Socio-economic information - Farming System, Livestock's, demography, crop production	ANRS woreda agriculture and rural development office

Table 2.1: Summary of secondary data sets for the modeling work in this thesis:-

S/No	**Recording station**	**Recording year**
1	1. Borkena River @ Albuko, 2.Borkena River @kombolcha and 3. Borkena @swamp outlet near kemissie.	River flow (1998-2018)
2	1.Dessie, 2.Maybar/Ancharo,3.kombolcha, 4. Albuko and 5.Swamp outlet kemissie	Climate (1998-2018)

3.3.1.1. Meteorological Data

The metrological data required were: precipitation, maximum and minimum air temperature, solar radiation, wind speed, and relative humidity on daily basis. If any of these data was not available, which is very likely, evaluate required output using WEAP and CropWat modeling program.

Precipitation-Wind speed and-temperature: The daily time series from Dessie, Kombolcha, Maybar/Ancharo, Albuko and Kemissie stations were prepared in dbf format. Solar radiation and relative humidity: data were available only for principal stations Dessie and Kombolcha. These data for the rest of the stations were dawn loaded from Global Weather data for SWAT. They were required to apply Penman Monteith equation to evaluate potential evapo-transpiration and annual Irrigation demand variation using CropWat.

3.3.1.2. Hydrological data

Monthly observed data is required for (WEAP) input as a head flow of the stream in the study area. This data was obtained from Ministry of Water, Irrigation and Energy Hydrological Department for the period 1998- 2018. Flow data was collected and arranged as per the requirements of (WEAP) model. The Data available gauging stations were south Wollo near Kombolcha station, Albuko station, Dessie station and at swamp outlet near Kemiessie.

3.3.1.3 .Thematic data

The digital elevation model (DEM) is any digital representation of a topographic surface and it is specifically made available in the form of raster or regular grid of spot heights. It is the basic input data for (WEAP) GIS-based, graphical drag & drop interface which was the data prepared in vector or raster format. The Borkena River Watershed was delineated and River networks were generated from DEM that has resolution of 30m x 30 m.

3.3.1.4. Socio-economic information

- **Demography**

Borkena watershed has 12 woreda and 91 kebeles including Kombolcha, Kemisie , Albuko, Dessie, Chaffie golana dawe ,Kutaber, Ancharo, gisheRabel, Tehulederie AnstokianGemez ,Artuma and Harbu/Kalu are woredas or towns found in the study area. The towns or woredas in this study Area are known for its high animal and human population density with different ethnic groups and religion. According to the data obtained from the Ethiopia Central static agency, the current population of the Woreda in the study area is estimated at about 1,734,366 of which 544,111are urban and the remaining 1,190,255 are rural, which is 54.3% of the total population in this area.

Muslim and orthodox seems to have been the two major religious groups in the study area (AWRDB, 2016). Sometimes it is difficult to judge which religion is dominant due to inter cultural and religious interactions (AWRDB, 2016). The general nature of the settlement pattern is rural and traditional, which is clustered into groups called "Got" are rather sparsely scattered throughout the area as in the case of south Wollo Zone, the inhabitants in this watershed is Amhara tribe in the upper part and Oromo in the lower part of the Area.

- **Farming System & Crop Production**

The farming system in this Area comprised field crop production, livestock rearing and tree growing (special to Kutaber). Agriculture is the main economic base of the community in the rural areas of the watershed. Both crop production and livestock rearing, mixed agriculture, was carried out with almost equal emphasis. The towns mainly Dessie, Kombolcha and Kemiessie are almost on the way of development. Kombolcha is industrial town of the region with different factories and future industrial reserve areas. But these industries are affecting the development of agriculture in the rural areas not only in occupying space but also polluting the agricultural environment. According to Eskinder (2011) study indicated that heavy metals are affecting the production of vegetable just below Kombolcha town.

Crop production is the leading economic activity in all part of the study area. The major crop type cultivate in Borkena watershed are cereal crop, Sorghum s and vegetables. The production system for almost all crop types is traditional with oxen plowing and packed animal transports of products. Farming operation and agricultural crop production process are carrying out throughout a year with limited amount of yield.

3.3.1.5 .Hydro-meteorological data Analysis

- **Filling of Missing Stream Flow**

In the analysis of hydrological data, the stations were required to have daily records for the required period of observation (1998-2018) years. It may so happen that a particular flow-gauge was not functional for a part of a month or year .It then becomes necessary to fill missing records. In this thesis, arithmetic mean value of the entire period was used to fill the missed records for the stations with less than 10 percent varies with neighboring station while for the stations having greater than 10 percent variation were normal- ratio method was used Table3:

Table 3: Description of the stream flow recording stations

Station Name	Latitude	Longtude	Recorded period
Borkena@swamp outlet	10:38: 0 N	39:56: 0 E	1998 - 2018
Borkena@ Nr. Albuko	11: 3: 0 N	39:44: 0 E	1998 - 2018
BorkenaRr.Nr.kombolcha	11:13: 0 N	39:37: 0 E	1998 -2018

- **Filling 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 study area help to fill the missing data on the assumption of hydro meteorological similarity of the group of stations a number of methods have been proposed to estimate missing rainfall data

1. Arithmetic Mean Method
2. Normal Ratio Method
3. Regression Method
4. Inverse Distance Method

The arithmetic Mean and Normal Ratio methods are used when the normal annual precipitation of the index stations differ by more than or less than 10% of the variation with missing station. The rainfall of the surrounding index stations are weighed by the Arithmetic and normal ratio of annual rainfalls using the following equation 1 and 2. The rain fall recording stations with their percentage-missed values are shown in the table 4:

$$Pm = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{Nm}{Ni}\right)Pi \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$Pm = \frac{p1+p2+p3\ldots\ldots+pn}{n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Table 4: Description of the rainfall recording stations

S/No	Station Name	Longitude	Latitude	Area (Km^2)
1	Dessie	39.63	11.12	136.014
2	Maybar/Ancharo	39.63	11.05	131.771
3	Combolcha	39.72	11.08	261.995
4	Kemissie	39.87	10.72	190.195
5	Albuko	39.7142	10.8139	538.409
	TOTAL			**1258.38**

- **Checking consistency and adjustment of rainfall data**

A consistent record is the one where the characteristic of the record has not changed with time. Adjusting for gage consistency involves the estimation of an effect rather than a missing value. The consistency of rainfall records on selected stations is commonly checked by double mass curve analysis. Double mass curve is a graphical method for identifying and adjusting inconsistency in a station record by comparing its time trend with those of adjacent stations.

If the conditions relevant to the recording of a rain gauge station have undergone a significant change during the period of record, inconsistency would arise in the rainfall data of that station. This inconsistency can be differentiated from the time significant change took place. If significant change in the regime of the curve is observed, it should be corrected by using Equation3. The mean annual cumulative rainfall of twenty years of each station was drawn in y-axis and the mean annual cumulative rainfall of five stations was drawn in the x- axis to check the consistency of each rainfall stations using double mass curve.

The stations used in this study have not undergone significant changes during the base line period (R-Square Value Greater than 0.98) of the study see the representative station of Kemiessie on figure 4: and see for the other stations figure A and table A1.1 on appendix 2:

$$Pcx = Px \frac{Mc}{Ma} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots .. (3)$$

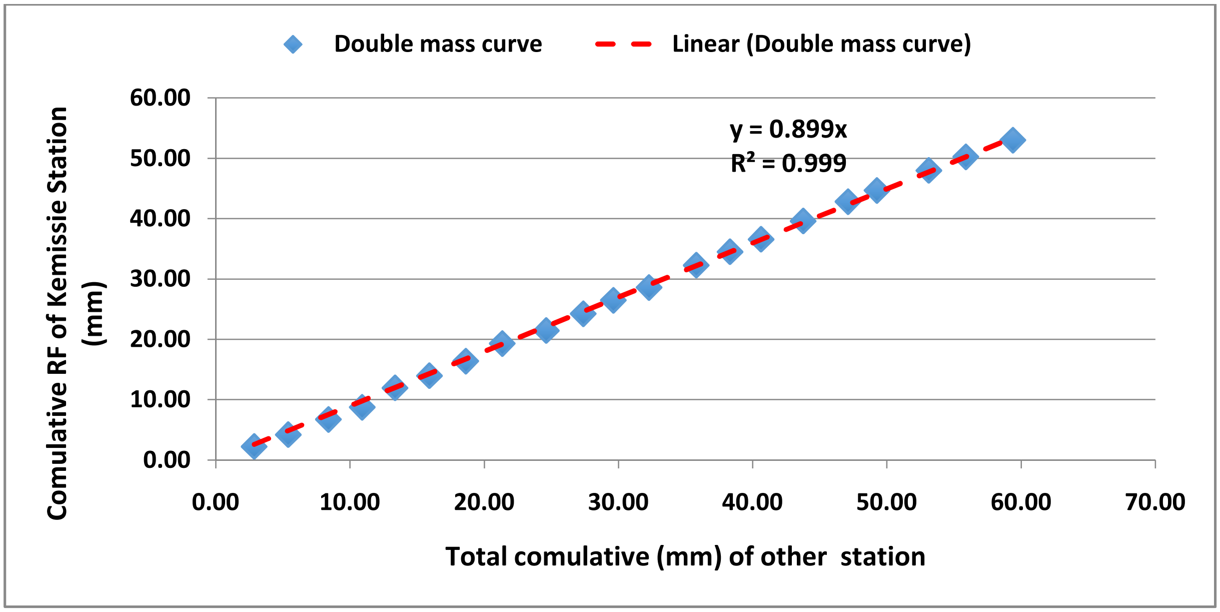


Figure 4: Double mass curve for selected stations

- **Checking homogeneity of selected rainfall station**

Homogeneity is an important issue to detect the variability of the data. In general when the data is homogeneous, it means that the measurements of the data are taken at a time with the same instruments and environments. However, it is a hard task when dealing with rainfall data because it is always caused by changes in measurement techniques and observational procedures, environmental characteristics and structures, and location of stations. One of the methods to check homogeneity of the selected stations in the study area is the non-dimensional rainfall records and plotted to compare the stations with each other see table B: in Appendix 2: Non-dimensional value of the monthly precipitation of each station can be computed equation4 and figure5 (GARG,2005):

$$Pi = \frac{Pi,av}{Pav} 100 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots .(4)$$

Where, Pi = is non - dimensional value of precipitation for the month in station i, $P_{i,av}$ = is over years averaged monthly precipitation for the station i and , P_{av} = is over year's averaged yearly precipitation of the station when the rainfall patterns are spatially identical or vary with in a range, they could consider as homogeneous. Homogeneity test

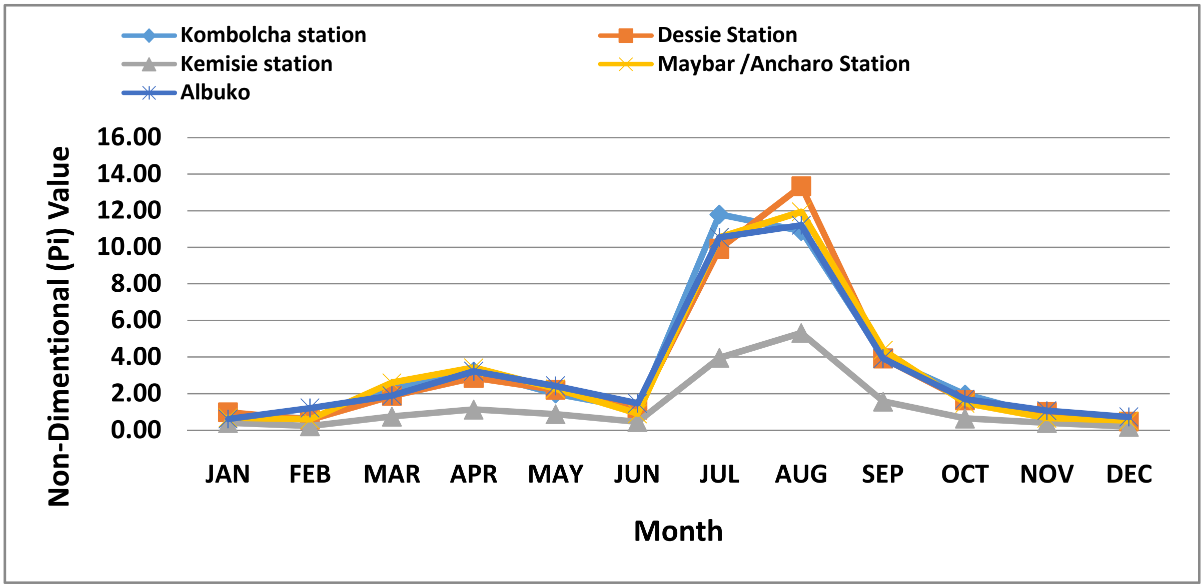


Figure 5: Non-dimensional plot of selected stations within the study area

3.3.2. Data Processing

3.3.2.1. Water Demands Data

The water Demands assessment for various needs in the sub-basin including domestic, livestock, agriculture and environmental are identifying in the sub-basin.

- **Domestic water demand**

Domestic water demand encompasses all domestic-type water requirements in urban and rural areas. Per capita water demands depends on GTP strategic plan which organized as national, zonal and woreda level in Ethiopia to provide access to safe and sustainable water supply for all citizens of the country in the planning period as per the minimum water supply access standard level set for GTP-1 and GTP-2 (Melekamu.etal, 2018). As result the GTP-2 water supply service level standard, it is required to provide safe water in minimum 25 l/c/day within a distance of 1 km for rural while in urban areas it is required to provide safe water in minimum 100 l/c/day for category 1 towns/cities (towns/cities with a population more than 1 million), 80 l/c/day for category 2 towns/cities (towns/cities with a population in the range of 100,000-1million), 60 l/c/day for category 3 towns/cities (towns/cities with a population in the range of 50,000 - 100,000), 50 l/c/day for category 4 towns/cities (towns/cities with a population in the range of 20,000-50,000) up to the premises, and 40 l/c/day for category-5 towns/cities (towns/cities with a population less than 20,000) within a distance of 250m (Melekamu.etal, 2018) table5:

Table 5: Categories of Towns in the study Area based on Population Range in GTP-II

Population Range	**<20000**	**10000-50000**	**50,000-100,000**	**100,000-1million**	**≥1million**
categories	category-5 , towns	category 4, towns	category 3, towns	category 2 towns	-
Towns in the study Area	Kutaber	Tehulederie	-	Kombolcha	-
	Albuko	Dessie Zuria	-	Dessie town	-
	Chaffie golana dawe	Harbu/Kalu	-	-	-
	gisheRabel	Anstokian Gemez	-	-	-
	Artuma	kemissie	-	-	-

Source: Main Report: Water Sector Development Program Volume II (2016)

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 2020 - 2025). Based on the newly revised water demand standard of GTP II, it ranges from 40 – 100 lpcd for urban and 25 lpcd for rural up to the year 2025. But in this study, the water demand forecasted was range from 40-100 lpcd for urban and 25 lpcd for rural Table 6A Appendix 2: then goes up to the year 2030 which lies in the third Growth and Transformation Plan (GTP III), therefore, the per capital demand will increase beyond 100 lpcd for urban and 25 lpcd for rural by assuming 25% increment from GTP II to GTP III, it becomes 125 liters per capita per day for urban and 32 liters per capita per day for rural for this analysis table 8:

- **Population Data and Population Projection**

One of the basic inputs in WEAP model is the population data. The population data collected from Central Statistical Agency is based on census 2017, and the population growth rate of the middle awash basin is found to be 5.2% for urban and 1.6% for Rural currently table 6: Hence the census 2017 population is projected to suitable year 2019 which is the current account year in my model using the following equations 5. The populations of the selected sites with their projections are given in table 7:

Table 6: Projection of Population growth rate starting from (1980-1990)

Year	Growth Rate Urban (%)	Growth rate Rural (%)
1980 – 1990	6.2	3.5
1990– 2000	5.5	2.8
2000 – 2010	6.2	2.2
2010 – 2020	5.2	1.6
2020 – 2030	4.2	2
2030 – 2040	5	1.6

Source: The International Food Policy Research Institute (IFPRI).

- **Geometric increase method**

This method is based on the assumption that the percentage increase in population remains constant.

$P1 = Po + K\,Po = Po\,(1 + K)$

$P2 = P1\,(1 + K) = Po\,(1 + K)\,(1 + K)$

$P3 = P2\,(1 + K) = Po\,(1 + K)\,(1 + K)\,(1 + K)$

$$Pn = Po \quad (1 + K) \quad n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

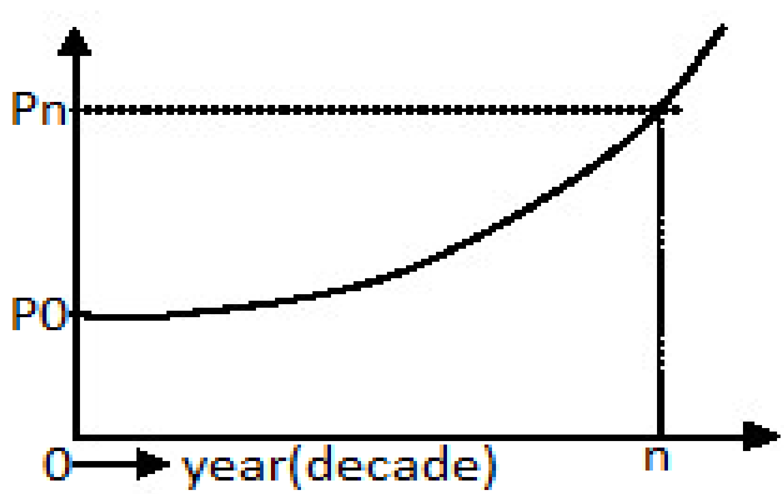


Figure 6: Geometric increase graph

Where, Po = initial population, Pn = population at n decades or years, n = decade or year, K = percentage (geometric) increase

This method is mostly applicable for growing towns and cities having vast scope of expansion.

Table 7: Population projection for different towns or woredas in the study area

S/No	Woreda towns In the study area	Projected from 2007 census for 2017		2017-2019	
				5.2%	1.6%
		Urban	Rural	Urban	Rural
1	kutaber	8618	104514	9537.575	107885.2
2	Tehulederie	25729	119131	28474.39	122973.7
3	Dessie Zuria	22240	199209	24613.1	205634.7
4	Harbu/Kalu	34552	192169	38238.84	198367.6
5	Albuko	6030	85138	6673.425	87884.21
6	Chaffie golana dawe	12044	152578	13329.14	157499.6
7	gisheRabel	4845	67869	5361.981	70058.18
8	Anstokian Gemez	21874	76871	24208.04	79350.55
9	Artuma	10361	88840	11466.56	91705.62
10	Kombolcha	102244	30840	113153.8	31834.78
11	Dessie town	209226	35903	231551.3	37061.09
12	kemissie town	33887	0	37502.88	0
Total				**544,111**	**1,190,255**

Water Demand = per capita water consumption (litter/c/day) x Number of population in selected are.

Table 8: The Annual Water Use Rate for Domestic Water Demand

Items type	Current Projected population of 2019	From 2020 – 2025 GDP-II Litter/c/day, assumed to be	From 2025 – 2030 GDP-III Litter/c/day, increment assumed to be 25%
Urban	544,111	100lpcd =19.86Mm^3 /year	125 lpcd = 24.82Mm^3 /year
Rural	1,190,255	25lpcd = 10.8Mm^3 /year	32 lpcd = 13.90Mm^3 /year
Total (DWD)		30.66 Mm^3/year	38.72 Mm^3/year

✓ **Livestock Production (LWD)**

Water Demand for livestock is an essential basis for subsistence and development of the Borkena watershed population and its main source of income which majority of population directly engaged in livestock production (AWRDB, 2016). The estimated livestock population data has been taken from The Amhara regional Woreda Agriculture and Rural Development Office Database, in order to simulate the study. Table 9A in Appendix 2: gives the details of livestock population and their types with corresponding current average growth rate of 1.1% for Cattle, horse, donkey and mule and 0.3% for sheep and goats by 2019. The surface water requirement for different types of livestock have been clubbed together and indicated as single demand node in the WEAP model. According to master plan study Awash basin (2018). Livestock water requirements vary significantly depending on the species Table 9: Water consumption is influenced by a number of factors, including: - age, rate of gain, pregnancy, lactation, activity, type of diet, feed intake and environmental temperature. Livestock obtain water to meet their requirements from wells, fountains, surface water and moisture found in feedstuffs (Miranda, et al. 2015). The method was given Livestock for per capita water consumption as shown in equation.

Water Demand = Per capita water consumption (Mm^3/year) x livestock population

Table 9: Estimated water requirements of livestock under air temperature of 27C^o, **(l/day)**

S/No	Species	Average water requirement per head
3	Cattle	7
4	Sheep	5
5	goat	5
6	donkey	3
7	Horse/ mule	6
8	chicken	0.1-0.2
In this study 25 lit/day required or 9.13Mm^3/year		

Source: FDRE Awash basin authority (2018)

✓ **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 (WSDP Volume II, 2016). For small- and medium-sized towns, it was estimated at 5 per cent of the DWD (WSDP Volume II, 2016). For larger towns, the CIWD estimate was 10 per cent of DWD (WSDP Volume II, 2016). Those allowances were applied to all towns. No allowances were made for CIWD from rural communities. Since the towns/woredas under this study are small- and medium-sized towns so, that 5% of DWD was used to determine CIWD as follow (WSDP Volume II, 2016).

- Urban WD =24.82 M m^3/year
- CIWD=5 % (UWD) = 5/100*24.82 = 1.241Mm^3/year

✓ **Industrial water Demand (IWD)**

Borkena watershed, in the North -central part of Ethiopia has been exposed to in a relatively greater number of large-scale manufacturing plants like textile, steel factory, Tannery/Leather factory, meet processing and BGI Industry are found nearby the main tributaries of Borkena River (Eskinder, 2011). This indicates that in the future surface water availability and demand imbalance will crash the hydrology of the watershed in the study area. According to Master Plan Study of awash basin (2018) water use standard among the different industries shown in table10: with corresponding to Annual Water Consumption (Mm^3) and Proportion of water consumed in (%).

Table 10: water use standard among different industries (MPSAB 2018).

S/No	Type of Industry	Annual Water con (Mm^3)	water consumed (%) in industry
1	Thermal power plant	35157.4	87.87
2	Engineering	2019.9	5.05
3	Pulp and paper	905.8	2.26
4	Textiles	829.8	2.07
5	Steel	516.6	1.29
6	Sugar	194.9	0.49
7	Fertilizer	73.5	0.18
8	others	314.2	0.78
9	WEAP input data is 1661Mm^3/year		100

Source: FDRE Awash basin authority (2018)

Table 11: Industrial Growth Rate

Demand type	GTP I	GTPII	GTPIII
	2005-2010	2010-2015	2015-2030
Industry WD	1.3	2	2.5

Source: GMIA in Ethiopia Case Study of awash basin by UNDP 2017

✓ **Environmental water demand (EWD)**

Apart from the domestic, livestock and agricultural water use Environmental flow is one of the important components in water resources planning, management and allocation, and sustainable environmental flow benefits the health and maintenance of the aquatic ecosystem (Eskinder, 2011). The environment is increasingly being considered a legitimate water user in many world countries. As a consequence the water requirement of the environment needs to be estimated. The amount of water that will be allocated to the environment is a decision made by society, and is to some extent arbitrary. The quantity of water allocated to the environment will always be less than what the environment ideally would require, namely the natural, undisturbed, flow regime of a river. Society, therefore has to weight the potential costs and benefits to the environment and to all other water users, of allocating (or not) a certain amount of water to the environment. In so doing, society accepts a certain modification of the natural environment. This accepted level of modification may differ from river to river, and is sometimes defined in terms of "ecological management classes". The environmental or in stream 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. However, an environmental in stream flow often fulfils a number of different functions despite the simplicity of the concept; difficulties arise in the actual estimation of EF values. This is primarily due to the inherent lack of both the understanding of and quantitative data on relationships between river flows and multiple components of river ecology.

There is a range of methods available for assessing in stream flow requirements based on:

1. Simple hydrological indices;
2. Hydrological simulations;
3. Consensus and discussion based approaches;
4. Historical data analysis;

5. Biological response simulation techniques often referred to as habitat simulation methods.

Hydrological index methods are the simplest type of environmental flow assessment, least data intense and rely on the use of historical hydrological data for making flow recommendations. These data are usually in the form of long-term, historical monthly or daily discharge records. In flow duration curve analysis naturalized or present-day historical flow records are analyzed over specific durations to produce curves displaying the relationship between the range of discharges and the percentage of time each of them is equaled or exceeded equation 7.

$$P = 100 \left(\frac{M}{n+1}\right) n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (6)$$

Agricultural water Demand

Agricultural demand comprises irrigation of large plots and formal schemes. Therefore, only scaled irrigation is represented in this sector. Within the WEAP model the irrigation water demand varied inter-annually or monthly based on rainfall. During wet years the irrigation demand reduces and during dry years it increases (McCartney,2005) Agricultural irrigation demands has been calculated by simulating demand node on WEAP and CropWat8 model of the Food and Agriculture Organization (FAO) was used to simulate the observed seasonal pattern of irrigation with different cropping seasons in the area. Metrological data were used to estimate net evaporation (ETo), Kc and effective rainfall from the study area and monthly share of irrigation demand in (%) in table 12:

Table 12: Monthly demand share of irrigation in (%)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Share of Irrigation-demand	7.6	18.8	18.8	9.8	8.68	0	0	0	1.4	11.2	11.8	12.0

According to the Ministry of Water, Irrigation & Energy of Ethiopia irrigation command areas can be classified into three groups (Awulachew et al, 2005). The first group is small scale irrigation areas of less than 200 ha, medium-scale between 200 and 3000 ha and large scale above 3000 ha. For this study, medium and large-scale schemes are considered based on this classification table13:

Table 13: Types and location of irrigation site

S/No	Irrigation	Location	Irrigation	Demand	Stage of development
1	Arakuti (SSIP)	Kutaber	1965 ha	wier	feasibility study completed
2	Galena(SSIP)	Tehuledere	1115 ha	Irrigation schems	feasibility study on going
			1250 ha	wier	feasibility study completed
4	Cheffa dwa MSP	Cheffa-robit	4000 ha	Cheffa	feasibility study completed
5	Others		4000 ha	Small sca	----
Total			**11326 ha**		

Source: ANRS Woreda Agriculture and Rural Development Office

CropWat8, which developed by FAO, is used to estimate crop water demand requirements for this study see table C in Appendix 2: According to Irrigation Development Master Plan (IDMP, 2016) studies in the study area, the main crops are Sorghum, Maize, and Vegetable, pulse, wheat and barley. As a result, these crops were chosen to estimate the crop water requirement for proposed irrigation. The penman-monteith formula was used In Cropwat8 model to determine the reference crop evapo-transpiration (ETo) and SCS method was used for effective rainfall.

Table 14: Agricultural growth rate

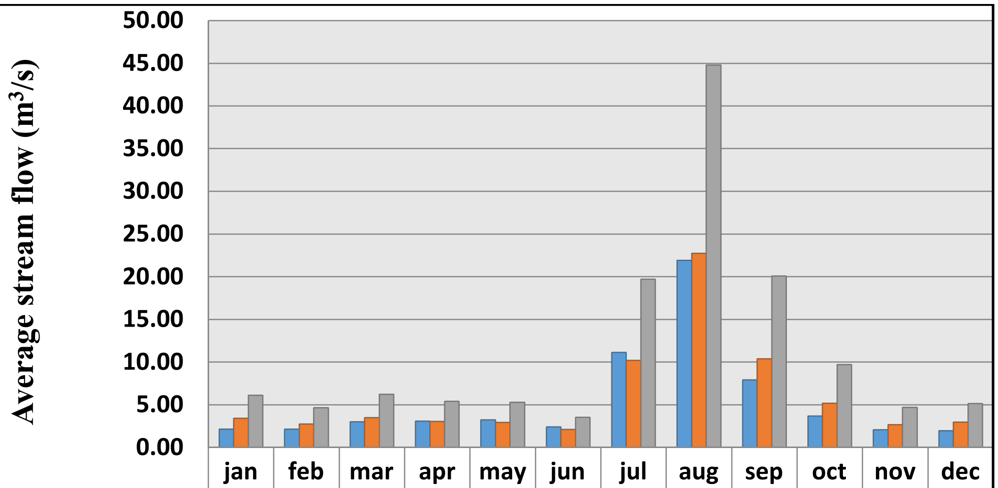
Demand type	GTP I 2005-2010	GTPII 2010-2015	GTPIII 2015-2030
Agriculture	5.6	6.6	7.6 assuming

Source: Growing Manufacturing Industry and agriculture in Ethiopia Case Study by UNDP 2017

3.3.2.2. Water Supply Data

- **Stream Flow**

Continuous stream flow records are necessary to make accurate surface water availability assessment. Stream flow records representing historical, natural hydrology unaffected by humans are fundamental to modeling basin hydrology (WMO).Stream flow data was collected from Ethiopian Ministry of Water, Irrigation & Energy office and stream flow is an important aspect of modeling a water system and helps in understanding how it operates under a variety of hydrologic conditions. Data available for the rivers were obtained from three gauging stations namely, Borkena@swamp outlet Nr kemmisie, Borkena@ Nr. Albuko, BorkenaRr. Nr.kombolcha. The Available monthly discharges converted into the volume of flow within the study area; therefore, the volume of runoff was determined by using direct observed flow data @ swamp outlet Nr kemissie. The mean monthly flow data from these gauge station were used for the WEAP model Figure 7:



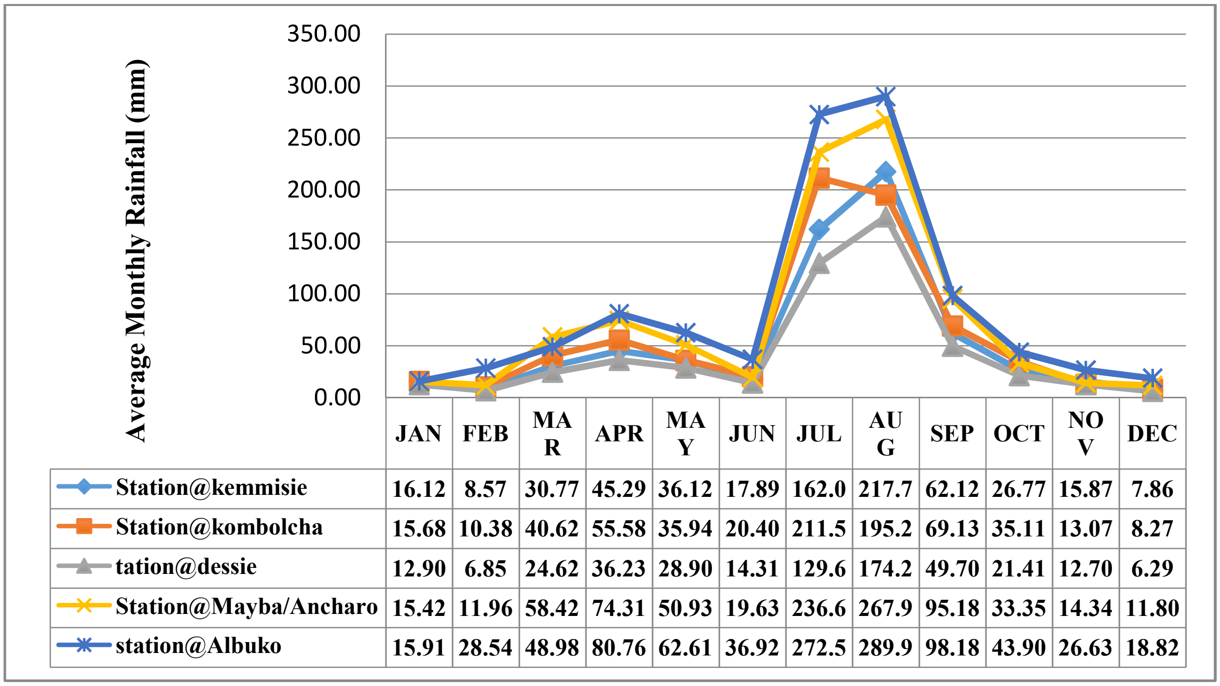
	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Average of Bor Nr kombolcha	2.12	2.13	2.99	3.06	3.20	2.39	11.12	21.90	7.90	3.68	2.08	1.94
Average of Bor Nr ALBUKO	3.42	2.74	3.48	3.03	2.94	2.12	10.18	22.74	10.36	5.18	2.68	2.95
Average of Bor Nr Kemmissie	6.12	4.66	6.21	5.40	5.27	3.54	19.69	44.80	20.07	9.68	4.69	5.13

Figure 7: Average stream flow of Borkena River in different stations

- **Rainfall and Climate**

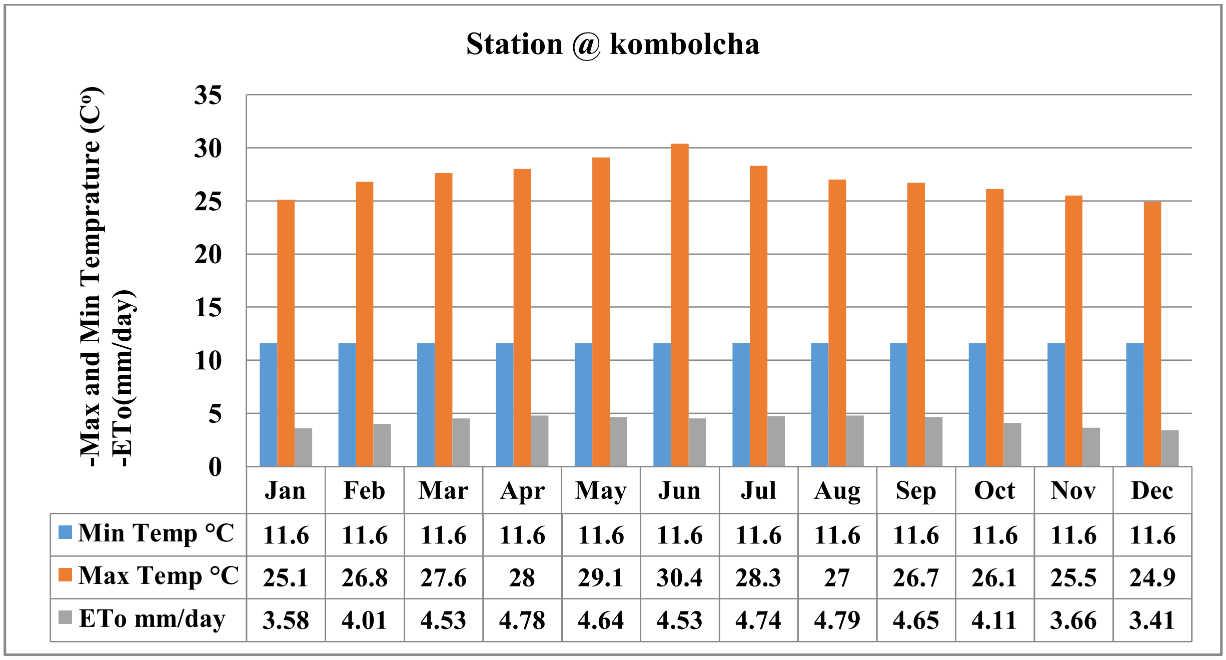
Rainfall and temperature are the prime factors in determining the climate and therefore the distribution of vegetation types (AWRDB, 2016). There is a strong correlation between climate and biomass in the study area to quantify current surface water availability to analyze demand scenario for future. The study area is characterized by two rainy seasons (quasi bimodal rainfall pattern). The main or the longer rainy season is during Kiremt extends from (June- September) which supports the major crop production while the small or the shorter rainy season is during *Belg* extends from (March-May) and allows minor crop production (Sileshi, 2012). The physiographic characteristics of the study area include: altitude of 1394 up to 3513 meters above sea level (AWRDB, 2016).

The area receives a mean annual rainfall of 710.94 mm @Upper Part Kombolcha Station to 648.6 mm @lower part Kemisie station with annual average maximum and minimum temperature of 27.1 C^o and 11.6 C^o @kombolcha and 32.9 C^o and 13.2 C^o @ Kemiessie, respectively in the present study figures 8, 9, 10: and see Figures and tables for the other station in Appendix 2:



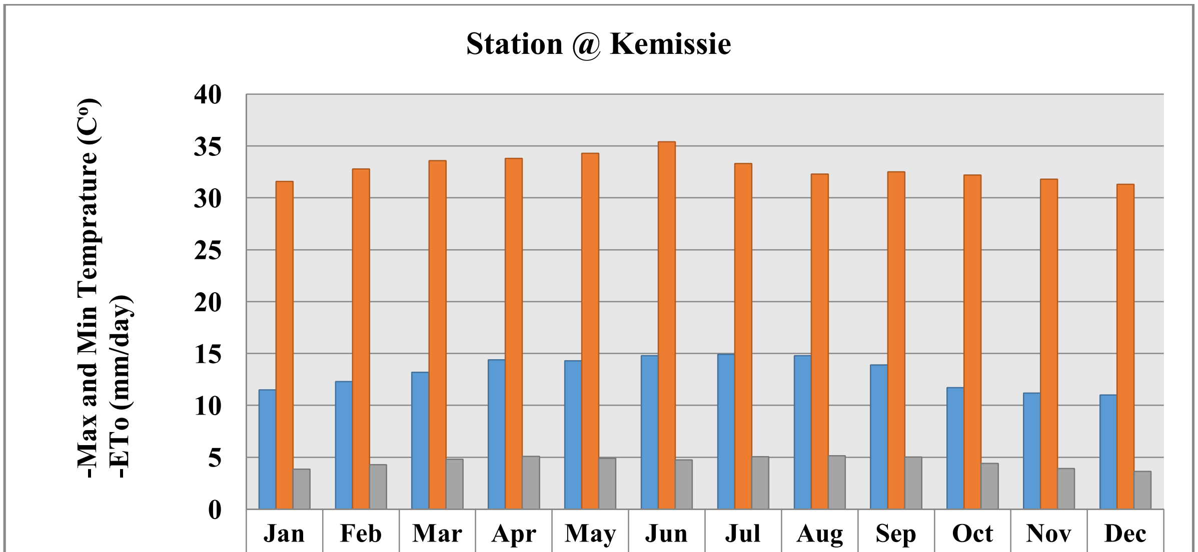
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Station@kemmisie	16.12	8.57	30.77	45.29	36.12	17.89	162.0	217.7	62.12	26.77	15.87	7.86
Station@kombolcha	15.68	10.38	40.62	55.58	35.94	20.40	211.5	195.2	69.13	35.11	13.07	8.27
tation@dessie	12.90	6.85	24.62	36.23	28.90	14.31	129.6	174.2	49.70	21.41	12.70	6.29
Station@Mayba/Ancharo	15.42	11.96	58.42	74.31	50.93	19.63	236.6	267.9	95.18	33.35	14.34	11.80
station@Albuko	15.91	28.54	48.98	80.76	62.61	36.92	272.5	289.9	98.18	43.90	26.63	18.82

Figure 8: Average monthly Rain fall of all station in the study area



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min Temp °C	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6
Max Temp °C	25.1	26.8	27.6	28	29.1	30.4	28.3	27	26.7	26.1	25.5	24.9
ETo mm/day	3.58	4.01	4.53	4.78	4.64	4.53	4.74	4.79	4.65	4.11	3.66	3.41

Figure 9: Average monthly Max and Min temperature of kombolcha station in the study area



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min Temp °C	11.5	12.3	13.2	14.4	14.3	14.8	14.9	14.8	13.9	11.7	11.2	11
Max Temp °C	31.6	32.8	33.6	33.8	34.3	35.4	33.3	32.3	32.5	32.2	31.8	31.3
ETo mm/day	3.84	4.28	4.82	5.1	4.9	4.75	5.04	5.15	5.03	4.41	3.91	3.64

Figure 10: Average monthly Max and Min temperature of Kemiessie station in the study area

3.3.3. Research Material

3.3.3.1. GIS for Watershed delineation

Determination of the study area boundary and stream delineation was done using the spatial analyst tool in ArcGIS version 10.4.1, using various thematic maps such as topography, and soil map.

3.3.3.2. CROPWAT

The CROPWAT 8.0 software was used in calculating crop water requirements. This software uses monthly averages of the climatic parameters. The ETo is calculated using the Penman-monteith method and effective rainfall is estimated by FAO formula. The software provides data on crop such as Kc, growing stage, rooting depth, soil moisture as defaults.

3.3.3.3. Water Evaluation and Planning

The Water Evaluation and Planning software selected for the purpose of this study. The WEAP model essentially calculates a mass balance of flow sequentially down a river system, making allowance for abstractions and inflows. The elements that comprise the water demand-supply system and their spatial relationship are characterized within the model.

In this thesis WEAP was used because WEAP has an integrated approach to simulate both natural and engineering components such as reservoirs, groundwater International discharge and water demand and supply, which can give water planner a more comprehensive view of the broad range of factors that must be considered in managing water resources for present and future, uses.

It can analyze a diverse range of issues such as climate variability, watershed conditions, anticipated demands, ecosystem needs, available infrastructures and operational objectives in a transparent manner. Several studies have used WEAP for water allocation for various uses in different catchments in Ethiopia. The results showed that possible regional conflicts affect water balance, while regional cooperation and using the best available technology can reduce water scarcity. In Ethiopia, WEAP model was used to assess irrigation and competing water demands scenarios on Tana Basin.

3.3.4. Methods Analyze

The Water Resources System Simulation modeling helps to understand the relationship between available water resources and the demand for those resources under existing and future development scenarios.

The modeling of a watershed using the WEAP consists of the following steps

1. Definition of the study area and time frame.
2. Creation of the current account.
3. Creation of scenarios.
4. Evaluation of the scenarios.

With WEAP, first Current Account of the water system under study is created. Then, based on a variety of economic, demographic, hydrological, and technological trends a "reference" scenario projection is established, referred to as a Reference Scenario. Then one or more what if scenarios are developed with alternative assumptions about future developments, the scenarios can address a broad range of "what if' questions. These scenarios may be viewed simultaneously in the results for easy comparison of their effects on the water system. The model simulation is structured as a set of scenarios with monthly time steps. WEAP21 solves the water allocation problem by a linear programmed with the objective of maximizing demand node satisfaction constrained by water availability, demand priority, supply priority and proximity to supply.

3.3.4.1. Catchments delineation

The river system was schematized from an Arc View GIS layer. The runoff from the catchment nodes in WEAP21 represented the head flow of the streams. In this study, Arithmetic Mean method was used to generate aerial rainfall over the catchment. The areal rainfall was estimated using arithmetic mean for the selected period of 1998 to 2018 (out of eight rainfall stations within the catchment only five of the rain gage stations had comprehensive data of monthly precipitation for 1998 to 2018 were used). The Arithmetic mean method is acceptable where a repaid estimate is required and for areas where either the gauges are or the precipitation is fairly uniformly distributed over the study area. Penman-Monteith method is recommended as the sole standard method for definition and computation of the reference Evapo-transpiration (ETo), crop coefficient (Kc), Effective rainfall (Effer) and share of Irrigation demand (%) were generated by using CropWat 8 model.

The simplified coefficient method in WEAP21 was used to simulate catchment processes (runoff). This method defines land use by crop coefficients, Kc, catchment area and effective precipitation while the climate is defined by precipitation and reference evapo-transpiration, ETo.

3.3.4.2. Cropwat8 model setup

CROPWAT is a decision support system developed by the Land and Water Development Division of FAO for planning and management of irrigation. CropWat8 model of the Food and Agriculture Organization (FAO) was used to simulate the observed seasonal pattern of irrigation with different cropping seasons in the area. Metrological data of the study area were used to generate net evaporation (ETo), Kc and effective rainfall from the study area and monthly share of irrigation demand in order to use as input for WEAP model

3.3.4.3. WEAP Model Setup

The WEAP model was developed by the Stockholm Environment Institute (SEI) and can be downloaded from www.weap21.org. It is a general multipurpose, multi- reservoir simulation program which determines the optimal allocation of water for each time step on the basic principle of water balance accounting. The model provides a comprehensive flexible and user-friendly framework for planning and policy analysis. WEAP has an integrated approach of simulating both the natural inflows and engineered components of water system. This allows the planner access to a comprehensive view of the factors that must be considered in managing water resources for present and future use.

This enables to predict the outcomes of the whole system under different scenarios, and carry out comparisons between the different alternatives to evaluate a full range of water development and management options (SEI, 2005, Ahmed, 2015). Based upon the following criteria, WEAP will be selected to perform water resources management modeling for the study area. According to (SEI), WEAP integration listed as following: -

- GIS-based, graphical drag & drop interface
- Physical simulation of water demands and supplies
- Additional simulation modeling: user-created variables, modeling equations and links to spreadsheets & other models
- Scenario management capabilities
- Seamless watershed hydrology, water quality and financial modules
- Developed by the U.S. Center of the Stockholm Environment Institute Integrated watershed hydrology and water planning model.

3.3.4.4. WEAP Model Calibration

The aim of calibration is to adjust the parameters so that the model solutions fit the observations in an optimal fashion (Ahmed, 2015). In the present study, the parameters controlling the generation of runoff from climate inputs were calibrated using the historical measurement of stream flow obtained from 3 gauging stations located on the kombolcha station, Albuko station and swamp outlet of Kemiessie station. Figure 11: Are the locations of the stream flow stations on GIS map. The longest available continuous stream flow data from the kombolcha. Albuko and Kemiessie gauging stations have been recorded from 1998-2018, respectively. Thus, the stream flow records at these stations are sufficient and appropriate for calibration purposes. The model evaluation statistics (coefficient of determination, R^2; Nash-Sutcliffe efficiency, NSE and Percent bias, PBIAS) were computed for each set of simulated and historical stream flow over the period 1998-2018.

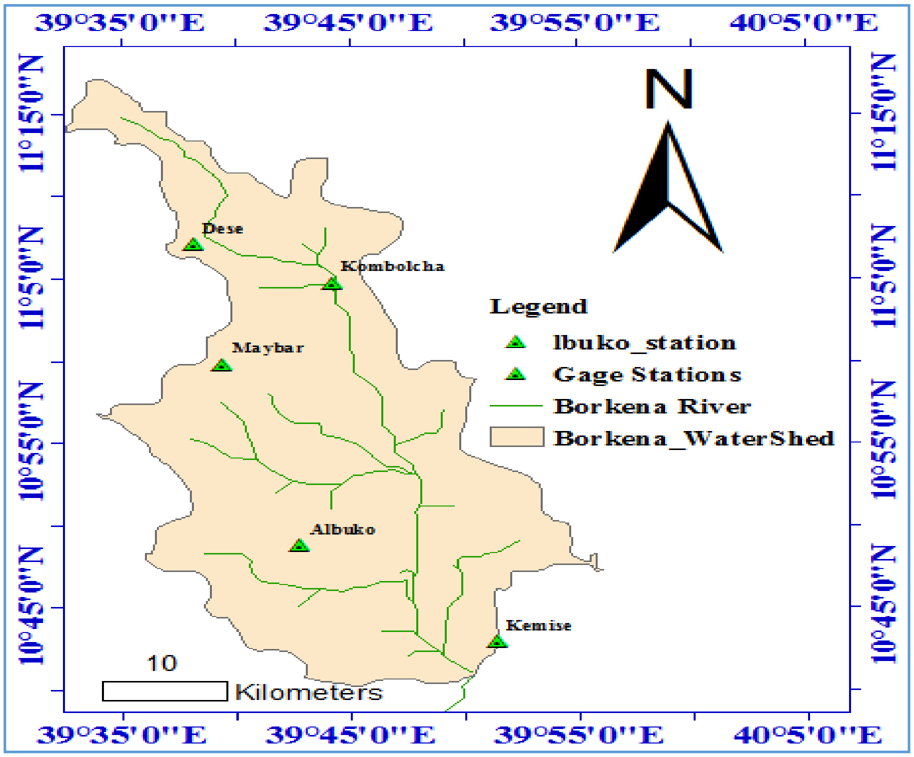


Figure 11: Awash kombolcha sub-basin of Borkena watershed stream gage station

3.3.4.5. Model Evaluation Statistics

The quantitative statistics used for the evaluation of model performance are the coefficient of determination (R^2), the Nash-Sutcliffe model efficiency (NSE) and the Percent bias (PBIAS).

- **Coefficient of determination (R^2).**

The coefficient of determination (R^2) outlines the degree of co linearity between simulated and observed data. R^2 describes the proportion of the variance in observed data explained by the model. R^2 ranges from 0 to 1, given higher values indicating less error variance. The Values which are greater than 0.5 considered as acceptable (IOPConf, 2017), the computation of R^2 is shown as below:

$$\mathbf{R^2} = \left[\frac{\sum_{i=1}^{n}(\text{yisim - ÿsim})(\text{yiobs - ÿiobs})}{\sqrt{\sum_{i=1}^{n}(\text{yisim - ÿsim})^2 \sum_{i=1}^{n}(\text{yiobs - ÿiobs})^2}}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where, $y_{i,Obs}$ = the i^{th} observed stream flow, $y_{i\ Sim}$= the i^{th} simulated stream flow, $\check{y}_i$ obs = the mean of observed stream flow, $\check{y}_i$ sim = the mean of simulated stream flow

- **Percent bias (PBIAS).**

Percent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than their observed counterparts. The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model under estimation bias, and negative values indicate model acceptable estimation bias (IOPConf, 2017). PBIAS is calculated as shown below:

$$\textbf{Percentage BIAS} = \left[\frac{\sum_{i=1}^{n}(\text{yiobs - yisim})}{\sum_{i=1}^{n}\text{yiobs}} \ast 100\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (8)$$

- **Nash-Sutcliffe efficiency (NSE).**

The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information") (IOPConf, 2017). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. NSE ranges between ∞ and 1.0 (1 inclusive), with NSE = 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance (IOP Conf, 2017). NSE is computed as shown below:

$$\textbf{NSE} = \mathbf{1} \ast \left[\frac{\sum_{i=1}^{n}(\text{yiobs - yisim})^2}{\sum_{i=1}^{n}(\text{yiobs - yisim})^2}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where, $y_{i,Obs} =$ the ith observed stream flow, $y_{iSim} =$ the ith simulated stream flow

3.3.4.6. Reference Scenario and Model Configuration

The reference scenario is the base scenario that uses the actual data, to help in understanding the best estimates about the studied period. For this scenario the existing data sets on the study area was used. These data input in WEAP was structured according to the schematic set-up of the study boundary and is the base scenario for other scenarios and any sub-scenarios that required. These was in the following steps (Shumet and Mengistu, 2016)

1. The model was first configured to simulate a base line year or current situation scenario, for which the water availability and demands can be confidently determined.
2. What if scenario analyses were building and the simulation was run for 2019 to 2030.
3. The scenarios are built on the data of the preceding scenario.
4. The following scenarios were therefore creating base on the reference scenario.

5. Development of the Reference Scenarios (2020–2030).

3.3.4.7. Scenario Analysis and model Development

- **Current account water demand**

Current Water Computation Sectors are identified in the study area in order to simulate current account available water demand between these Sectors. The Demand sites categories are domestic, agriculture, livestock, environment and Industrial. In the study area domestic water demand was the top priority fallowed by, agriculture, livestock, and environmental table 15:

Table 15: Scenarios Priority demand

Demand	Priority
Domestic	1
Agricultural	2
Livestock	3
Environmental	4
Industrial	5

The input data requirement in WEAP model was prepared by adding GIS based raster and vector maps to the projected area, the background vector data was added from a shape file format. This format was created by ArcGIS 10.4.1software once the area is open the years, time steps and units are set. In this study the current accounts in year (2019) with the start year scenarios to end year 2030, the time steps per year is set to be 12 and the time step boundary to "based on calendar month", starting with the month of January.

The current accounts year is chosen to serve as the base of the model and all system information (for instance demand and supply data) is the input into the current accounts. The current account is the dataset from which the scenarios are built; the "current scenario" carries forward the current accounts data into the entire project up to (2020-2030), river path is drawn in WEAP by clicking on the "River" symbol in the element window.

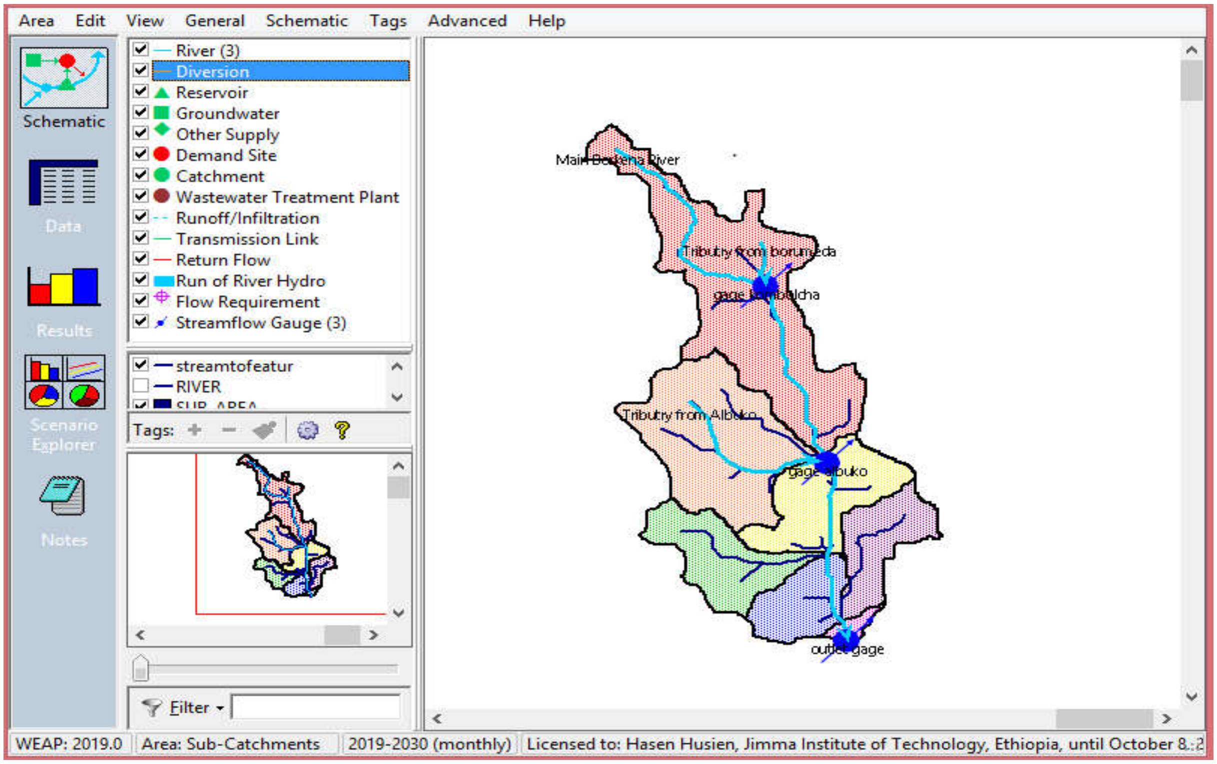


Figure 12: Data input into WEAP interface and Catchment boundary in WEAP model

- **Model Development**

WEAP has a module to model hydrologic processes (IOPConf, 2017). The hydrological model is semi-theoretical, continuous time, semi-distributed, and deterministic. As the model is semi-theoretical, it needs calibration to check model performance (IOPConf, 2017). To develop the model structure, the whole study area is divided into six (6) hydrological catchments (according to available hydrological data) and six (6) Demand site which may have considered domestic and non-domestic demands. Besides, it contains three (3) Stream gage and five Rain gage Station sites located inside the study area.

Next, the model structure developed considering involved elements including River (stream), Demand site, Transmission link, Catchment, Stream flow gauge, for monthly time steps between2019 to 2030. Figure13: is the schematic of the model showing WEAP node-network topology overlaid over a few GIS layers. And, several scenarios were developed and defined in the model to investigate the surface water resources problems and probable of water issues which may be occur in the near future.

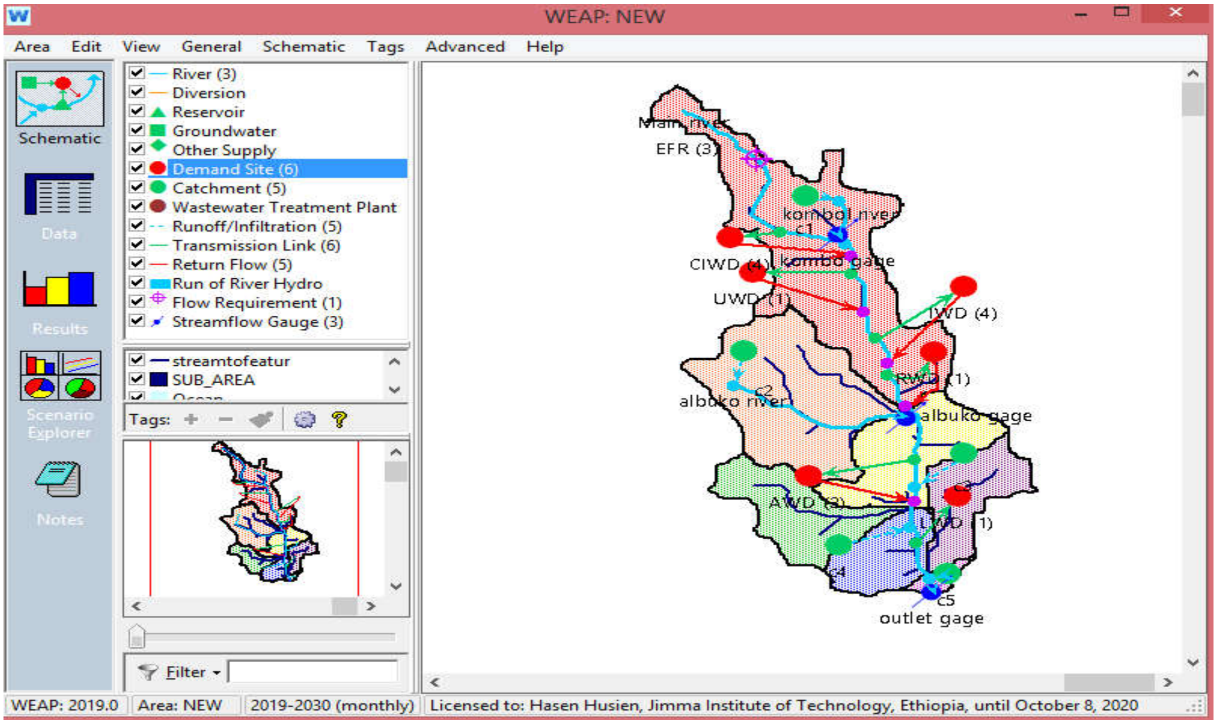


Figure 13: Schematic illustration of the Borkena watershed in WEAP

- **Demand sites and supply sources**

A demand site is best defined as a set of water users that share a physical distribution system, that are all within a defined region, or that share an important withdrawal supply point and the user-defined priority system determines the order of allocations to demand sites.

Water demand is defined as the volume of water required by users to satisfy their needs. In a simplified way it is often considered equal to water consumption. The water demand per site is calculated with the total area (in hectares)/or Total Activity level/and the annual water demand per unit of area (m^3/ha) or person/Capita/as well as the together with the monthly variations

3.3.4.8. Scenario Creation

Demand calculations for various measures of social and economic activity such as population served, livestock population and agricultural production units these are referred to as the activity levels. The activity levels multiply by the Annual water use rates of each activity defined as water use per unit of activity, each activity level and water use rate was individually projected into the future use linear growth rate function.

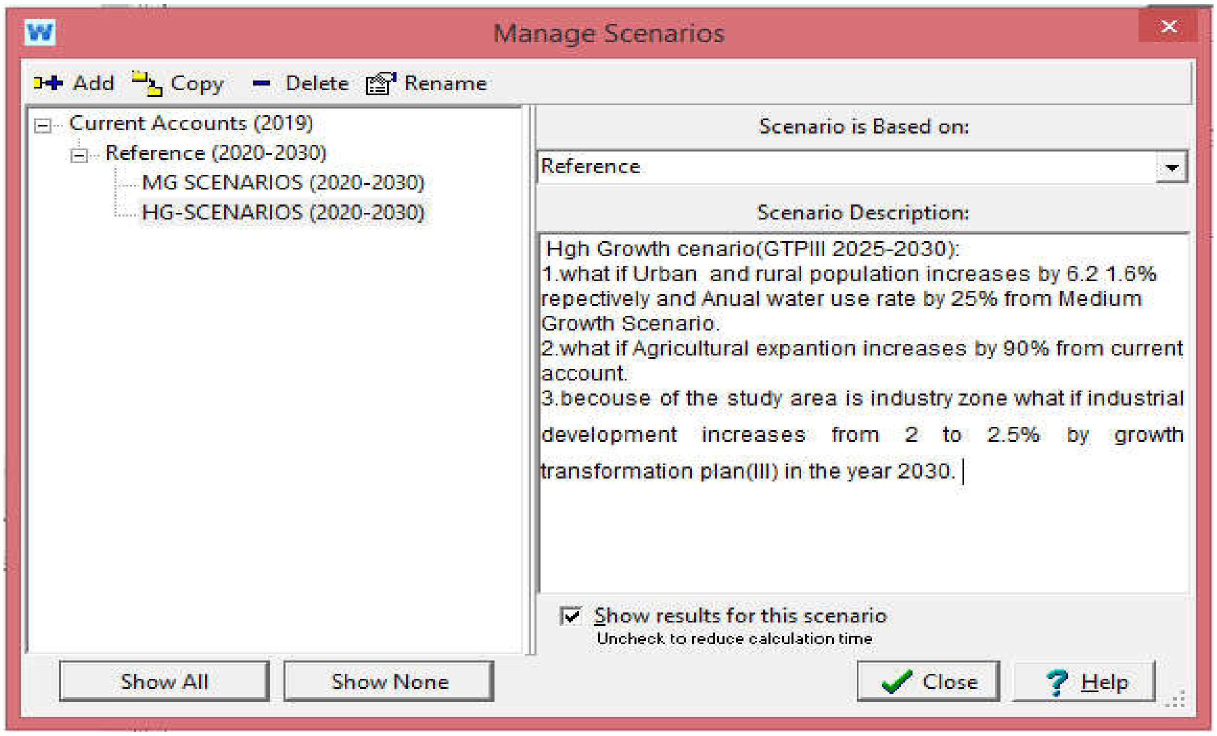


Figure 14: Creation of Scenarios in WEAP

- **Current scenarios** (2019)

Reference scenario also known as a default scenario which is established from the Current Accounts, it represents the basic definition of the current system including the specification of supply and demand data for the first year of the study on a monthly basis, to stimulate likely evolution of the system without intervention (SEI, 2011). Current scenario carried out entire project specified (2019), the current data into the entire time horizon in which no changes are imposed and serves as a point of comparison for the other scenarios in which changes are made in the system data.

In this study current scenario was applied to analyze the situation of Borkena River without any development in of the system except the average population growth rate 4.7, 1.3% per annum for, urban and rural respectively and the average annual growth rate for livestock is estimated 0.7%.

- **Medium Growth (MG) scenario**

After analyzing the possible impact in current scenarios WEAP was configured in medium growth scenarios, these scenarios is to evaluate the impact of a population growth rate and extended Agricultural area for the study.

Medium growth (MG) scenario it assumed by what if urban population growth rate increase from 4.7 to 5% per annum and rural population growth rate 1.8% and livestock population 0.85% and agricultural land expansion by 6.6% which reach from 11,326 ha to 23,680 ha in the medium Growth Scenario. these determined by due to the livestock and population of the study has become increasingly dependence upon the agriculture and livestock raring in 2030 for medium growth scenario, the production of animals to meet both export and internal demand has raising and come almost entirely from low living standard to high living standard sectors of the community, compare the current scenario which very low production and currently the existing 13 shed manufacturing industries out of greater number of micro enterprises in this area, so, the living standard of the people will a rising and annual water use rate of people has become increasing which reach 100 (l/d) per person and 25(l/d)per person for urban and rural respectively.

- **Higher growth (HG), scenario**

The socio-economic development activities in the Awash River Basin such as investment in agricultural development through irrigation, land conversion by pastoral groups and the expansion of industries due to expansion of output markets and macro-economic policy support are expected to be the major drivers of land degradation challenges. This process can be strengthened in association with the expansion of urbanization and population growth which will add pressure on water, land and related resources in the basin (ABA, 2017)

In this scenarios also we called worst scenarios, generally high growth scenarios we assumed by the urban and rural water development had been increased by the performance of commercial and eradicating the poverty situation as well as improving national food self sufficiency. By the same time, the rate of urban population has been increased from the rural area of the country to the big town, therefore annual growth rate increase by 5.8 and 2 % per annum for urban and rural respectively, annual water use rate raising 125 and 32 (l/d) per person, it assumed 25% when comparing in the medium growth scenarios. Agricultural growth assumed to be 7.6%, it reach 23.680 ha to 35,450 ha it shows 90% increment when comparing from current scenario industrial growth 2 to 2.5 % by Growth transformation plan (III) by the year 2030.

- **Environment and river flow**

In the annual discharge of the river Borkena it assumed that the currently amount of river flow will be constant up to three scenarios, also the minimum environmental flow requirement will be constants in the three scenario since there is no reliable projection in the study it can be increase or reduce in the environmental flow.

4. RESULTS AND DISCUSSIONS

4.1. WEAP Model Calibration

4.1.1. Data Observations to Calibrate WEAP Model

The aim of calibration is to adjust the parameters so that the model solutions fit the observations in an optimal fashion (Ahmed, 2015). In the present study, the parameters controlling the generation of runoff from climate inputs were calibrated using the historical measurement of stream flow obtained from 3 gauging stations located on the kombolcha station, Albuko station and swamp outlet of Kemiessie station. Are the locations of the stream flow stations on GIS map. The longest available continuous stream flow data from the kombolcha. Albuko and Kemiessie gauging stations have been recorded from 1998-2018, respectively.

There are three different types of observations to calibrate WEAP Model: 1.Stream flow, 2.Reservoir storage and 3.Catchment snowpack (SEIM, 2018). It may select one or more types to calibrate and one or more within each selected type. For Stream flow, PEST will compare the stream flow gauge data entered in the Data View, with stream flow results for the node immediately upstream of the gauge. For Reservoir storage, PEST will compare the reservoir storage data entered in the Observed Volume variable for the reservoir in the Data View, with the reservoir storage results. For Catchment snowpack, PEST will compare the snowpack data entered in the Snow Accumulation Gauge variable for the catchment in the Data View, with the Snow Accumulation results for the catchment.

So, calibration of the WEAP model for this study was based on the stream flow at swamp outlet of gauging stations near Kemissie it was done for the period 1998-2018, WEAP simulation results entirely depend on the quality of the input data like Hydrological and meteorological data. The area of each sub-watershed inputs, I chose to use data sets from the period 2006-2018 for calibration. The adjustment parameters of the WEAP model were calibrated by trial and error using the simplified coefficient method in WEAP21 by adjusting trial parameter like: reference evapo-transpiration and effective rainfall.

The quantitative statistics (coefficient of determination, R^2; Nash-Sutcliffe efficiency, NSE and Percent Bias, PBIAS) were computed for each set of simulated and historical observed stream flow over the period 2006-2018, then I obtained the result which is R^2 =0.954 figure

15 and 16: and NSE = 0.80 ,PBIAS = 0.8 see table EE and EE1 in Appendix 2, it can be observed that the simulated and observed flows are comparable in Borkena Rivers at gauge Station, there is good match between simulated and observed flow values, the result shows that the simulated is fitting well in the observed data and the model performance are perfect and provides a good estimate.

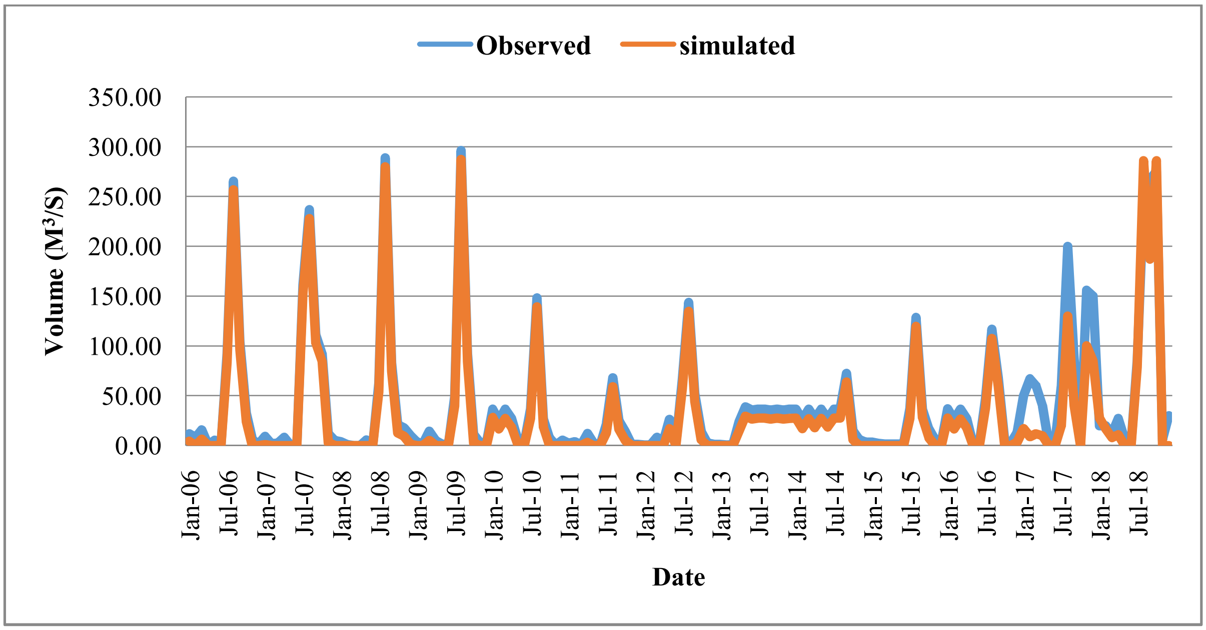


Figure 15: Monthly Observed Vs simulated stream flow in Borkena River for calibration

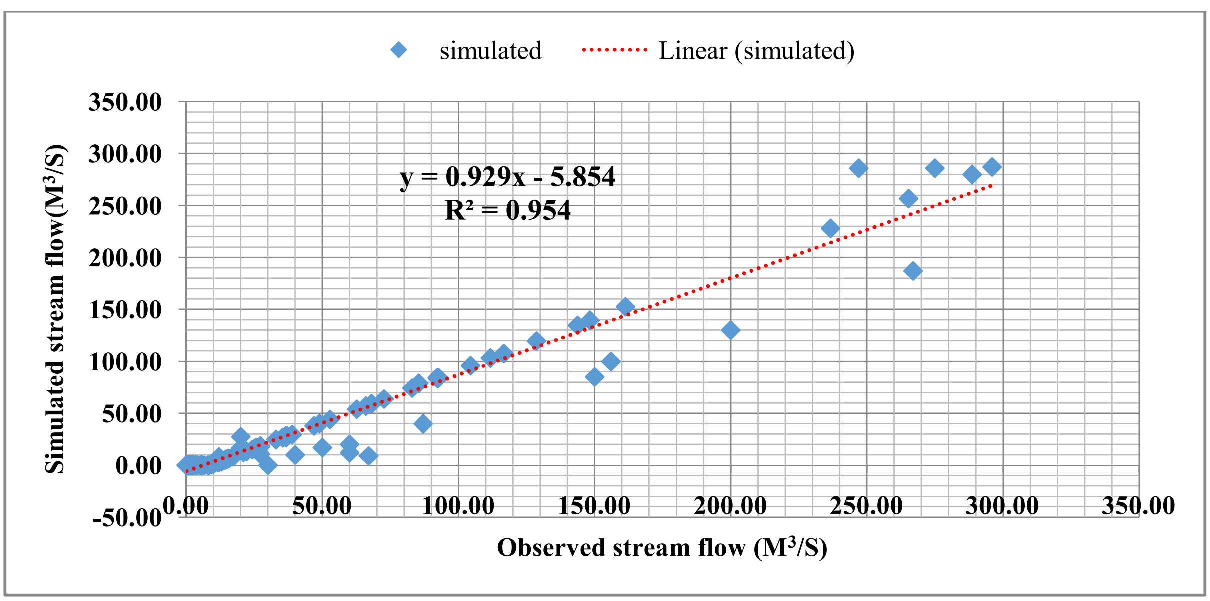


Figure 16: Coefficient of determination (R2) for Simulated Vs Observed stream flow, calibration.

4.2. Environmental flow requirement

In order to maintain the ecological services as well as the natural channel habitat associated to the historic flow regimes of the Borkena River, a certain reserve flow has to be maintained and could be considered as a sectoral demand on its own. 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 monthly discharge values are assigned a rank (M) starting with 1 for the largest and the probability of exceedence (P) calculated as follows. Assuming a comparably low reserve flow of 92% exceedence (with corresponding discharge 142 Mm^3/year or Q-92% = 4.50m^3/s) for WEAP input in the Borkena River watershed just for the sake of not neglecting this sector, by using low flow analysis concepts Table 16: and figure 17:

Table 16: Flow duration curve of Borkena River @ swamp outlet Near Kemiessie

Month	Q (Mm^3/YEAR)	ARANK(M)	N+1	P=100(M/N+1)
Aug	1443	1	13	8%
Sep	663	2	13	15%
Jul	651	3	13	23%
Oct	335	4	13	31%
Mar	226	5	13	38%
Jan	223	6	13	46%
Apr	200	7	13	54%
May	196	8	13	62%
Dec	192	9	13	69%
Nov	178	10	13	77%
Feb	177	11	13	85%
Jun	142	12	13	92%

The many small fresh water lenses and shallow wells along the dunes and eastern coastal areas are likely to be affected if there any changes in the flows to the swamps any future study or investigation should have to consider these water requirements. The assessment of environmental water requirements is done by a range of methods based on simple statistical hydrological indices, one such methods is flow duration curve, the flow duration relationship shows the frequency or percentage of time that stream discharge falls within various ranges (Wurbs et al, 2002)

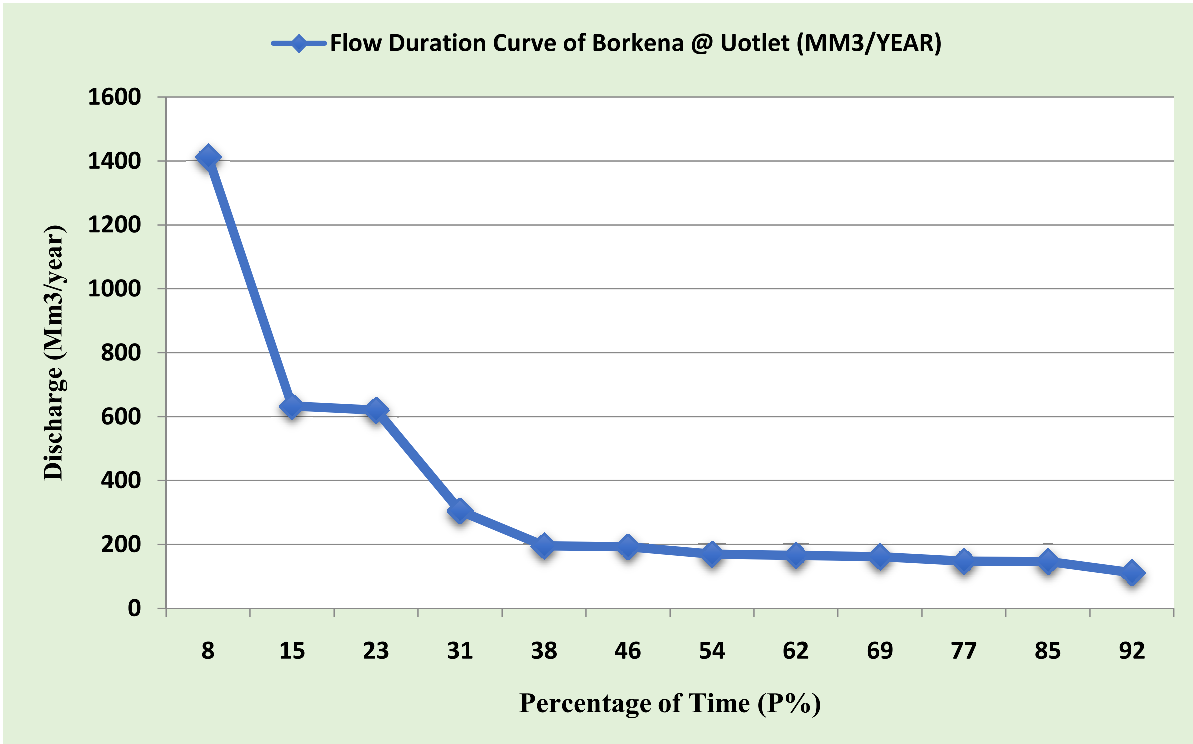


Figure 17: Flow Duration Curve for minimum Environmental Flow Requirement

4.3. Surface Water Availabilities

4.3.1. Stream Flow

The available data for Borkena river watershed, 20-year data were taken to estimate the river flow at swamp outlet near Kemiessie, which is the outlet of the sub-basin. The total river flow at this station has been estimated to be 4,080.3 MCM or 4.1 BCM by 2020-2030 but current average annual at the outlet gage station has been estimated to be 544.5Mm^3 in year 2019 of the available water resource in the study area currently in year (2019). The higher flows of 2019, 2020, 2021 and 2022 Figure 18: due to the expected higher rainfall occurred in those years. The peak monthly flow in Borkena River is occurring on July to September, Furthermore, the highest monthly average flow occurs in August and the lowest occurring in June with values 265.4 and 0.26 M m^3 respectively Table 17:

The total volume of runoff generated from each Catchments Contribution as head flow of the Borkena River less than 30% because of low rainfall in the area. A result of 11year river flow simulation using WEAP model (2019 to 2030) shows that there is inter-annual variability in annual discharge with peak flow registered in 2020, while the smallest flow recorded on 2024.

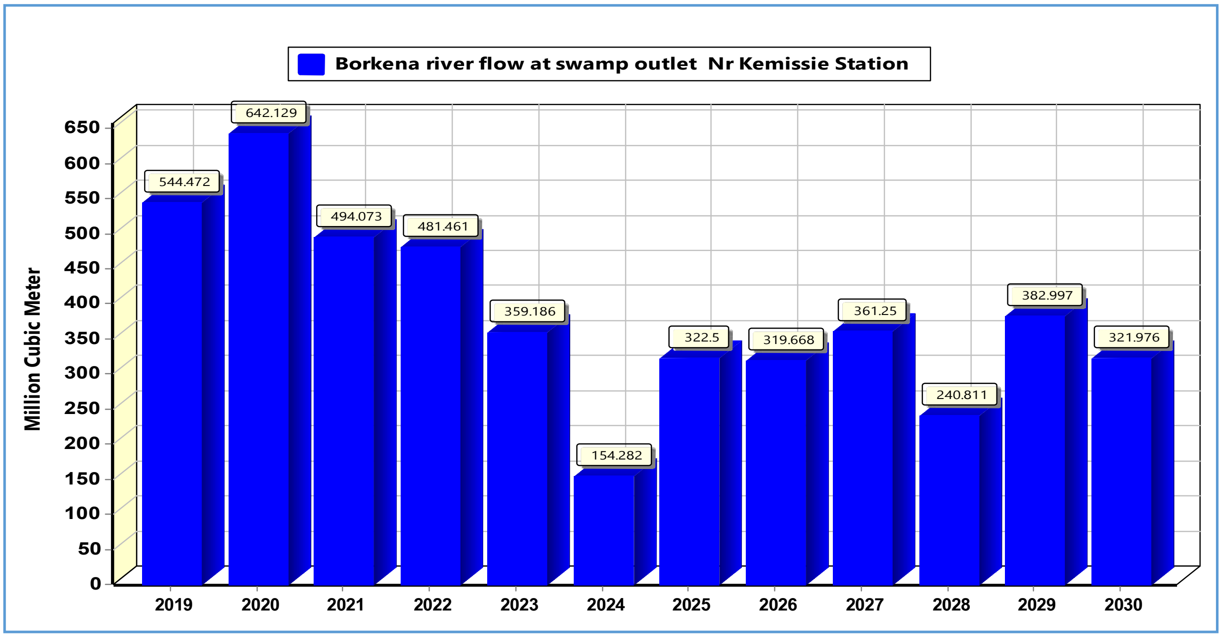


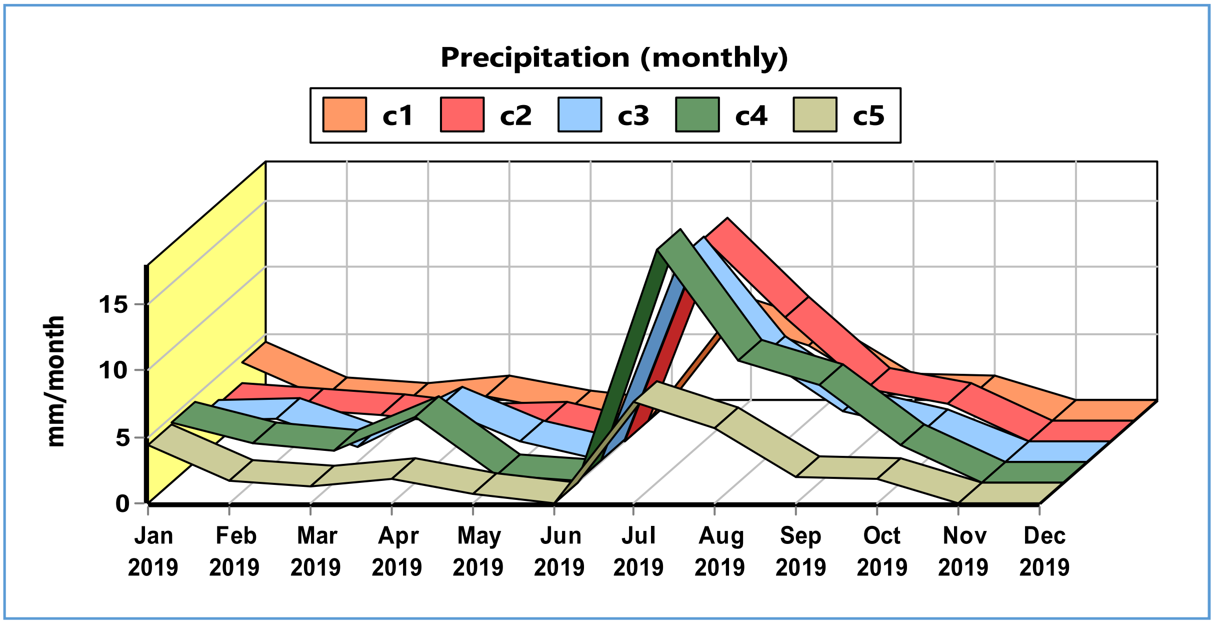
Figure 18: Annual Stream flow data at @swamp outlet (2019-2030)

Table 17: Annual and monthly Borkena Stream Flow (MCM) at swamp outlet Nr Kemiessie

Year 2019-2030	Annual stream flow (Mm^3)	Current-2019	monthly stream flow(Mm^3)
2019	544.47	Jan-19	11.97
2020	642.13	Feb-19	7.89
2021	494.07	Mar-19	15.67
2022	481.46	Apr-19	0.70
2023	359.19	May-19	5.60
2024	154.28	Jun-19	0.26
2025	322.5	Jul-19	92.32
2026	319.67	Aug-19	265.38
2027	361.25	Sep-19	104.43
2028	240.81	Oct-19	33.02
2029	383	Nov-19	5.65
2030	321.98	Dec-19	1.58
Sum	4624.8	Sum	544.47

4.3.2. Precipitation within Borkena Watershed

The results show that Borkena watershed receives the amount of rainfall estimated around 54.4 MCM annually by year (2020-2030) Table 18: but currently in year (2019) the result showed that around 9 MCM, which can to enhance rainwater harvesting in the study area. The higher month's rainfall is occurring from July to September and lowers from March to May. Moreover, the highest monthly average rainfall over the area occurs in August and the lowest occurring in February. There are also substantial variations of rainfall regime from one month to another, and from station to another. The rainfalls from a five stations showed significant monthly variations over the year Figure 19.



Note: C1, C2, C3, C4 and C5 are catchment 1, catchment 2 and catchment 3.catchment 4 and catchment 5.

Figure 19: monthly average precipitation for the selected stations

Table 18: Simulated Precipitation Monthly Average (MCM) in Borkena watershed

year	c1	c2	c3	c4	c5	Sum
2020	1.99	1.56	1.52	0.92	0.07	6.05
2021	1.49	1.80	1.29	1.17	0.05	5.79
2022	0.84	0.43	0.21	0.67	0.03	2.17
2023	1.99	1.41	0.84	1.65	0.07	5.96
2024	1.01	1.24	1.38	0.57	0.04	4.23
2025	2.32	1.03	1.14	0.98	0.07	5.54
2026	0.66	0.80	0.40	0.54	0.02	2.42
2027	1.43	1.06	0.65	0.86	0.05	4.04
2028	0.72	1.20	0.88	0.63	0.03	3.46
2029	1.56	1.69	1.24	2.00	0.05	6.54
2030	2.24	2.24	1.18	2.41	0.08	8.15
Sum	**16.25**	**14.45**	**10.71**	**12.41**	**0.55**	**54.37**

Note: C1, C2, C3, C4 and C5 are catchment 1, catchment 2 and catchment 3.catchment 4 and catchment 5.

4.3.2.1. Runoff generated from precipitation

WEAP offers five methods to simulate watershed hydrological processes such as evapo-transpiration, runoff, and infiltration. These methods are (1) Irrigation Demands only (simplified coefficient method), (2) Rainfall Runoff (simplified coefficient method) and (3) the Soil Moisture Method, MABIA (FAO 56, dual KC, daily) and Plant Growth (daily; CO2, water and temperature stress effects) (WB,2017). This study used WEAP's Simplified Coefficient Approach Method to estimate the surface runoff throughout the study area.

The runoff generated from the rainfall of the study area has been estimated using Rainfall Runoff (Simplified Coefficient) method in WEAP21 model. As a result of the calculations, based on this method in WEAP21, it was found that the total annual surface runoff from a given precipitation in the study area estimated to be 15.1 (MCM) by (2020-2030) Table 19: and the current monthly surface runoff is 2.5 MCM in year (2019) which is 27.8 % from the total precipitation over the study area.

The result from the model shows that on average, of 27.8 % rainfall is contributing to surface and subsurface flow and 72.2% of precipitation losses expected by evapo-transpiration, infiltration, retention and depreciation that means 6.5 MCM areal monthly precipitations lose which is around 72.2% of rainfall from Borkena River watershed.

Table 19: Runoff Monthly Average (MCM) in Borkena watershed

year	Runoff from C1 to kombol river	Runoff from C2 to Main river	Runoff from C3 to Main river	Runoff from C4 to Main river	Runoff from C5 to Main river	Sum
2020	0.72	0.68	0.17	0.12	0.02	1.70
2021	0.54	0.79	0.14	0.15	0.01	1.63
2022	0.30	0.19	0.02	0.09	0.01	0.61
2023	0.72	0.62	0.09	0.21	0.02	1.66
2024	0.36	0.55	0.15	0.07	0.01	1.14
2025	0.83	0.45	0.13	0.13	0.02	1.56
2026	0.24	0.35	0.04	0.07	0.01	0.71
2027	0.51	0.46	0.07	0.11	0.01	1.17
2028	0.26	0.53	0.10	0.08	0.01	0.97
2029	0.56	0.74	0.14	0.26	0.01	1.71
2030	0.81	0.99	0.13	0.31	0.02	2.25

Note: C1, C2, C3, C4 and C5 are catchment 1, catchment 2 and catchment 3.catchment 4 and catchment 5.

4.4. Modeling of Water Demand for all scenario

4.4.1. Current Scenario (2019)

The current account of the model was developed using the demand data of 2019 and simulated stream flow data (Supply) at outlet Kemiessie is 544.5Mm^3 in year 2019. The study area has at least six consumptives demand, urban water demand, rural water demand, agriculture, livestock, Industrial water demand and Institutional water demand. Table 20: summarizes the results of the model for the current account (water consumption). These results indicate that, the utilization is low compare with a population within the Borkena river watershed.

The current total water consumption within the study area is estimated to be 390.47 MCM per year. Therefore, the water withdrawal in Borkena watershed is around 71.6 % of the total water available in the area, which is 544.5Mm^{3}per year. Comparing the water requirements with the available surface water, in Borkena watershed had a capacity to utilize 71.6 % of the current water available in the area for consumptive. This scenario carried out entire project specified (2019), the current data into the entire time horizon in which no changes are imposed and serves as a point of comparison for the other scenarios in which changes are made in the system data.

Table 20: Average monthly Water Consumption all demand node current account (Mm^3)

Month	AWD	CIWD	IWD	LWD	RWD	UWD	EFR	Sum
	1,1326ha	**-**	**-**	**1,610,161**	**1,190,255**	**544,111**	**-**	**-**
19-Jan	0.2	0	0.34	6.29	1.1	1.69	5.30	14.92
19-Feb	0.49	0	0.3	5.68	0.99	1.52	4.13	13.11
19-Mar	0.49	0	0.34	6.29	1.1	1.69	6.02	15.93
19-Apr	0.26	0	0.32	6.09	1.06	1.63	0.19	9.55
19-May	0.23	0	0.34	6.29	1.1	1.69	3.18	12.83
19-Jun	0	0	0.32	6.09	1.06	1.63	0.05	9.15
19-Jul	0	0	0.34	6.29	1.1	1.69	52.88	62.30
19-Aug	0	0	0.34	6.29	1.1	1.69	111.67	121.09
19-Sep	0.04	0	0.32	6.09	1.06	1.63	62.67	71.81
19-Oct	0.29	0	0.34	6.29	1.1	1.69	27.08	36.79
19-Nov	0.31	0	0.32	6.09	1.06	1.63	3.21	12.62
19-Dec	0.32	0	0.34	6.29	1.1	1.69	0.63	10.37

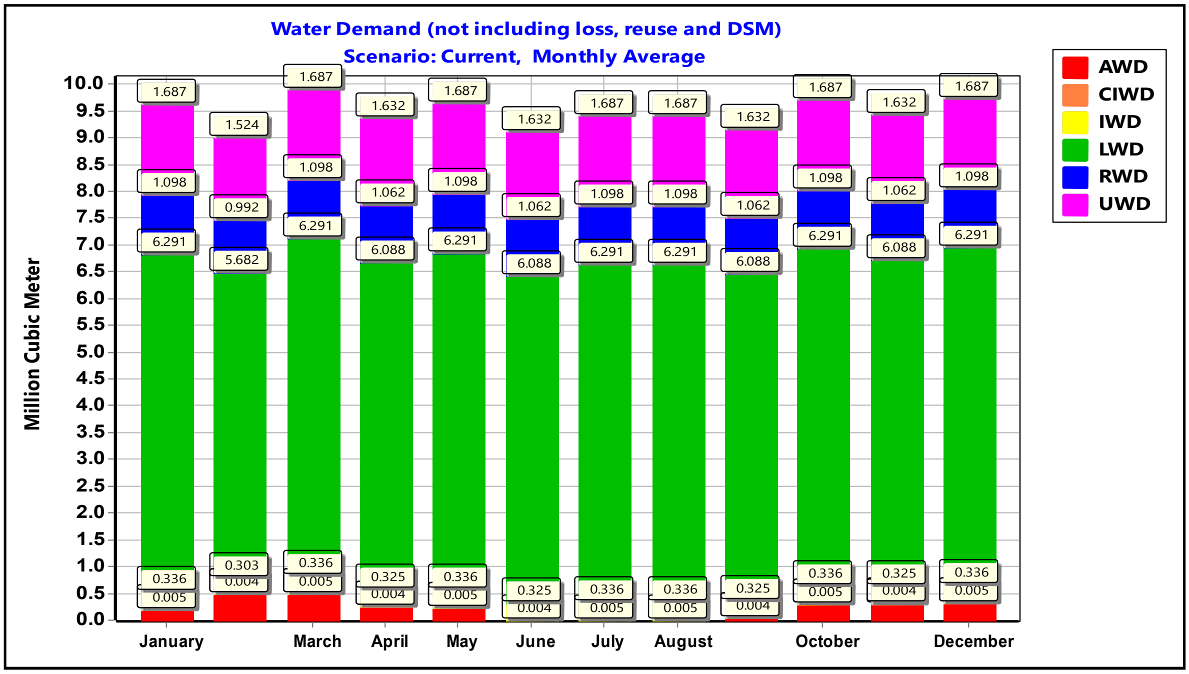


Figure 20: Current Monthly average water demand of all sectors in demand node

4.4.1.1. Unmet demand, demand coverage and demand reliability for Current-scenarios

Unmet demand, Coverage and Demand Reliability were considered in this study. Unmet demand is the amount of each demand site's requirement that is not met, and coverage is the percent of each demand site's requirement (adjusting for demand site losses, reuse and demand-side management savings) that is met, from 0% (no water delivered) to 100% (delivery of full requirement). Reliability is a measure of frequency or probability that a system is in a satisfactory state meeting a given criterion.

- **Unmet demand for Current-scenarios (2019)**

Unmet demand is defined as the quantity of water that cannot be physically delivered from the river during a certain period of the year. This situation is likely to deteriorate in the future due to the progression of water demand if no measures have taken to address them. The simulation with WEAP suggests that the requirements for the months of April to June and November to December. Will be difficult to be met in years that have hydrographs similar to where precipitation occurs late in the season and the peak flows appear in July to October with flows still quite low in April to June and November to December in current account Figure 21:

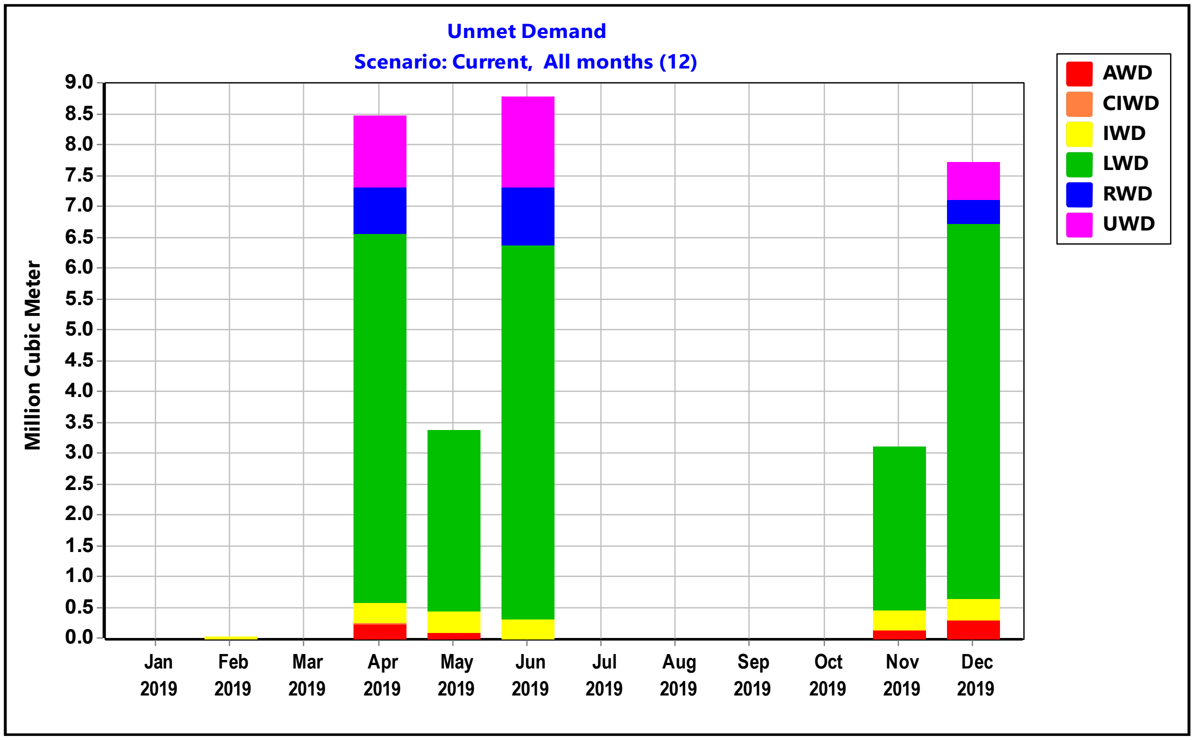


Figure 21: Current Monthly average unmet demand of all nodes

- **Demand site coverage (%) for Current-scenarios (2019)**

In the case of all Sectors in demand node are note covered 100% except during July to October .While the other month over the year are note fully covered example during April to June average percent of coverage is 31.07% (unmet demand, 20.7 Mm3) and during November to December average percent of coverage is 42.7% (unmet demand, 10.8 Mm3) which is the total unmet demand 20.7+10.8 = 31.46 Mm^3 and the total met demand (359.01Mm^3),the result shows that 8.1% demand coverage is unmet and 91.9% demand coverage is met with corresponding value 31.46 Mm^3,359.01Mm^3 during current account respectively. This variation clearly shown in the study area based on the result from WEAP model. Here, seasonal variations of rainfall lead to varying flow from each sub-watershed in the study area.

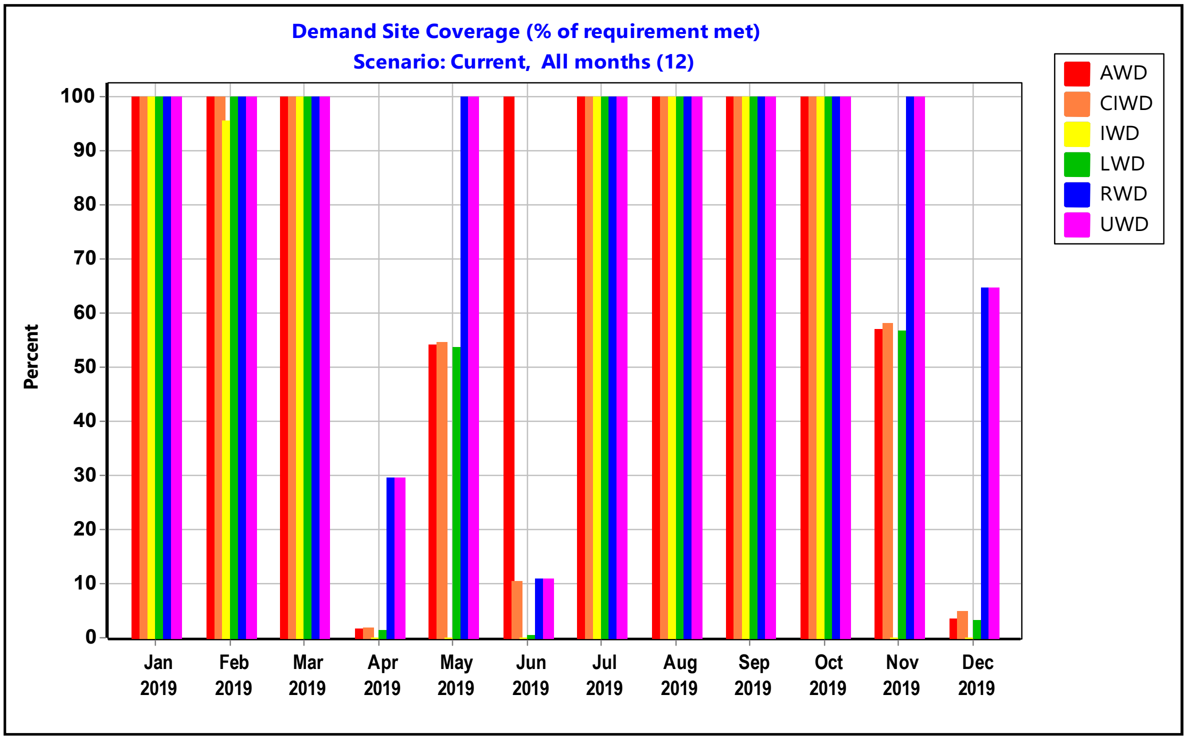


Figure 22: All Demand site coverage in (%) current scenario

- **Demand site Reliability(2019)**

The demand reliability in the current -Scenario for all demand sites not reaches 100% because available surface water is highly depending on precipitation so that this precipitation variation under the study area leads demand reliability or dependability on available surface water to be decreased. The demand reliability of all demand sites are shown in table 21: respectively.

Table 21: Demand site Reliable percentage for current -Scenario

Demand site Reliable	AWD	CIWD	IWD	LWD	RWD	UWD
Percent (%)	62.50	55.56	54.17	55.56	75.00	75.00

4.4.2 .Reference Scenario (2020-2030)

Reference Scenario (2020-2030) represents the changes that are likely to occur in the future without intervention new policy measures, it increases in population growth. The average population growth rate is 4.7% urban and 1.3 rural% and for livestock is average 0.7 % annually. While assuming that similar trends of the stream flow situation will exist in future. Hydrological condition, Industrial and commercial and institutional water demand is assumed unchanged into the future in this scenario. Climate change scenarios and their impact on surface water resources in this study are hardly to be taken into account due to limitation of climate data.

Table 22: Water Consumption (MCM) of the Reference Scenarios 2020_2030

Year	AWD	CIWD	IWD	LWD	RWD	UWD	EFR	Sum
2020	2.77	0.05	4.1	74.07	13.09	20.12	13.01	127.21
2021	2.94	0.05	4.25	74.07	13.26	20.38	8.53	123.48
2022	3.12	0.05	4.4	74.07	13.44	20.64	13.09	128.81
2023	3.33	0.05	4.56	74.07	13.61	20.91	10.17	126.7
2024	3.55	0.05	4.73	74.07	13.79	21.18	8.4	125.77
2025	3.8	0.05	4.9	74.07	13.97	21.46	5.36	123.61
2026	4.07	0.05	5.07	74.07	14.15	21.74	39.77	158.92
2027	4.37	0.05	5.26	74.07	14.33	22.02	89.57	209.67
2028	4.7	0.05	5.45	74.07	14.52	22.31	40.15	161.25
2029	5.07	0.05	5.65	74.07	14.71	22.6	13.57	135.72
2030	5.47	0.05	5.85	74.07	14.9	22.89	5.43	128.66
Sum	43.19	0.55	54.22	814.77	153.77	236.25	247.05	1549.8

The analysis of the result shows that there is not a significant change in the demand within the area when comparing this reference scenario with scenario of current account and is around 8.7 % from the total of surface water availability in the study area. Therefore, there is a significant increase in livestock, rural and urban demand, due to the population in this area highly depends on livestock.

4.4.2.1. Unmet Demand and Demand coverage in Reference Scenario (2020-2030)

The simulation with WEAP suggests that the unmet demand for this scenario shows significant change when comparing from current account, the requirements for the months of January to June and November to December. Still the change followed similar to hydrographs during rainy season that have a peak flows in the month of July to November with flows higher shortage in the month January to June and November to December with corresponding value of total demand coverage (%) and demand unmet is 46.52% of coverage and unmet demand 384.7MCM. Figure23:

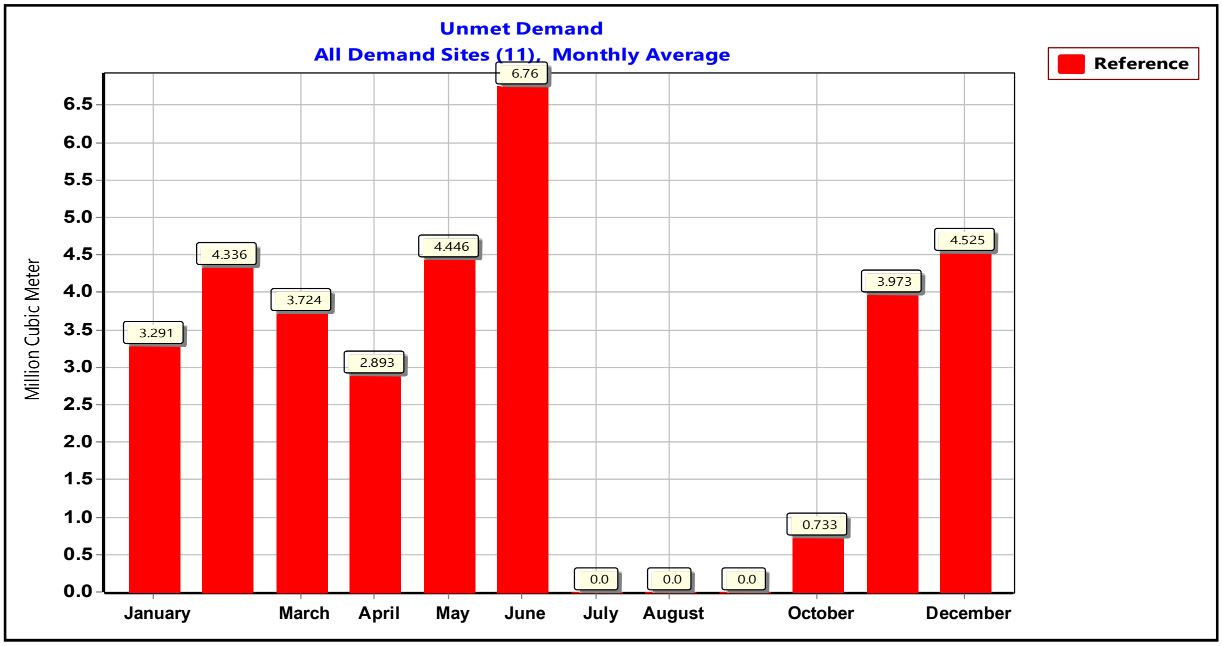


Figure 23: Unmet Demand for all nodes in Reference Scenario (2020-2030)

4.4.3. Medium growth up to 2030

Assuming a general medium growth scenario for 2030, where again livestock populations are increased by 1,610,161 to 1,776,937 with corresponding value of average growth rate 0.7% annual water used to be 81.9Mm^3 this means the annual water use rate 90.5% increment shown when we compared from current scenario. The population in the study area has been grown to almost 5% annual increased by 544,111 to 930,615 and 1.8% annual increased by 1,190,255 to 1448323 for urban and rural respectively (in 2030) Table A: in Appendix 2: the annual water demand is 35.9 Mm^3 for urban and 15.8 Mm^3 for rural, as result the annual water use rate 59.3% urban and 87.97% rural increment shown when we compared from current scenario. Environmental flow demands stay the constant (annually 247.05 Mm^3 for the Borkena River).

Table 23: Water demand of all demand nodes based on medium scenarios

Year	AWD	CIWD	IWD	LWD	RWD	UWD	EFR	Sum
2020	2.93	0.05	4.11	75.41	13.4	21.89	13.01	130.8
2021	3.3	0.05	4.28	76.77	13.88	24.14	8.53	130.95
2022	3.73	0.06	4.45	78.16	14.39	26.61	13.09	140.49
2023	4.24	0.06	4.63	79.57	14.91	29.34	10.17	142.92
2024	4.83	0.06	4.82	81.01	15.45	32.35	8.4	146.92
2025	5.52	0.06	5.01	82.47	16.01	35.66	5.36	150.09
2026	6.33	0.06	5.22	83.97	16.59	39.32	39.77	191.26
2027	7.3	0.06	5.43	85.48	17.2	43.35	89.57	248.39
2028	8.45	0.07	5.65	87.03	17.82	47.79	40.15	206.96
2029	9.81	0.07	5.87	88.6	18.47	52.69	13.57	189.08
2030	11.43	0.07	6.11	90.21	19.14	58.09	5.43	190.48
Sum	67.87	0.67	55.58	908.68	177.26	411.23	247.05	1868.34

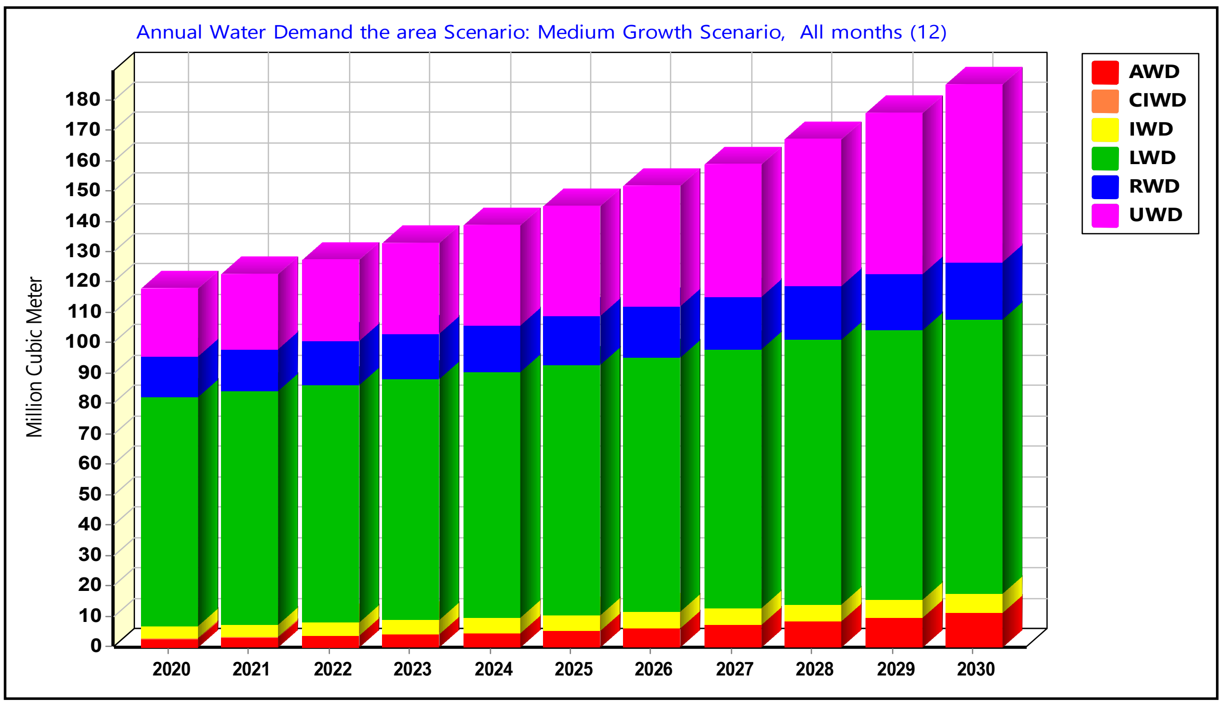


Figure 24: Water demand of all demand nodes based on medium scenarios

It must be highlighted at this point again, that there is extremely trends of demand in livestock development and hence assumes quite high water demand and has envisioned correspondingly high absolute abstractions from the rivers, these at some point might surpass the available river flows in this scenarios for the Borkena river for instance in the total water demands of 1868.34Mm^3 have been abstracted from the total annual stream flow of 4625 Mm^3, and 2757 Mm^3 is reaming to the river.

4.4.3.1. Unmet Demand for Medium Growth Up To 2030

The unmet water demand are much higher in this scenarios, the dry season demands and supplies are not balanced, however the analysis show that the situation of the unmet water demand in monthly have been selected (January to June) and (October to December). Average of monthly projections for river flows were selected the highest unmet water demand in June. The result in this scenarios shows that still considering the flow at the Kemiessie out let of gauge station, the unmet demand during the June are hence projected as 64.4Mm^3 for Borkena River, and the total unmet water demand is 515.2 Mm^3 with corresponding to its demand coverage 38.8%, due to the agricultural, population and livestock developments and demand variation on monthly flow are achieved in the medium growth scenario, hence the dry season the unmet water demand are relatively high as compared with the rain season. But extending the Socio-economic development in these scenarios with the increasing of agricultural, industrial, and commercial and institutional development as result the remaining surface water availability above in 4.4.3 will be sufficient based on wet seasons but in dry months over the year demand is greater than the supply due to the available water resource is highly depend on seasonal rain fall.

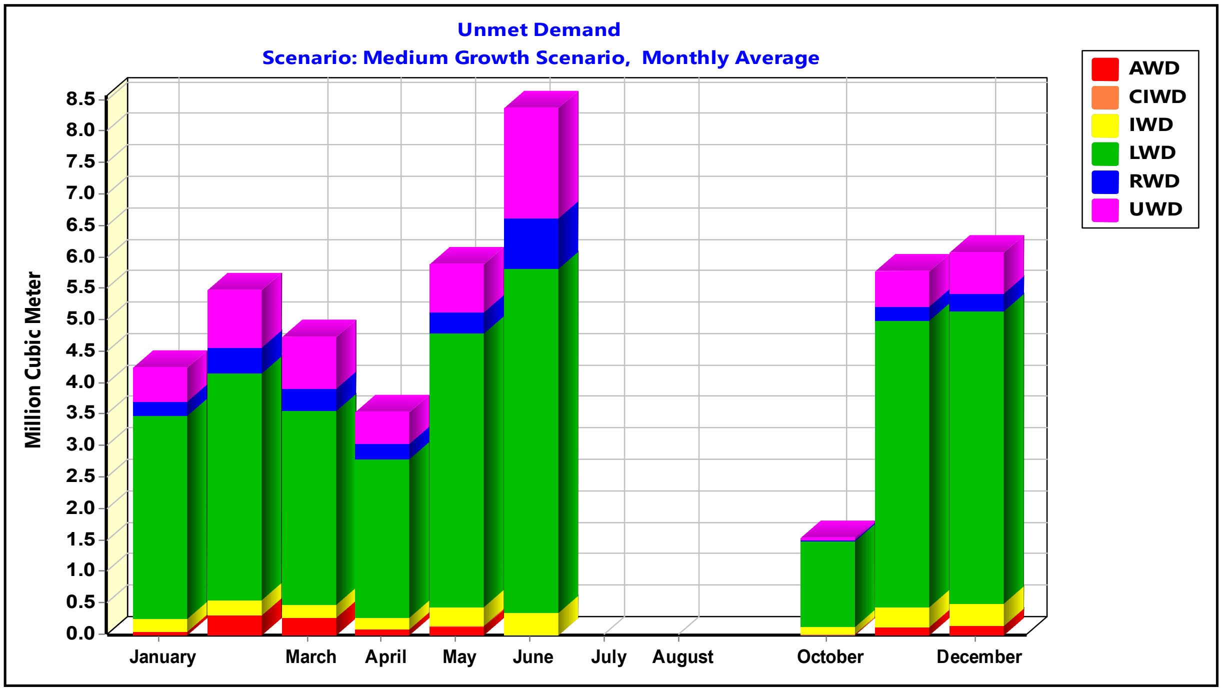


Figure 25: Unmet water demand based on medium scenarios

In the Borkena watershed the urban, rural, livestock and agriculture water demands make up about 33.86 % from the total surface water availability and Industrial and Commercials water demand make up about 1.22 % according to this scenario, the Domestic and livestock water demands make up 32.4 % of the total annual demands of the study area is due to the fact that the highest shorter of water demands occur for these sectors during (January, to June) and (October, to December). The medium growth scenarios indicated in Figure 25 show the higher increasing trend rather than the baseline, which will cause a significant water availability reduction in the future and will affect the economic and environmental condition due to it highly dependent on rain fall of the area and around the catchment.

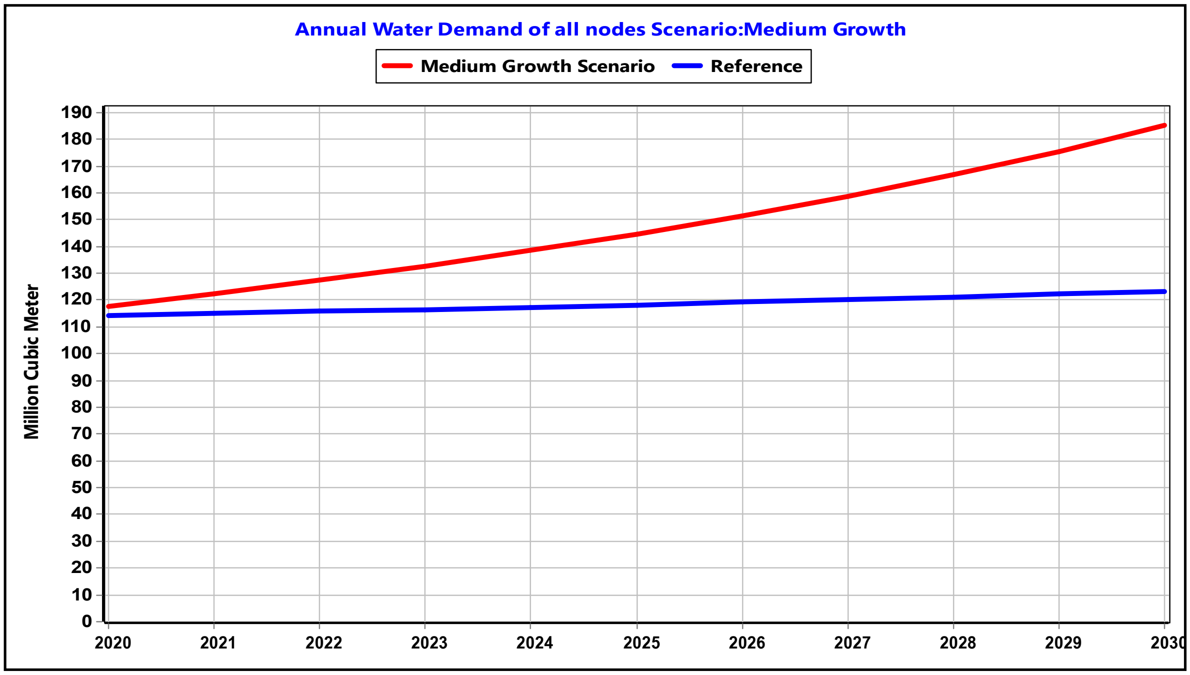


Figure 26: Comparison of Annual water demand for all nodes between Medium growth and reference Scenario**.**

4.4.4. High growths up to 2030

The result in this scenarios also shows that still considering the flow at the Kemiessie out let of gauge station, the unmet demand during the June are hence projected as $68.8Mm^3$ for Borkena River, and the total unmet water demand is 572.6 Mm^3 with corresponding to its demand coverage 30.9%, due to the population density and large livestock size extremely expose in surface water shortage for the other socio- economic developments scenario except rainy season figure 31.

Table 24: Water demand of all demand nodes based on High scenarios

In (Mm3)	AWD	LWD	RWD	UWD	CIWD	IWD	EFR	Total
Annual Activity	35,450ha	1,786,648	1,479,933	1,011,649	-	-	-	
Water demand	122.86	914.26	181.75	457.58	0.66	59.2	247.05	**1983.3MCM**
Unmet demand	**572.6Mm3**							

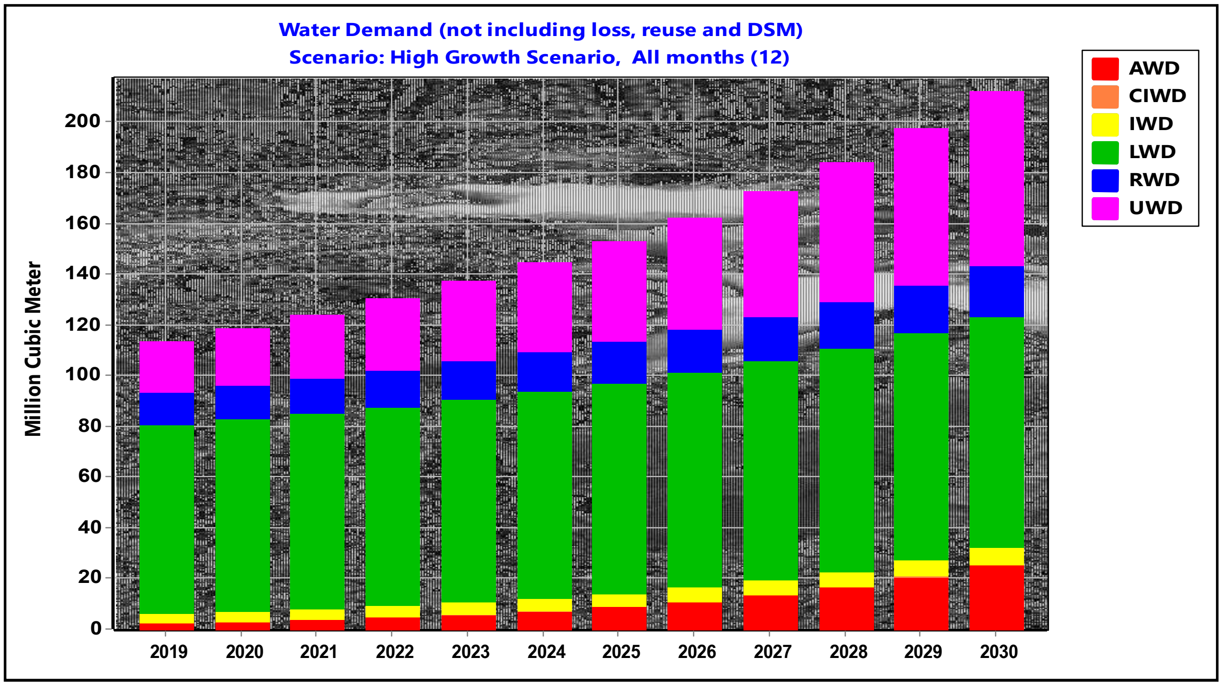


Figure 27: All scenarios in annual water demand

Table 25: Comparison among all scenarios of water demand, unmet demand and coverage

All Scenario	(Total Available surface water resource(MCM) up to (2019-2030) = **4625 MCM**	water used from Available (MCM)	Available water remaining (MCM)	Unmet demand(MCM) Observed during (Jan to June) & (Oct to Dec)	Demand Coverage (%) Observed during (Jan to June) & (Oct to Dec)
Current account by 2019	544.5	390.5	154	31.5	73.77
Reference 2020-2030	4080.3	1549.81	2530.49	384.7	46.52
Medium Growth up to 2030	4080.3	1868.35	2211.95	515.2	38.8
High Growth up to 2030	4080.3	1983.32	2096.98	572.6	30.9

Table 26: Comparison water demand for all scenarios

All Demand site	current data by 2019	Reference scenario up to 2030	Medium Growth up to 2030	High Growth up to 2030
AWD	2.62	43.19	67.87	122.82
CIWD	0.05	0.59	0.66	0.66
IWD	3.95	54.21	55.58	59.20
LWD	74.07	814.74	908.68	914.26
RWD	12.93	153.77	177.25	181.75
UWD	19.86	236.25	411.25	457.58
EFR	277.00	247.05	247.05	247.05
Sum	390.48	1549.81	1868.35	1983.32

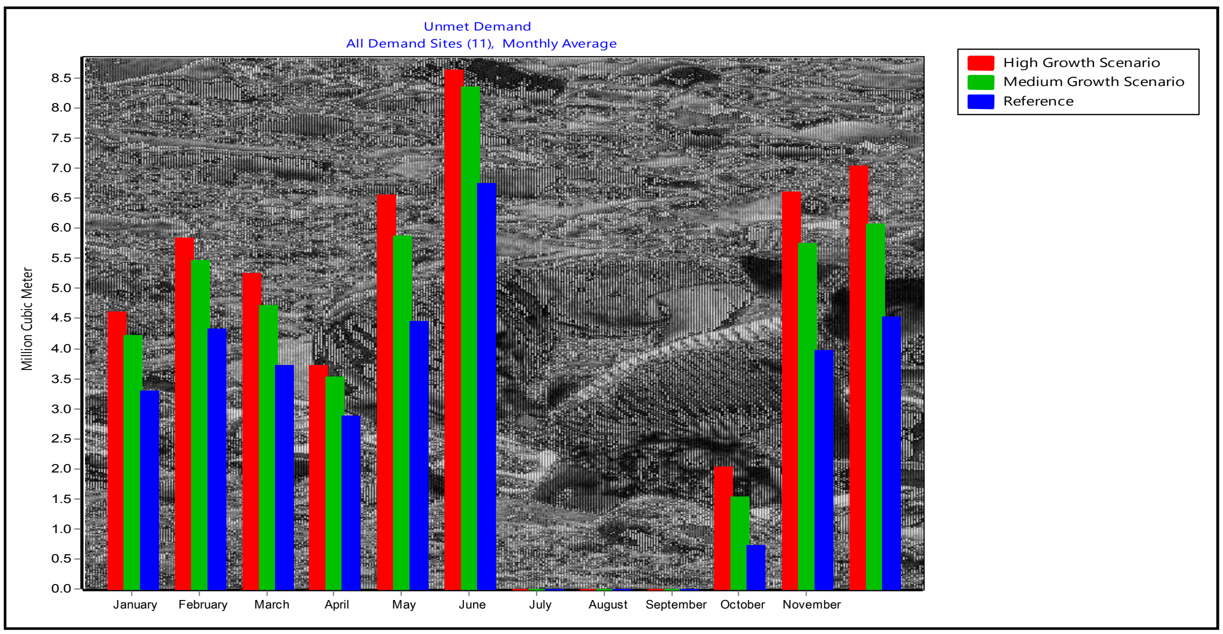


Figure 28: Unmet Demand of all Scenarios in the study area

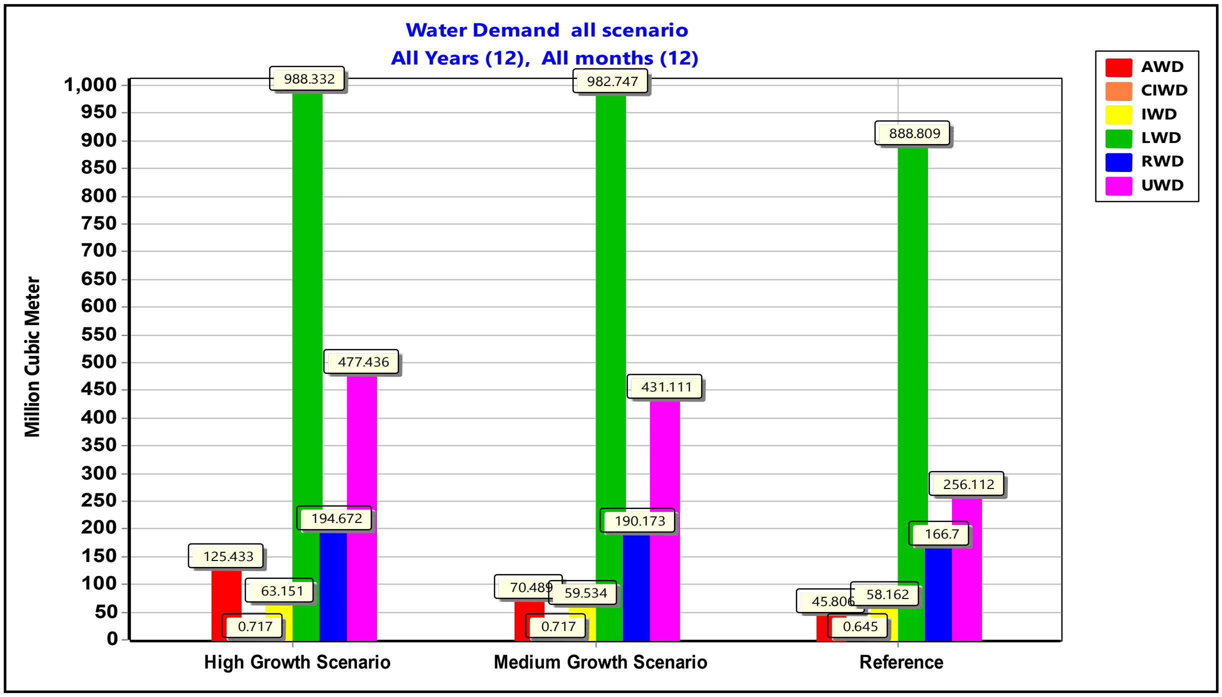


Figure 29: Summary of total water demand by2020 - 2030 scenarios

4.5. Surface Water resource Planning and Management

Ethiopia is currently experiencing significant natural and socioeconomic changes, which are modifying the availability and demand of water resources. Because of its geography and climate, Ethiopia has always been characterized by high hydrological variability, compounded by the almost total absence of water storage and highly vulnerable watershed (Beatrice…etal, 2015). Climate change is expected to lead to more uncertainty and extremes in weather patterns as well as increased rainfall variability (Beatrice…etal, 2015).

In addition, the spectacular economic growth and population increases of the last decade demand a lot of good quality water resources and give rise to well-known pollution problems. Nevertheless, Ethiopia's water sector continues to be characterized by little integrated planning, so that water resources are being allocated in ways that neither take into account competing demands nor are based on a systematic understanding of 'how much water' is available. This is already leading to instances of conflict, as demonstrated in the case of the Awash River Basin between upstream, middle and downstream water users (Beatrice…etal, 2015). The existing legal and policy framework for WRM already enshrines the basic principles of Integrated Water Resources Management (IWRM).However; it requires updating and strengthening; and basin planning through embryonic River Basin Authorities (AWRBAs) remains weak. The establishment of ‘good enough (WRM) institutions in Ethiopia is hampered by a lack of knowledge of resource conditions, patterns of use, and drivers of change; and a lack of capacity and skills within institutions to plan water allocation, assess the impacts and others (Beatrice…etal, 2015).

4.5.1. The Possible Adaptation of Surface Water

The figure 28 above indicated that the demand coverage (%) in this area for all sectors over the year is satisfied during the month (July to September) since the rain fall of the area is characterized by mono modal types of rain fall pattern that mean long rainy season and short rainy season which the short rainy month Mar to April are not satisfy the demand of all sector even if environmental flow requirement in the study area, while the other months out of the two rainfall pattern such as: October, November, December, January, February, May and June are dry Due to this reason the other optional implantation must be required like rain water harvesting, surface water harvesting and groundwater combined should be reserved to meet dry months peak requirement when the stress on the surface water resource availability is felt among these scenario of all water use sector.

However these combined uses of surface and groundwater therefore could enhance and address the issues related in water availability scarce during (January to June) and (November to December) and need to be considered as a key strategy for demand coverage and efficient utilization but groundwater recharge from surface water has to be improving, and using by integrated large scale for watershed management.

The results of this study indicated clearly, that there seems to have a surplus in supply side during rainy season in the sub-basin of all scenarios, which mean an integrated approach for the development of water resources in the sub-basin is necessary in order to meet the water requirements of all sectors to avoid competition and conflicts in water use during the dry season. The water resources in sub-basin watershed required to assigning a considerable demand on the dawn stream water resource like the river jara and at swamp wetland in order to manage water fairly. Adding to that, this surplus in supply side during wet season over the year needs for safeguarding to meet future water demand if it harvesting carefully.

One of the main objectives of this study is to assess surface water availability in terms of demand and supply system within Awash kombolcha Sub-basin of Borkena River. The output in this study is to forward the prediction of demand and supply by 2030 to evaluate the possible impact of future scenario in terms of surface water availability.

Stakeholder and civil society participation in water management and water conservation efforts must be encouraged through education and capacity building, and through making the political process more transparent and cooperative. It is exaggeration to suggest that Integrated River Basin Management be incorporated as a critical component of efficient and effective strategy to deal with water scarcity, and particularly for dry month from using in increasingly scarce resource in the study area.

Provide all stakeholders, including the public, with full opportunities to share their views & influence the outcome; raise awareness at the basin level & develop a host of preventive & mitigation measures against flood & droughts; build consensus & public support for the outcomes; build stakeholders‟ commitment; ensure implementation of basin flood management plans with full public support; ensure sustainability of plans & associated decisions; and build resilience of flood-prone communities.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Based on the findings of the study, the following conclusions were drawn:

Surface water availability in this sub-basin is (544.5Mm^3 runoff) with the mean annual discharge is 17.3m^3/s at swamp outlet gage station near Kemiessie respectively, under the current water demand situation water demand for domestic and livestock with. 106.9 Mm^3 is the largest consumer of surface water followed by Agriculture, commercial & institutional and industrial 6.6 Mm^3 and environmental water demands is 142 Mm^3. Currently the total annual water demand within the basin make up 20.85% of the total surface water availability is sufficient to sustain all the water demands site base on wet month.

The analysis and simulation of surface water availability and demand in the Borkena watershed was conducted under limited data availability, through the basic functions of WEAP, without using linkage to a groundwater analysis and climate change.

In this study, the assessment model used to operate at the WEAP sub-watershed scale and on a monthly time-step. The period of the study was from year 2019 –2030.The computation of the assessment model was done by computing the entire model for the Reference Scenario, a default scenario that was generated using the Current Accounts information for the period of study (2019 – 2030). Current Accounts year is chosen to serve as the base year of the assessment model. In this study, all the data in Current Accounts were base on the year 2019.

The result in medium growth scenario shows that still considering the flow at swamp outlet of gauge station Nr Kemiessie, the unmet demand during the June are hence projected as 64.4Mm^3 for Borkena River, and the total unmet water demand is 515.2 Mm^3 with corresponding to its demand coverage 38.8%, due to the agricultural, population and livestock developments and demand variation on monthly flow are achieved in this scenario, hence the dry season the unmet water demand are relatively high as compared with the rain season.

In addition to this water abstraction will be 45.8% from total available surface water in this area for medium growth scenario. However the result in high growth scenario show that the total unmet water demand is 572.6Mm^3 with corresponding to its demand coverage 30.9%, due to the population density and large livestock size extremely expose in surface water shortage for the other socio- economic developments scenario except rainy season.

5.2. Recommendations

Several recommendations can be derived from the results obtained and its analysis, it can be summarized as the following:-

1. Further development of the assessment model towards Borkena Watershed is recommended in order to investigate the hydrological response and its consequences for the sake of the current and future water demand during dry season.

2. It is also clear that the study area is found in the middle part of awash which is very vulnerable to drought situations; therefore there is an urgent need to increase reservoir, dams and weirs should be constructed along should River to improve water availability in the watershed during water scarcity.

3.Groundwater resource needs to be investigated and explored further to enable a more investigation into the analysis of water management in this sub-basin, the possibility of using ground water for all demand and water supply in dry season especially there is fear of water shortage problem due to extreme monthly variation in the area.

4. Since the area is drought prone area Attention should be given to community and marginal farmers to increase their level of awareness for adoption during Dry month over the year.

5. Scenarios analysis results from this study should be used in discussion among water planners, decision makers, and local authorities relating with management plans for the improvement of Borkena river watershed.

6. This study should be repeated for the same watershed in future using WEAP model after gathering adequate industrial and commercial &institutional demand data for enhancing planning and management program as the study should focus on the supply and demand to produce more realistic water resources availability scenarios.

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LIST OF APPENDINCIES

Appendix 1

Figure AA: checking consistency by double mass curve

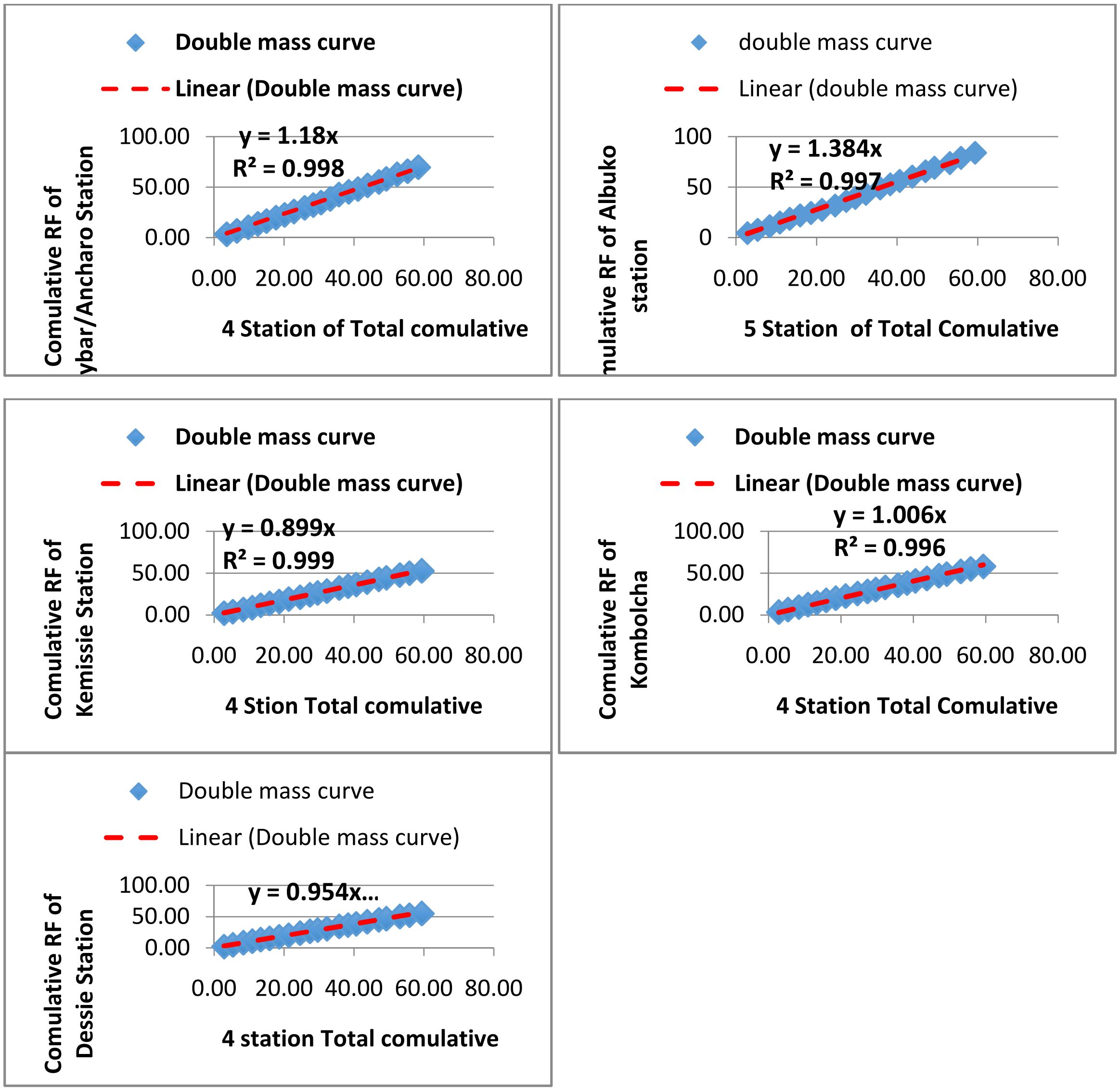

Table AA1: checking consistency by double mass curve Data set

year	total average sum	Total cumulative	Double mass curve	Double mass curve	Double mass curve	Double mass curve	double mass curve
1998	3.22	2.85	3.50	3.61	2.29	2.29	4.41
1999	2.54	5.39	6.85	6.50	4.25	5.10	7.65
2000	3.00	8.39	10.49	9.81	6.76	8.40	11.40
2001	2.52	10.91	13.80	12.52	8.79	11.00	14.82
2002	2.45	13.35	16.57	14.97	12.00	13.29	18.53

2003	2.56	15.92	20.03	17.68	14.00	15.32	21.99
2004	2.71	18.62	22.79	20.16	16.43	18.11	24.45
2005	2.72	21.34	26.07	22.83	19.34	20.58	27.45
2006	3.28	24.62	29.63	25.87	21.50	23.82	31.84
2007	2.76	27.38	32.62	28.37	24.28	26.61	36.15
2008	2.24	29.62	34.86	30.61	26.52	28.84	39.34
2009	2.66	32.27	38.63	33.25	28.63	30.96	43.29
2010	3.53	35.80	42.90	35.70	32.32	34.64	48.78
2011	2.51	38.31	45.76	38.46	34.54	36.86	52.78
2012	2.31	40.63	48.22	41.11	36.61	38.93	56.24
2013	3.13	43.76	51.88	43.88	39.65	41.98	60.46
2014	3.34	47.10	55.53	47.17	42.87	45.19	65.78
2015	2.16	49.26	58.41	49.23	44.72	47.04	69.17
2016	3.86	53.11	63.00	52.35	48.03	50.36	73.98
2017	2.76	55.88	66.00	55.36	50.29	52.61	79.11
2018	3.50	59.38	70.00	58.40	53.04	55.37	84.09
			Mayber/ancharo	**kombolcha**	**kemissie**	**dessie**	**Albuko**
			1	2	3	4	5

Table BB: Homogeneity Test Pi-Value for all station

	Checking Homogeneities test				
Non-Dimentional	Pi-value	Pi-value	Pi-value	Pi-value	Pi-value
MONTH	Albuko	Kemisie s	Dessie	Kombolcha	Maybar
JAN	0.61514	0.394078	0.987934	0.874582	0.687026
FEB	1.217356	0.231815	0.58115	0.639022	0.588304
MAR	1.893351	0.752145	1.885591	2.26499	2.602296
APR	3.226021	1.143936	2.867792	3.202543	3.420601
MAY	2.420099	0.882825	2.2132	2.00401	2.268806
JUN	1.474737	0.451748	1.132512	1.175719	0.903711
JUL	10.53636	3.959921	9.927333	11.79598	10.53955
AUG	11.20703	5.322857	13.34415	10.88738	11.93692
SEP	3.921714	1.568997	3.9334	3.983539	4.381235
OCT	1.696981	0.654216	1.640088	1.957911	1.485563
NOV	1.063712	0.400899	1.005036	0.753144	0.660215
DEC	0.727498	0.192191	0.481814	0.461177	0.525775

Table BB1: Homogeneity Test P_{ave} for all station

month	P_{ave}	p_{ave}	p_{ave}	P_{ave}	p_{ave}
jan	3.973805	2.506952	2.506952	2.75459	3.448449
feb	3.973805	2.506952	2.506952	2.75459	3.448449
mar	3.973805	2.506952	2.506952	2.75459	3.448449
apr	3.973805	2.506952	2.506952	2.75459	3.448449
may	3.973805	2.506952	2.506952	2.75459	3.448449
jun	3.973805	2.506952	2.506952	2.75459	3.448449
jul	3.973805	2.506952	2.506952	2.75459	3.448449
aug	3.973805	2.506952	2.506952	2.75459	3.448449
sep	3.973805	2.506952	2.506952	2.75459	3.448449
oct	3.973805	2.506952	2.506952	2.75459	3.448449
nov	3.973805	2.506952	2.506952	2.75459	3.448449
dec	3.973805	2.506952	2.506952	2.75459	3.448449

Table BB2: Homogeneity Test $P_{i\ ave}$ for all station

month	p_{iav}	p_{iav}	p_{iav}	P_{iav}	p_{iav}
jan	0.733333	0.743011	0.743011	0.722734	0.710753
feb	1.451261	0.437075	0.437075	0.528073	0.608621
mar	2.257143	1.418126	1.418126	1.871736	2.692166
apr	3.845873	2.156825	2.156825	2.646508	3.53873
may	2.8851	1.664516	1.664516	1.656068	2.347158
jun	1.758095	0.851746	0.851746	0.971587	0.934921
jul	12.56083	7.466206	7.466206	9.747926	10.90353
aug	13.36037	10.03594	10.03594	8.997081	12.34916
sep	4.675238	2.958254	2.958254	3.291905	4.53254
oct	2.023041	1.233487	1.233487	1.617972	1.536866
nov	1.268095	0.755873	0.755873	0.622381	0.683016
dec	0.867281	0.362366	0.362366	0.381106	0.543932

Table CC: Estimated Water Requirement of Existing Irrigation within the Study Area

month	kc	CWR(M/day	Area (1ha=10^4)	Crop water demand (Mm^3)	Existing Crop pattern durindg dry seseon	Area Coverage (%)
Jan	0.81	0.0301	1685	50.7185	Wheat , Barley	33%
Feb	0	0	0	0	-	0
Mar	0	0	0	0	-	0
Apr	0	0	0	0	-	0
May	0	0	0	0	-	0
Jun	0	0	0	0	-	0
Jul	0	0	0	0	-	0
Aug	0	0	0	0	-	0
Sep	0.50	0.0056	732.6	4.10256	Pulses	10%
Oct	0.55	0.021766667	879.12	19.135512	maize	12%
Nov	1.01	0.042666667	1831.5	78.144	Vegitable	25%
Dec	1.14	0.049666667	2197.8	109.1574	Sorghum	30%
total	**4.01**	**0.1498**	**7326.02**	**10.97Mm^3**		**100%**

Figure DD: Rain fall of the other station

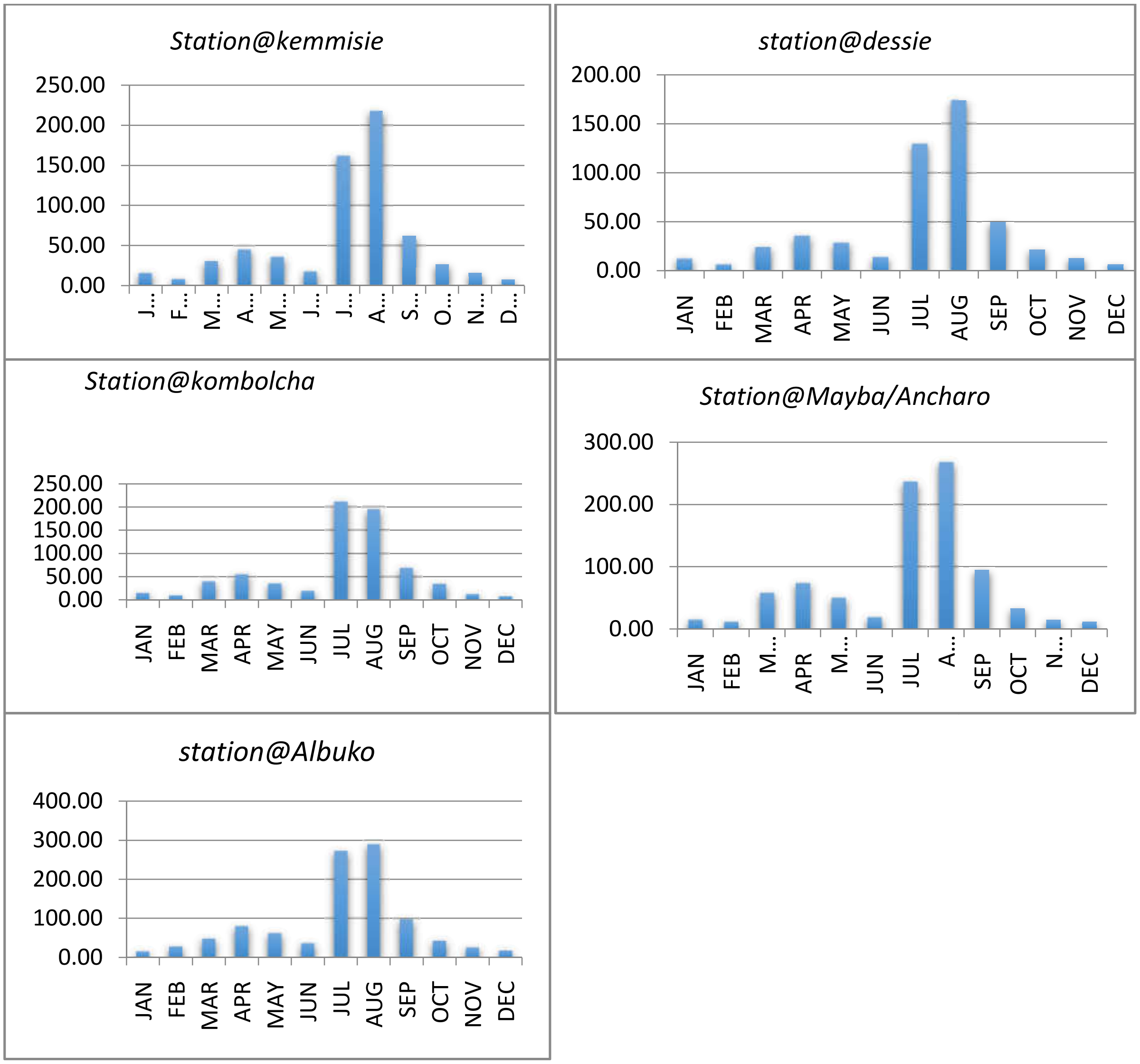

Table DD1: Annual average Rain fall of the five stations

year	Average of Albuko Pricip	Average of Maybar/Ancharo	Average of KOMBOLCHA	Average of Dessie	Average of kemissie
1998	4.415342466	3.496986301	3.614520548	2.290136986	2.290136986
1999	3.243287671	3.352876712	2.886027397	1.955890411	1.955890411
2000	3.748087432	3.642896175	3.31010929	2.518852459	2.518852459
2001	3.421643836	3.307945205	2.705753425	2.02630137	2.02630137
2002	3.70630137	2.770410959	2.449041096	2.286027397	2.286027397
2003	3.464109589	3.461643836	2.716164384	2.034794521	2.034794521
2004	2.458196721	2.756557377	2.481420765	2.793989071	2.793989071
2005	3.000273973	3.280547945	2.671506849	2.460547945	2.460547945
2006	4.384657534	3.564109589	3.038630137	3.249315068	3.249315068
2007	4.315616438	2.983287671	2.494520548	2.783287671	2.783287671
2008	3.185519126	2.242622951	2.243989071	2.23442623	2.23442623
2009	3.95369863	3.767123288	2.63369863	2.113424658	2.113424658
2010	5.487123288	4.270136986	2.455890411	3.687123288	3.687123288
2011	3.996164384	2.861917808	2.759726027	2.218630137	2.218630137
2012	3.460382514	2.457103825	2.649453552	2.07295082	2.07295082
2013	4.226027397	3.667945205	2.767123288	3.043835616	3.043835616
2014	5.322191781	3.641917808	3.296986301	3.213150685	3.213150685
2015	3.385753425	2.883287671	2.052328767	1.851780822	1.851780822
2016	4.806010929	5.671311475	3.127868852	3.315027322	3.315027322
2017	5.130136986	3.54630137	3.005479452	2.253972603	2.253972603
2018	4.984657534	5.47369863	3.035342466	2.754520548	2.754520548

Table DD2: Kemiessie meteorological station

Month	Min Temp	Max Temp	Humidity	Wind	Sunshine	Radiation	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
Jan	11.5	31.6	63	1	11.4	23.7	3.84
Feb	12.3	32.8	56	1	11.7	25.7	4.28
Mar	13.2	33.6	57	1	11.9	27.5	4.82
Apr	14.4	33.8	57	1	12.2	28.4	5.1
May	14.3	34.3	47	1	12.5	28.3	4.9
Jun	14.8	35.4	40	1	12.6	27.9	4.75
Jul	14.9	33.3	56	1	12.6	28	5.04
Aug	14.8	32.3	64	1	12.4	28.3	5.15
Sep	13.9	32.5	65	1	12.1	27.7	5.03
Oct	11.7	32.2	56	1	11.8	26.1	4.41
Nov	11.2	31.8	59	1	11.5	24.1	3.91

Dec	11	31.3	60	1	11.4	23.1	3.64
Average	13.2	32.9	57	1	12	26.6	4.57

Table DD3: Kombolcha meteorological station

Month	Min Temp	Max Temp	Humidity	Wind	Sunshine	Radiation	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
Jan	11.6	25.1	63	1	11.4	23.6	3.58
Feb	11.6	26.8	56	1	11.6	25.5	4.01
Mar	11.6	27.6	57	0	11.9	27.4	4.53
Apr	11.6	28	57	1	12.3	28.5	4.78
May	11.6	29.1	47	1	12.5	28.3	4.64
Jun	11.6	30.4	40	1	12.6	27.9	4.53
Jul	11.6	28.3	56	1	12.6	28.1	4.74
Aug	11.6	27	64	1	12.4	28.3	4.79
Sep	11.6	26.7	65	1	12.1	27.7	4.65
Oct	11.6	26.1	56	0	11.7	25.9	4.11
Nov	11.6	25.5	59	1	11.5	24	3.66
Dec	11.6	24.9	60	1	11.4	22.9	3.41
Average	**11.6**	**27.1**	**57**	**1**	**12**	**26.5**	**4.29**

Table DD4: Dessie meteorological station

Month	Min Temp	Max Temp	Humidity	Wind	Sunshine	Radiation	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	7.5	23.9	63	1	21.3	37.2	5.19
February	7.9	24.4	56	1	23.5	42.9	6.13
March	8.8	24.8	57	1	22.8	44.2	6.7
April	9.5	25.1	57	1	23.5	45.8	7.13
May	9.8	25.5	47	1	23.2	44.4	6.74
June	10.1	26.2	40	1	20.7	39.9	5.98
July	10.5	25.5	56	1	17.5	35.3	5.7
August	10.2	25	64	1	18.6	37.7	6.14
September	9.6	24.9	65	1	20	39.8	6.36
October	8.2	24.5	56	1	22.2	41.4	6.09
November	7.4	23.9	59	1	22.6	39.4	5.47
December	6.9	23.4	60	1	21.7	36.8	4.92
Average	8.9	24.8	57	1	21.5	40.4	6.05

Table DD5: Maybar/ancharo meteorological station

Month	Min Temp	Max Temp	Humidity	Wind	Sunshine	Radiation	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
Jan	10.2	29.9	63	1	11.4	23.6	3.8
Feb	10.8	30.3	56	1	11.6	25.5	4.19
Mar	11.3	30.8	57	1	11.9	27.4	4.7
Apr	12.2	32	57	1	12.2	28.4	5.01
May	12.8	32.8	47	1	12.5	28.3	4.9
Jun	12.5	33.2	40	1	12.6	27.9	4.7
Jul	12.8	33	56	1	12.6	28.1	5.04
Aug	12.6	32	64	1	12.4	28.3	5.18
Sep	11.9	30.9	65	0	12.1	27.7	4.97
Oct	10.5	30.8	56	0	11.7	25.9	4.36
Nov	9.5	29.8	59	0	11.5	24	3.85
Dec	9.4	29.4	60	1	11.4	23	3.56
Average	11.4	31.2	57	1	12	26.5	4.52

Table DD6: ALBUKO meteorological station

Month	Min Temp	Max Temp	Humidity	Wind	Sunshine	Radiation	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	8.6	23.6	62	138	6.8	17.1	3.17
February	8.6	25	61	164	7.6	19.5	3.71
March	7.9	25.7	59	164	8.3	21.8	4.13
April	9.1	27.2	59	138	8	21.9	4.25
May	10	27.9	48	181	7.8	21.3	4.67
June	9.9	29	41	199	7	19.7	4.8
July	14.2	26.1	60	173	4.8	16.5	3.89
August	13.7	25.5	64	138	5.9	18.4	3.88
September	13.4	25.2	64	112	5.5	17.6	3.66
October	9.7	25.1	60	104	8	20.3	3.78
November	7.9	24.3	59	104	7.9	18.8	3.32
December	8.2	24.3	60	147	7.6	17.7	3.26
Average	10.1	25.7	58	147	7.1	19.2	3.88

Appendix 2

Table A: water demand in reference (2019-2030)

year	AWD	LWD	population		Water demand (Mm3)			
			RWD	UWD	AWD	LWD	RWD	UWD
2019	11,326	1,610,161	1,190,255	544,111	2.62	74.07	12.93	19.86
2020	11,994.37	1,610,161	1,205,728	551,184	2.77	74.07	13.09	20.12
2021	12,727.02	1,610,161	1,221,403	558,349	2.94	74.07	13.26	20.38
2022	13,530.78	1,610,161	1,237,281	565,608	3.12	74.07	13.44	20.64
2023	14,413.33	1,610,161	1,253,366	572,961	3.33	74.07	13.61	20.91
2024	15,383.28	1,610,161	1,269,659	580,409	3.55	74.07	13.79	21.18
2025	16,450.37	1,610,161	1,286,165	587,955	3.80	74.07	13.97	21.46
2026	17,625.54	1,610,161	1,302,885	595,598	4.07	74.07	14.15	21.74
2027	18,921.17	1,610,161	1,319,823	603,341	4.37	74.07	14.33	22.02
2028	20,351.22	1,610,161	1,336,980	611,184	4.70	74.07	14.52	22.31
2029	21,931.5	1,610,161	1,354,361	619,130	5.07	74.07	14.71	22.60
2030	23,679.91	1,610,161	1,371,968	627,178	5.47	74.07	14.90	22.89

Table A1: water demand in reference (2019-2030)

year	AWD	LWD	population		Water demand (Mm3)			
			RWD	UWD	AWD	LWD	RWD	UWD
2019	11,326.00	1610161	1190255	544111	2.62	74.07	12.93	19.86
2020	11,994.40	1624652	1211680	571316	2.93	75.41	13.40	21.89
2021	12,727.00	1639274	1233490	599882	3.30	76.77	13.88	24.14
2022	13,530.80	1654028	1255693	629876	3.73	78.16	14.39	26.61
2023	14,413.30	1668914	1278295	661370	4.24	79.57	14.91	29.34
2024	15,383.30	1683934	1301304	694438	4.83	81.01	15.45	32.35
2025	16,450.40	1699090	1324728	729160	5.52	82.47	16.01	35.66
2026	17,625.50	1714381	1348573	765618	6.33	83.97	16.59	39.32
2027	18,921.20	1729811	1372847	803899	7.30	85.48	17.20	43.35
2028	20,351.20	1745379	1397559	844094	8.45	87.03	17.82	47.79
2029	21,931.50	1761088	1422715	886299	9.81	88.60	18.47	52.69
2030	23,679.90	1776937	1448323	930614	11.43	90.21	19.14	58.09

Table A2: water demand in medium growth (2019-2030)

year	Demand site		Water Demand		
	Industry Area occupation (ha)	Commercials & institution size in (bldg unit)	IWD	CIWD	EFR
2019	2,380	27,000	3.95	0.05	13.01
2020	2,423	27,000	4.10	0.05	8.53
2021	2,466	27,000	4.25	0.05	13.09
2022	2,511	27,000	4.40	0.05	10.17
2023	2,556	27,000	4.56	0.05	8.40
2024	2,602	27,000	4.73	0.05	5.36
2025	2,648.9	27,000	4.90	0.05	39.77
2026	2,697	27,000	5.07	0.05	89.57
2027	2,745	27,000	5.26	0.05	40.15
2028	2,795	27,000	5.45	0.05	13.57

2029	2,845	27,000	5.65	0.05	5.43
2030	2,896	27,000	5.85	0.05	5.16

Table A2.1: **water demand in medium growth (2019-2030)**

year	AWD	LWD	population		Water demand (Mm3)			
			RWD	UWD	AWD	LWD	RWD	UWD
2019	11,326	1610161	1190255	544111	2.62	74.07	12.93	19.86
2020	12,563.93	1625458	1214060	575669.4	3.22	75.48	13.45	22.23
2021	13,937.17	1640899	1238341	609058.3	3.96	76.92	13.99	24.88
2022	15,460.5	1656488	1263108	644383.6	4.87	78.39	14.56	27.85
2023	17,150.34	1672225	1288370	681757.9	6.00	79.89	15.15	31.18
2024	19,024.87	1688111	1314138	721299.9	7.38	81.41	15.76	34.90
2025	21,104.28	1704148	1340420	763135.2	9.08	82.97	16.39	39.07
2026	23,410.98	1720337	1367229	807397.1	11.18	84.55	17.06	43.73
2027	25,969.8	1736680	1394573	854226.1	13.75	86.16	17.74	48.95
2028	28,808.3	1753179	1422465	903771.2	16.92	87.81	18.46	54.79
2029	31,957.05	1769834	1450914	956190	20.82	89.49	19.21	61.33
2030	35,449.96	1786647	1479932	1011649	25.63	91.19	19.98	68.65

Table A3: water demand in High growth (2019-2030)

year	Demand site		Water Demand in (MCM)		
	Industry Area occupation (ha)	Commercials & institution size in (bldg unit)	IWD	CIWD	EFR
2019	2,380	11,326	3.95	0.05	13.01
2020	2,428	11,994	4.11	0.05	8.53
2021	2,476	12,727	4.28	0.05	13.09
2022	2,526	13,531	4.45	0.06	10.17
2023	2,576	14,413	4.63	0.06	8.40
2024	2,628	15,383	4.82	0.06	5.36
2025	2,680	16,450	5.01	0.06	39.77
2026	2,734	17,626	5.22	0.06	89.57
2027	2,789	18,921	5.43	0.06	40.15
2028	2,844	20,351	5.65	0.07	13.57
2029	2,901	21,932	5.87	0.07	5.43
2030	2959	23680	6.11	0.07	5.16

Table A3.1: water demand in High growth (2019-2030)

year	Demand site		Water Demand in (MCM)		
	Industry Area occupation (ha)	Commercials & institution size in (bldg unit)	IWD	CIWD	EFR
2019	2380	27000	3.95	0.05	13.01
2020	2439.5	27000	4.15	0.05	8.53
2021	2500.488	27000	4.36	0.05	13.09
2022	2563	27000	4.58	0.06	10.17
2023	2627.075	27000	4.82	0.06	8.40
2024	2692.752	27000	5.06	0.06	5.36
2025	2760.07	27000	5.32	0.06	39.77
2026	2829.072	27000	5.59	0.06	89.57
2027	2899.799	27000	5.87	0.06	40.15
2028	2972.294	27000	6.17	0.07	13.57
2029	3046.601	27000	6.48	0.07	5.43
2030	3122.766	27000	6.81	0.07	5.16

Table 6A: Per capital water use for different categories of urban & rural towns

GDP Range	**Towns and woredas**	**Categories of urban & rural towns**	**Per Capita Water Consumption (l/c/day)**	
			Urban	**Rural**
From 2020 – 2025 GDP-II	Kutaber	category-5 , urban & rural	40	25
	Albuko	category-5 , urban & rural	40	25
	Chaffie golana dawe	category-5 , urban & rural	40	25
	gisheRabel	category-5 , urban & rural	40	25
	Artuma	category-5 , urban & rural	40	25
	Tehulederie	category 4, urban & rural	50	25
	Dessie Zuria	category 4, urban & rural	50	25

	Harbu/Kalu	category 4, urban & rural	50	25
	Anstokian Gemez	category 4, urban & rural	50	25
	kemissie	category 4, urban & rural	50	25
	Kombolcha	category 2 urban & rural	100	25
	Dessie town	category 2 urban & rural	100	25
From 2025– 2030 GDP-III			125 lpcd	32 lpcd

Source: Main Report of Water Sector Development Program Volume II (2016)

Table 9A: Types of Livestock population and their location

Region	**Woredas/towns**	**Livestock Type & Livestock population**					
		Cattle's	**sheep**	**goat**	**horse**	**donkey**	**Mule**
Upper	kutaber	10,665	50,934	30,117	7,475	16,147	2,634
	Tehulederie	10,594	10,986	56,121	20,256	33,857	1,265
	Dessie Zuria	15,749	65,789	21,751	7,680	14,477	827
	Kombolcha town	34,152	75,230	49,874	14,210	9,874	2,250
	Dessie town	15,930	98,084	10,314	25,477	17,464	335
Middle	Albuko	10,944	24,738	6,798	27,341	144	1,316
	Harbu/kalu	56,860	27,658	18,143	1,802	3000	9,633
	Chaffie golana dawe	10,263	12,520	73,324	3468	4459	1,204
	gisheRabel	35,433	11,123	11,522	16,203	6,987	1,923
lower	Anstokian Gemez	52,220	75,874	58,628	3,694	334	6,899
	Artuma	20,002	25,896	17,540	8,128	4,650	3,650

	kemissie town	15,808	142,963	48,291	10,987	1,803	5,470
	Total	288,620	621,795	402,423	146,721	113,196	37,406
	All Total	**1,610,161**					

Source: Amhara regional Woreda Agriculture and Rural Development Office.

Table EE: Summary of Annual and Monthly Fit Statistics for Simulated by WEAP and Observed Stream Flows at swamp out let near Kemise.

	ANNUAL PRECIPITATION,CMORPH						1	2		3
month	Simulated	GUAGE	PEST-POBSER	SQARE OF CELL D	POBSR-AVRGE OF POBSR	PEST-AVGOF PEST	SQRTOF CELL F	SQRT OF CELL G	CELL F*CELL G	ABSLOUE OF PEST-POBSR
JAN	9.70	15.30	-5.6	31.39	-16.8	-16.3	282.8	264.21	273.3	5.6
FEB	5.62	10.26	-4.6	21.54	-21.9	-20.3	477.8	413.50	444.5	4.6
MAR	9.93	15.95	-6.0	36.22	-16.2	-16.0	261.3	256.58	258.9	6.0
APR	7.56	13.81	-6.2	38.99	-18.3	-18.4	335.2	338.09	336.6	6.2
MAY	6.17	11.10	-4.9	24.27	-21.0	-19.8	441.8	391.29	415.8	4.9
JUN	3.77	6.06	-2.3	5.25	-26.1	-22.2	678.8	492.01	577.9	2.3
JUL	52.17	61.08	-8.9	79.40	29.0	26.2	838.7	687.16	759.1	8.9
AUG	141.80	150.71	-8.9	79.40	118.6	115.8	14064.7	13420.84	13739.0	8.9
SEP	54.02	62.73	-8.7	75.89	30.6	28.1	937.4	787.89	859.4	8.7
OCT	14.76	22.83	-8.1	65.11	-9.3	-11.2	86.2	125.17	103.9	8.1
NOV	3.25	8.23	-5.0	24.74	-23.9	-22.7		515.32	542.4	5.0
DEC	2.67	7.34	-4.7	21.85	-24.8	-23.3		542.22	576.9	4.7

SUM	311.4	385.4	-74.0	504.0	0.0	0.0	18404.5	18234.3	18887.7	74.0
AVERAGE	26.0	32.1		5658.8			442.9	448.1		
TOTAL NUMBER OF DATA		**12**								

Table EE1: NASH Fit Statistics for Simulated by WEAP and Observed Stream Flows at swamp out let near Kemise.

CONTINUOUS STATISTICAL ANALYSIS		
MEAN ERROR(ME)	-6.2	
ROOT MEAN SQUARE(RMSE)	6.5	
RELATIVE ROOT MEAN SQUARE(RMSE)	20.2	IN PERECENT
BIAS	0.8	
Percent BIAS(PBIAS)	-19.2	
MEAN ABSOLUTE ERROR)MAE)	6.2	
CORELATION COEFFCIENT	1.0	
NASH	0.8	

WEAP Data Expressions Report

```
Area: NEW
Current Accounts
Date: 12/13/2019


Key Assumptions
  unit urban growth rate
  unit rural growth rate
  Urban Anual activity level       (cap)                                        544111
  rural anual activity level       (cap)                                        1190255
  ICWD growth                      (m^3)                                        1.99
  Urban anual water use rate       (m^3)                                        36.5
  rural anual water use rate       (m^3)                                        10.86
  industrial growth rate           (%)                                          1.3
  industrial water use             (m^3)                                        2.98
  irrigation monthly variation     (%)                                          MonthlyValues( Jan,
7.56,  Feb, 18.77,  Mar, 18.77,  Apr, 9.8,  May, 8.68,  Jun, 0,  Jul, 0,  Aug, 0,  Sep, 1.4,
Oct, 11.2,  Nov, 11.76,  Dec, 12.04 )
```

```
  irrigationgrowth rate            (%)                                   LinForecast(
2019,0,  2020,6.6,  2021,6.6,  2022,6.6,  2023,6.6,  2024,6.6,  2025,6.6,  2026,7.6,
2027,7.6,  2028,7.6,  2029,7.6,  2030,7.6 )
  average growth rate  livestock   (%)                                   0.7
Demand Sites and Catchments
  c4                               Land Use            Area (km^2)
215.52
                                                       Kc
MonthlyValues( Jan, 27.72,  Feb, 0,  Mar, 0,  Apr, 0,  May, 0,  Jun, 0,  Jul, 0,  Aug, 0,
Sep, 0,  Oct, 19.8,  Nov, 25.74,  Dec, 29.99 )
                                                       Effective Precipitation (%)
87
                                   Climate             Precipitation (mm/month)
ReadFromFile(C:\Users\jon\Desktop\WEAP INPUT FINAL\albuko average.csv, "Precipitation[mm]", ,
, , , , , , Cycle)
                                                       ETref (mm)
MonthlyValues( Jan, 3.17,  Feb, 3.71,  Mar, 4.13,  Apr, 4.25,  May, 4.67,  Jun, 4.8,  Jul,
3.89,  Aug, 3.88,  Sep, 3.66,  Oct, 3.78,  Nov, 3.32,  Dec, 3.26 )
                                   Advanced            Method
Rainfall Runoff (simplified coefficient method)
  IWD                              Water Use           Annual Activity Level (ha)
2380
                                                       Annual Water Use Rate (m^3/ha)
1661
                                                       Consumption (%)
90
                                   Priority            Demand Priority
3
                                   Advanced            Method
Specify yearly demand and monthly variation
  LWD                              Water Use           Annual Activity Level (cap)
1610161
                                                       Annual Water Use Rate (m^3/cap)
46
                                   Priority            Demand Priority
2
                                   Advanced            Method
Specify yearly demand and monthly variation
  AWD                              Water Use           Annual Activity Level (ha)
11326
                                                       Annual Water Use Rate (m^3/ha)
231
                                                       Monthly Variation (% share)
Key\irrigation monthly variation[%]
                                                       Consumption (%)
86
                                   Priority            Demand Priority
2
                                   Advanced            Method
Specify yearly demand and monthly variation
  CIWD                             Water Use           Annual Activity Level (bldg)
27000
                                                       Annual Water Use Rate (m^3/bldg)
1.99
                                                       Consumption (%)
45
                                   Loss and Reuse      Loss Rate (%)
40
                                   Priority            Demand Priority
2
                                   Advanced            Method
Specify yearly demand and monthly variation
  c2                               Land Use            Area (km^2)
282.96
                                                       Kc
MonthlyValues( Jan, 27.91,  Feb, 18.72,  Mar, 0,  Apr, 0,  May, 0,  Jun, 0,  Jul, 0,  Aug, 0,
Sep, 0,  Oct, 9.852,  Nov, 19.7,  Dec, 31.86 )
                                                       Effective Precipitation (%)
56
```

```
                                   Climate             Precipitation (mm/month)
ReadFromFile(C:\Users\jon\Desktop\WEAP INPUT FINAL\ANCHARO average.csv, "Precipitation[mm]", ,
, , , , , , Cycle)
                                                       ETref (mm)
MonthlyValues( Jan, 3.8,  Feb, 4.19,  Mar, 4.7,  Apr, 5.01,  May, 4.9,  Jun, 4.7,  Jul, 5.04,
Aug, 5.18,  Sep, 4.97,  Oct, 4.36,  Nov, 3.85,  Dec, 3.56 )
                                   Advanced            Method
Rainfall Runoff (simplified coefficient method)
  c3                               Land Use            Area (km^2)
255.28
                                                       Kc
MonthlyValues( Jan, 32.69,  Feb, 15.53,  Mar, 0,  Apr, 0,  May, 0,  Jun, 0,  Jul, 0,  Aug, 0,
Sep, 0,  Oct, 9.709,  Nov, 17.15,  Dec, 34.63 )
                                                       Effective Precipitation (%)
89
                                   Climate             Precipitation (mm/month)
ReadFromFile(C:\Users\jon\Desktop\WEAP INPUT FINAL\COMBOLCHA WEAP.csv, "Precipitation[mm]", ,
, , , , , , Cycle)
                                                       ETref (mm)
MonthlyValues( Jan, 3.58,  Feb, 4.01,  Mar, 4.53,  Apr, 4.78,  May, 4.64,  Jun, 4.53,  Jul,
4.74,  Aug, 4.79,  Sep, 4.65,  Oct, 4.11,  Nov, 3.66,  Dec, 3.41 )
                                   Advanced            Method
Rainfall Runoff (simplified coefficient method)
  c1                               Land Use            Area (km^2)
426.88
                                                       Kc
MonthlyValues( Jan, 17.03,  Feb, 0,  Mar, 0,  Apr, 0,  May, 0,  Jun, 0,  Jul, 0,  Aug, 0,
Sep, 0,  Oct, 14.6,  Nov, 39.9,  Dec, 54.5 )
                                                       Effective Precipitation (%)
64
                                   Climate             Precipitation (mm/month)
ReadFromFile(C:\Users\jon\Desktop\WEAP INPUT FINAL\dessie average.csv, "Precipitation[mm]", ,
, , , , , , Cycle)
                                                       ETref (mm)
MonthlyValues( Jan, 5.19,  Feb, 6.13,  Mar, 6.7,  Apr, 7.13,  May, 6.74,  Jun, 5.98,  Jul,
5.7,  Aug, 6.14,  Sep, 6.36,  Oct, 6.09,  Nov, 5.47,  Dec, 4.92 )
                                   Advanced            Method
Rainfall Runoff (simplified coefficient method)
  RWD                              Water Use           Annual Activity Level (cap)
Key\rural anual activity level[cap]
                                                       Annual Water Use Rate (m^3/cap)
Key\rural anual water use rate[m^3]
                                                       Consumption (%)
70
                                   Advanced            Method
Specify yearly demand and monthly variation
  UWD                              Water Use           Annual Activity Level (cap)
Key\Urban Anual activity level[cap]
                                                       Annual Water Use Rate (m^3/cap)
Key\Urban anual water use rate[m^3]
                                                       Consumption (%)
80
                                   Advanced            Method
Specify yearly demand and monthly variation
  c5                               Land Use            Area (km^2)
13.72
                                                       Kc
MonthlyValues( Jan, 30.43,  Feb, 12.7,  Mar, 0,  Apr, 0,  May, 0,  Jun, 0,  Jul, 0,  Aug, 0,
Sep, 0,  Oct, 8.863,  Nov, 21.86,  Dec, 35.16 )
                                                       Effective Precipitation (%)
76
                                   Climate             Precipitation (mm/month)
ReadFromFile(C:\Users\jon\Desktop\WEAP INPUT FINAL\kemise average.csv, "Precipitation[mm]", ,
, , , , , , Cycle)
                                                       ETref (mm)
MonthlyValues( Jan, 3.84,  Feb, 4.28,  Mar, 4.82,  Apr, 5.1,  May, 4.9,  Jun, 4.75,  Jul,
5.04,  Aug, 5.15,  Sep, 5.03,  Oct, 4.41,  Nov, 3.91,  Dec, 3.64 )
                                   Advanced            Method
Rainfall Runoff (simplified coefficient method)
Hydrology
  Water Year Method                Current Accounts                        Normal
```

```
  Read from File                   Read from File                          Not Specified
Supply and Resources
  River
    Main river                       Inflows and Outflows Headflow (CMS)
ReadFromFile(C:\Users\jon\Desktop\WEAP INPUT FINAL\kemise average.csv, "Stream Flow[m3/s]", ,
, , , , , , Cycle)
                                     Water Quality       Model Water Quality?
No
      Flow Requirements
        EFR                              Water Use           Minimum Flow Requirement (CMS)
FDCShift(ReadFromFile(C:\Users\jon\Desktop\WEAP INPUT FINAL\kemise average.csv, "Stream
Flow[m3/s]", , , , , , , , Cycle), A)
                                                             Priority
3
      Reaches
        Below Main river Headflow
        Below EFR
        Below Withdrawal Node 4
        Below kombol river Inflow
        Below CIWD Return
        Below Withdrawal Node 1
        Below UWD Return
        Below Withdrawal Node 3
        Below IWD Return
        Below Withdrawal Node 2
        Below RWD Return
        Below  Inflow
        Below Withdrawal Node 5
        Below c3 Runoff
        Below AWD Return
        Below c4 Runoff
        Below Withdrawal Node 6
        Below c5 Runoff
      Streamflow Gauges
        outlet gage                      Streamflow Data (CMS)
ReadFromFile(C:\Users\jon\Desktop\WEAP INPUT FINAL\kemise average.csv, "Stream Flow[m3/s]", ,
, , , , , , Cycle)
    albuko river                     Inflows and Outflows Headflow (CMS)
; Inflow from Catchment c2 (values not shown in Data View)
                                     Water Quality       Model Water Quality?
No
      Reaches
        Below albuko river Headflow
        Below c2 Runoff
      Streamflow Gauges
        albuko gage                      Streamflow Data (CMS)
ReadFromFile(C:\Users\jon\Desktop\WEAP INPUT FINAL\COMBOLCHA WEAP.csv, "Stream Flow[m3/s]", ,
, , , , , , Cycle)
    kombol river                     Inflows and Outflows Headflow (CMS)
; Inflow from Catchment c1 (values not shown in Data View)
                                     Water Quality       Model Water Quality?
No
      Reaches
        Below kombol river Headflow
        Below c1 Runoff
      Streamflow Gauges
        kombo gage                       Streamflow Data (CMS)
ReadFromFile(C:\Users\jon\Desktop\WEAP INPUT FINAL\dessie average.csv, "Stream Flow[m3/s]", ,
, , , , , , Cycle)
  Transmission Links
    to IWD
      from Withdrawal Node 3           Linking Rules       Supply Preference
4
    to LWD
      from Withdrawal Node 6
    to AWD
      from Withdrawal Node 5
    to CIWD
      from Withdrawal Node 4
    to UWD
      from Withdrawal Node 1
```

```
    to RWD
      from Withdrawal Node 2
  Runoff and Infiltration
    from c4
      to c4 Runoff
    from c3
      to c3 Runoff
    from c2
      to c2 Runoff
    from c1
      to c1 Runoff
    from c5
      to c5 Runoff
  Return Flows
    from IWD
      to IWD Return
    from AWD
      to AWD Return
    from CIWD
      to CIWD Return
    from RWD
      to RWD Return
    from UWD
      to UWD Return
Other Assumptions
```