JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR

SURFACE WATER POTENTIAL ASSESSMENT AND DEMAND SCENARIO ANALYSIS IN MEKI WATERSHED, ETHIOPIA

By

GIRMA MOHAMMED WELINGO

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

December, 2022

Jimma, Ethiopia

JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR

SURFACE WATER POTENTIAL ASSESSMENT AND DEMAND SCENARIO ANALYSIS IN MEKI WATERSHED, ETHIOPIA

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

By

GIRMA MOHAMMED WELINGO

Main Advisor: Dr-Ing. Zeinu Ahmed (PhD)

Co-Advisor: Mr. Tadele Shiferaw (MSc)

December, 2022

Jimma, Ethiopia

DECLARATION

I, Girma Mohammed welingo declare that this thesis entitled "surface water potential assessment and demand scenario analysis in Meki watershed, Ethiopia" is my original work and that it has not been presented and will not be presented by me to any other university for similar or another degree award.

______________________	________________	__________________
Student name	Signature	Date
______________________	________________	__________________
Main Advisor	signature	Date
______________________	________________	__________________
Co-Advisor	signature	Date

APPROVAL SHEET

The under signed certify that the thesis entitled: “surface water potential assessment and demand scenario analysis in Meki watershed, Ethiopia” is the work of Girma Mohammed and has been accepted and submitted for examination with our approval as university advisors in partial fulfillment of the requirements for Degree of Master of Science in Hydraulic Engineering.

Dr. Ing Zeinu Ahmed (PhD)	_______________	________________
Main advisor name	signature	date
Tadele Shiferaw (MSc)	________________	__________________
Co-advisor name	signature	date

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

________________	_______________	__________________
Internal Examiner	Signature	Date
Dr. Ing kassa Tadele (PhD)	_________________	_______________
External examiner	Signature	Date
Nasir Gebi (Ass.Prf)	__________________	________________
Chairperson	signature	Date

ACKNOWLEDGMENT

My first deepest thank is to the almighty GOD, for his mercy and grace upon me during all my works and in all my life.

I am thankful for everything which I get important advances, encouragement and the right way how to begging of the proposed development up to the completion of my final thesis work and sharing other nice academic knowledge from my main advisor Dr. Ing Zaiynu.A (PhD) and co-advisor Mr. Tadele shiferaw (MSc).

The last but the least is to my family for their endless encouragement and friends who beside on me to the end.

ABSTRACT

Water resource available was not well managed due to rainfall variability and unavailability, insufficient knowledge about available water resource and coordination in water resource management, population growth, expansion of irrigation. and environmental requirements, particularly during low flow periods. These clearly show that there was a need to analyze the water balance of the river basin and formulate water allocation strategies and principles for the present and future. To achieve this general objective Soil and Water Assessment Tool (SWAT) model was used to determine the surface water potential. The types of data that used to achieve this objective were Digital Elevation Model (DEM), land use and land cover (LuLc), Soil data, Meteorological data, Hydrological data, population data irrigation data, annual water use rate, and crop types. After sensitivity analyses, calibration and validation of the model by SWAT-CUP the Water evaluation and Planning (WEAP) model was used to analysis current and future water demand and under scenario development. The result revealed that an estimated mean annual precipitation was 144.11mm. Total surface water potential from the watershed was 350.76 million-cubic meter (Mm^3) annually during the current account year (2021). The model was calibrated and validated by using 18-year (1996-2013) stream flow data. The performance was found good during calibration (R^2 = 0.83), Nash-Sutcliffe efficiency (NSE)=0.69, and PBIAS=-19%, while validation (R^2= 0.86, NSE=0.76, and PBIAS=-18%). In the base year 109.47Mm^3 of water was required by both consumptive use and non-consumptive use (environmental flow requirement). In the base year (2021) there was no unmet water demand annually. The estimated total annual consumption water demand may be expected to be for reference scenario, high population growth scenario, increase irrigation area scenario, and increase water demand scenario were 82.44Mm^3, 161.4Mm^3, 173.2Mm^3, and 210.6Mm^3 respectively. High flow during rainy season and low or no flow during dry season hence, congestive use of water is recommended.

Keywords*: WEAP, SWAT, ArcGIS, Meki watershed, Surface water potential, demand allocation.*

TABLE OF CONTENTS

DECLARATION i
APPROVAL SHEET ii
ACKNOWLEDGMENT iii
ABSTRACT iv
TABLE OF CONTENTS v
LIST OF FIGURES viii
LIST OF TABLES ix
ACRONYMS AND ABBREVIATIONS x
1 NTRODUCTION 1
1.1 Background 1
1.2 Statement of the Problem 2
1.3 Research Questions 3
1.4 Objective of the Study 4
1.4.1 General Objective 4
1.4.2 Specific Objectives 4
1.4.3 Scope of the Study 4
1.4.4 Significance of the Study 4
1.4.5 Limitations of the Study 4
2 LITERATURE REVIEW 5
2.1 Hydrological Cycle and its Components 5
2.2 Irrigation Potential in the River Basin 7
2.3 Surface Water Resource Potential 8
2.4 Hydrological and Water Resource Models 9
2.5 The Water Evaluation and Planning System Version 21(WEAP21) model 9
2.6 SWAT Model 11
2.7 CROPWAT Model Description 12
2.8 Model Selection Criteria 12
2.9 Previous Related Study 14
3 MATERIALS AND METHODS 16
3.1 Description of the Study Area 16

3.1.1 Location of the Study Area 16
3.1.2 Topography and Drainage 17
3.1.3 Climate 17
3.1.4 Soil Type 18
3.2 Tools used for this study 18
3.2.1 Arc View GIS Software 18
3.2.2 Microsoft Excel 18
3.2.3 Xlstat2019 19
3.2.4 SWAT Weather Data Base Software 19
3.2.5 Hydrological Models 19
3.2.6 Water Evaluation and Planning (WEAP) Model 19
3.2.7 Soil and Water Assessment Tool (SWAT) Model 19
3.2.8 CROPWAT8 Model 20
3.2.9 SWAT-CUPS Software 20
3.3 Methodology 20
3.3.1 Data Collection and Source of Data 20
3.3.2 Meteorological Station 21
3.3.3 Hydrological Data 23
3.3.4 Missing Data Estimation 23
3.4 Population Projection and Water Demand 26
3.4.1 Population Projection 26
3.4.2 Water Demand 28
3.5 SWAT Model Setup 33
3.5.1 Watershed Delineation 33
3.5.2 Hydrological Response Units 34
3.6 SWAT Hydrological Process Analysis 38
3.6.1 Runoff Simulation 39
3.7 SWAT-CUP software 40
3.7.1 Sensitivity Analysis 40
3.7.2 SWAT Model Calibration and Validation 41
3.7.3 Model efficiency/performance evaluation 41

3.8 WEAP Model setup and Sharing of Water 42
3.8.1 WEAP Model setup 42
3.8.2 Schematic of WEAP21model 44
3.8.3 Sharing of Surface Water 44
3.8.4 Scenario Development 45
3.9 Flow Chart Representation of Methodology 49
4 RESULTS AND DISCUSSIONS 50
4.1 Sensitivity Analyses 50
4.2 Calibration and Validation of the Model 51
4.3 Current Surface Water Potential Assessment 52
4.4 Water Demand in the Current Account Year 55
4.4.1 Current Domestic Water Demand 55
4.4.2 Environmental flow Requirement 56
4.4.3 Current Irrigation Water Demand 56
4.4.4 Unmet Water Demand in the Current Account year (2021) 57
4.5 Future Water Demand and Allocation under selected Scenarios 57
4.5.1 Reference Scenario (2022-2051) 58
4.5.2 Scenario 1: High Population Growth Scenario 59
4.5.3 Scenario 2: Projection in Irrigation Command Area 60
4.5.4 Scenario 3: Increase Domestic Water Demand Scenario 61
5 CONCLUSION AND RECOMMENDATION 64
5.1 Conclusion 64
5.2 Recommendation 65
6 REFERENCE 66
7 APPENDIXS 72

LIST OF FIGURES

Figure 2.1 Hydrological processes 7
Figure 2.2 Phases of selection and evaluation 13
Figure 3.1 Geographical location of the study area 16
Figure 3.2 Meteorological station 22
Figure 3.3 Average monthly rainfall data series 23
Figure 3.4 Average annual maximum temperature 24
Figure 3.5 Average annual minimum temperature 24
Figure 3.6 Double mass curve of Meki watershed 25
Figure 3.7 Homogeneity test 26
Figure 3.8 A) DEM and B) slope of meki watershed 34
Figure 3.9 A) Land use and B) soil class map of Meki watershed 36
Figure 3.10 A) HRU and B) Sub- basin number of Meki watershed 38
Figure 3.11 Schematic of WEAP21model configuration Meki watershed 43
Figure 3.12 Scenario development by a WEAP model 46
Figure 3.13 Flow chart representation of methodology 49
Figure 4.1 Observed against simulated monthly flow in model calibration (1998-2007) 52
Figure 4.2 Observed against simulated monthly flow in model validation (2008-2013) . 52
Figure 4.3 Meki watershed water balance 54
Figure 4.5 Annual water demand for reference scenario 58
Figure 4.6 Water demand for scenario one (High population growth scenario) 59
Figure 4.7 Unmet water demand under high population growth scenario 60
Figure 4.8 Water demand for scenario two 60
Figure 4.9 Unmet water demand under increase irrigation area scenario 61
Figure 4.10 Water demand for increase domestic water demand scenario 62
Figure 4.11 Unmet water demand under increase domestic water demand scenario 62
Figure 4.12 Water coverage of each scenario in the watershed 63

LIST OF TABLES

Table 3.1 Data and source of data 21

Table 3.2 Meteorological station 22

Table 3.3 Percentage of rural and urban population growth rate 27

Table 3.5 Land cover types of Meki watershed 35

Table 3.6 Meki watershed soil types 37

Table 3.7 Areal distribution of slop in Meki watershed 37

Table 4.1 Fitted and most sensitive parameter of the best value of objective function 51

Table 4.2 Numerical value of calibration and validation of objective function 51

Table 4.3 Average annual water balance value of the watershed 54

Table 4.4 Average monthly water balance values of the watershed 55

Table 4.5 Current water demand in the watershed 57

ACRONYMS AND ABBREVIATIONS

a.s.l	above sea level
CROPWAT	Crop Water Requirement Software Development by
CN	Curve Number
CSA	Central Statistical Agency
CRV	Central Rift Valley
CWR	Crop Water Requirement
DEM	Digital Elevation Model
DMC	Double Mass Curve
DSS	Decision Support Model
EFR	Environmental Flow Requirement
ET	Evapotranspiration
FAO	Food and Agricultural Organization
GCS	Geographical Coordinate System
GIS	Geographical Information System
GTP	Growth and transformation program
ha	Hectare
h. time	hour time
HRU	Hydraulic Response Unit
IWR	Irrigation Water Requirement
IWRM	Integrated Water Resource Management
Km^2	Kilometer squire
l/c/day	liter per capital per day
lulc	Land use and Land cover

mm	mile mater
Mm^3	Million-meter cube
m^3/s	meter cube per second
MoWR	Ministry of Water Resource
MMM	Million Meter Cube
MWSWAT	Map Window SWAT
NAM	National Meteorological Agency
NIWR	Net Irrigation Water Requirement
NSE	Nash-Sutcliffe Efficiency
OWWDSE	Oromia Water Work Design and Supervision Enterprise
PBASS	Present of biases
SEI	Stockholm Environmental Institute
SCSCN	Soil Conservation Service Curve Number
SNNPR	South Nation Nationalities and People Region
SSI	Small Scale Irrigation
SUFI2	Sequential Uncertainty Fitting algorithm version 2
SWAT	Soil and Water Assessment Tool
SWAT-CUP	Soil and Water Assessment Tool Calibration Uncertainty program
UTM	Universal Transverse Mercator
WGNE-user	Weather Generator User
WGS	World Geodetic System
WEAP	Water Evaluation and Plan

1 INTRODUCTION

1.1 Background

Out of the three basic needs, Water is the most significant element of life on earth, it is also fundamental for living the base for the entire organic world, and an integral part of the ecological system. It covers approximately 70 % of the Earth's surface by seas, lakes, and rivers (Meng *et al*., 2015). It also plays a vital role in increasing productivity in human activities such as energy and industrial production, agriculture, sanitation, fishing, transportation services, tourism, etc. (Hussen *et al*., 2018).

Surface water resource is influenced by many factors such as population growth, climate change, economic development, urbanization, industrialization, and expansion of irrigation on freshwater availability (Asghar *et al*., 2019). The influence on water resources leads to undesirable consequences such as imbalance between demand and availability, water quality reduction, not equal share between sectors, and even regional and international conflict (Mersha *et al.*, 2018). All the above factor contributes to an increase in global water demand. Thus the integrated water resource management approach helps to manage and develop water resource in a sustainable and balanced way, taking account of social, economic and environmental interest (GWP, 2009).

Ethiopia has a vast amount of surface water resources it make a water tower in Africa, but, due to a variety of problems, including a lack of adequate financial resources, technical difficulty, and poor governance in the water sector; the available water resource is not completely realized and turned into development (Berhanu *et al*., 2014). Additionally, the increasing human population, uncontrolled urbanization, inadequate infrastructure, and the use of agricultural fertilizer cause serious quality degradation of surface water (Berhe, 2020). Therefore, it is necessary to analyze and study the relationship between the supply and demand of the water resource in the study area. And also, simultaneous use of surface water and ground water is of importance for cohesive water resource management. It has afford an effective means to satisfy the ever-increasing water demand from different water users and solve with surface water shortage problem (Zhang, 2015).

Meki watershed is one of the sub-watersheds located in the central rift valley basin. This river used for drinking, source of food for wildlife, water for livestock, bathing, clothe washing, and irrigation purposes. Factor which affect water quality and quantity were socio-economic development, and lowest standard of living, poor environmental condition, and low level of social service (Kebede *et al*., 2014). Additionally, population growth, urbanization, flooding, expansion of irrigation were an important factor in the watershed (Bunta and Abate, 2021).
In this study rainfall is not uniformly distributed at all-time throughout the year (the high rainy season in the summer locally known as "Kiremt") extending June to September and the dry season locally known as 'Bega" extending October to February. At rainy season Lake Ziway, which is directly fed by the flow from the Meki river catchment (Legesse *et al*., 2020). Due to this, the level of lake Ziway increase but, the available water resource of the Meki watershed would be decrease. And also, the watershed reduced because of evaporation (Musie *et al*., 2020). Therefore, to solve such problems and distribute available water resources effectively between different water users without affecting the downstream, to use of different hydrological model.

Even thought there was no study on the Meki watershed exactly but, assessing the impact of existing and future water demand on economic and environmental aspect was conducted on by related area Meki-ziway sub-basin, Ethiopia using WEAP model only for the assessment of both surface and water demand scenario (Shumet and Mengistu, 2016). But in this study using hydrological model Soil and Water Assessment Tool (SWAT) to determine surface water potential of Meki watershed exactly with calibration and validation. And then the output of the SWAT model used as input for Water Evaluation and Planning (WEAP) model to allocate the water demand between different water sector in the watershed. Therefore, this study uses the Soil and Water Assessment Tool (SWAT) model for estimating surface water potential and Allocating surface water into different user using the Water Evaluation and Planning (WEAP) model Statement of

1.2 Statement of the Problem

The process of rapid population growth, climate change, economic growth, urbanization, and hydrological and hydraulic condition has resulted in a rapid demand increase for

Water resource in the world (Phue and Chuenchooklin, 2020). Ethiopia still does not use the available water resource effectively at all because of the absence of integrated water resource management system, economic incapability, and wide spatial and temporal rainfall variability (Negash *et al*., 2020). Additionally, Ethiopia is facing major challenge in allocating water resource to grow water demands due to Rapid population increase, economic growth, urbanization, industrialization, climate change, and expansion of irrigation. It is a difficult task of allocating limited water resources among users as a result, the difference between available water resources and water demand is ever-increasing (Asghar *et al*., 2019).

In Meki River there were different factors that affect surface water potential and water demands such as expansion of agriculture, climate change, population growth, urbanization and economic growth (Bunta and Abate, 2021). Additionally, the water resource available is not well managed as there is an excess flow of water in rainy season and a low flow of water or no flow in dry season of the river (Legesse *et al*., 2020). Moreover, insufficient attention is paid to the analysis of how much water is available, how much should be shared among users, and environmental requirements, particularly during low flow periods. These clearly show that there is a need to analyze the water balance of the river basin and formulate water allocation strategies and principles for present and planning.

So, assessing surface water potential and analysis of current and future water demand is very essential requirement to meet the water demand in a different sector. Soil and Water Assessment Tool (SWAT) to estimate surface water potential and the Water Evaluation and Planning (WEAP) model to allocate available water resources between different sectors are very essential in this study.

1.3 Research Questions

i. How much surface water potential is available in meki watershed?
ii. How much water is currently required for different consumption?
iii. How much water will be needed for different scenario?

1.4 Objective of the Study

1.4.1 General Objective

The general objective of the study is to assess the surface water potential and demand scenario analysis of Meki watershed using SWAT and WEAP model.

1.4.2 Specific Objectives

i. To estimate existing surface water potential in Meki watershed.

ii. To determine existing water demands.

iii. To predict future water demands based on different development scenario in Meki watershed.

1.4.3 Scope of the Study

This study conducts the surface water resource potential and demands through scenario analysis for effective water management in Meki watershed using SWAT and WEAP model. It mostly, emphasis on analysis of selected demands such as (domestic, irrigation, and environmental flow requirement) for water allocation in Meki watershed.

1.4.4 Significance of the Study

After the study is conducted in the Meki watershed, the government and non-governmental Organizations working in the area of water resource-related projects will use this study as an input guide for future water expansion in order to satisfy community water demand complain.

Different researcher studies on the area of water demand concern in the study will be used as input for further research investigation in the area. By taking appropriate measurements on the different factors that affect quantity of surface water resources, and assessing the current surface water resource potential and future water demand to provide sustainable water management. In so doing, this the available surface water resource will be continuous, sufficient, and equal share of water at right time and space between users.

1.4.5 Limitations of the Study

Due to the availability of data, the scope of this research has been limited to the allocation of surface water over the most dominant water user such as irrigated land for agriculture and domestic water user water demand in the watershed.

2 LITERATURE REVIEW

2.1 Hydrological Cycle and its Components

The hydrological cycle is the sum total of all processes in which water moves from the land and ocean surface to the atmosphere and back in form of precipitation *(Legesse et al*., 2010) (figure 2.1). The source of all water is rainfall. As rain is fall reaches the ground called "water"; some part of this water is percolated into the ground known as groundwater and the other is surface water which is the primary source of water on the surface of the earth (Hussen *et al*., 2018). This water is either store or flows on the landscape that has not penetrated the surface of the ground underneath. It must be observed on the earth's surface as streams, rivers, lakes, oceans, wetlands, etc. river basin modeling requires a clear understanding of the hydrologic cycle at the sub-catchment scale. The catchment hydrologic cycle involves many processes. The basis of generating rainfall-runoff processes lies in the hydrological cycle.

Through the hydrological cycle, water moves from one reservoir to another reservoir through precipitation, evaporation, transpiration, infiltration, percolation, groundwater flow, surface runoff, and stream flow.

a) **Precipitation:** precipitation is a process by which atmospheric water vapor falls under gravity in the form of rain, sleet, snow, fog, and hail, the amount and types of precipitation after soil development, vegetation growth, and the generation of runoff, which transport soil, nutrients, and pollutants. Water that evaporates or sublimates (the transition of ice direct change into water vapor) from the earth's surface is stored as water vapor in the atmosphere before returning to the earth as precipitation, as rain falls from the atmosphere, some are intercepted by vegetation and building, and this is called "interception." A portion of interception rainfall is evaporated back to the atmosphere from the plant surface and never reaches the ground. This is the process by which rainwater is temporarily retained on leaves and stems of plants, roofs, and other surfaces that are above the ground and are capable of holding water. In particular for rural catchments, the interception of water by vegetation is of prime importance. In this stage on leaves and stems of plants, evaporate into the atmosphere and the other stored water drops to the ground from the leaves and stems (Easton, 2015).

b) **Infiltration:** infiltration is the other hydrological process defined physical phenomenon, in which water penetrates into the soil from surface sources such as snowfall, precipitation, and irrigation. Information on infiltration is essential in hydrologic design. Watershed management, irrigation, and agriculture (Sihag., 2018)

c) **Evaporation:** evaporation is the combined effect of evaporation (movement of water directly into the atmosphere as water vapor from a surface, such as the soil or water body) and transpiration (the process by which plants carry water from the soil into lives, where it is released to the atmosphere as water vapor). Due to the difficulty in separating the process of evaporation and transpiration, the two processes are generally considered together and referred to as "ET". The combined process of evaporation from the soil and transpiration from the plant is called evapotranspiration (Stefano et al., 2019). The left rain from evaporation and infiltration is flow on the earth in the form of streams, rivers, oceans, and lakes. The excess rainfall flows in the stream to large water bodies called surface water. Factors like soil type, vegetation, geology, and topography of the large determine the quantity of rainfall excess available as stream flow from the perceptible water.

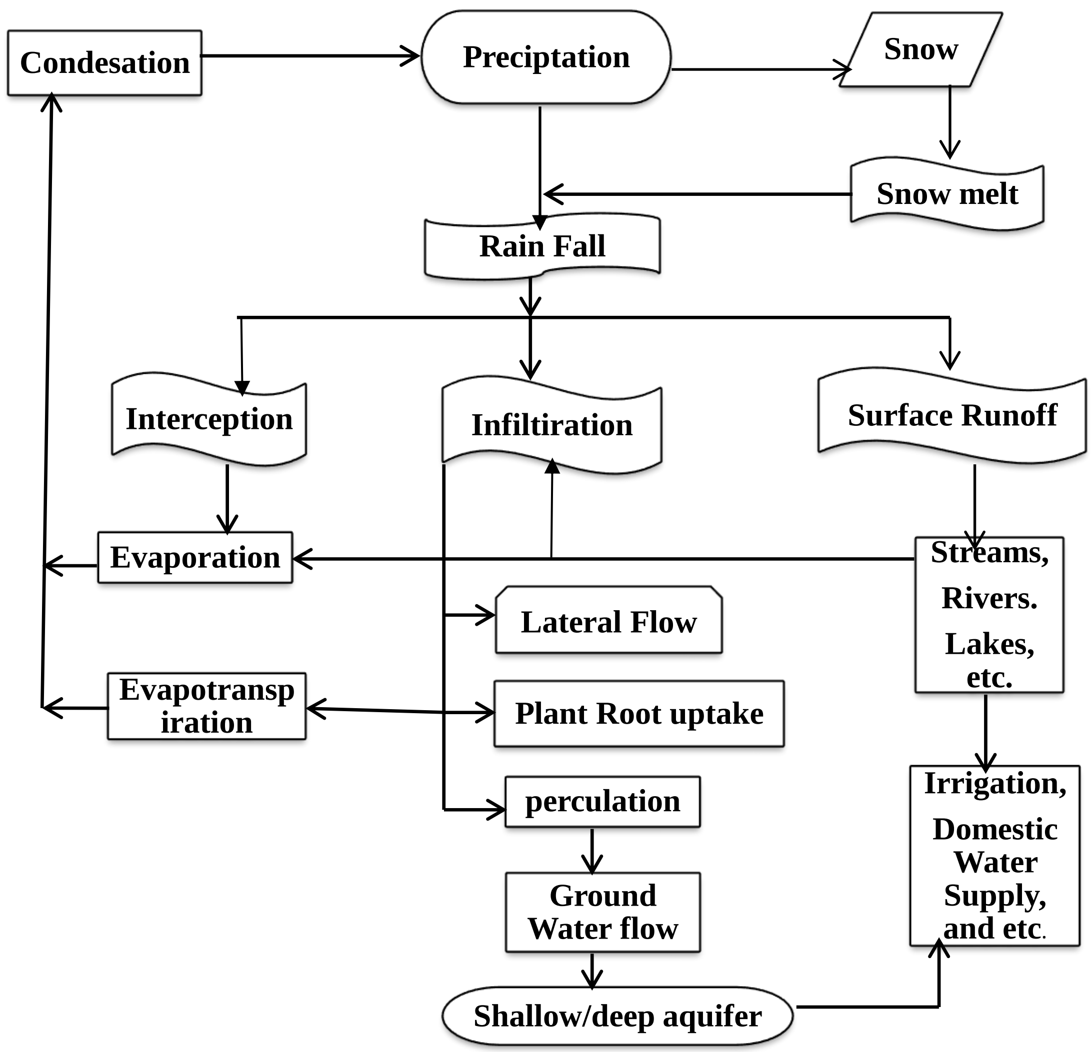


Figure 2.1 Hydrological processes

2.2 Irrigation Potential in the River Basin

The availability of water resources is very important for irrigation agriculture. In Ethiopia, where agriculture serves as the main source of the economy as well as ensures the well-being of the people (Hussen *et al*., 2018). The development of the Small-Scale Irrigation (SSI) scheme is the main support of the food security strategy which, on the other hand, has become a means to increase the expansion of irrigation agriculture in Ethiopia. The strategy explores the construction of more SSI schemes as well as increases the interest of individual landholders to extract more river water using their small transportable pumps (Jebelli, 2018). The central rift valley is a region in Ethiopia where such a strategy has resulted in massive scale investments in floriculture greenhouses and strong development in smallholder irrigation schemes. The association with the increase in irrigation water abstraction from surface water and groundwater resources puts an increase in condensation over insufficient water resources in the area (Shumet and Mengistu, 2016).

Most of the people live in rural areas depending on agriculture for their livelihood. The agricultural practices are mainly traditional and use rain-fed systems (Tewodros et al., 2018). Meki river is the sub-basin of the CRV basin, most irrigation activity was performed in Dugda woreda (i.e. Bekele Girisa, Gemo Shubi and Oda Bokota)(Meki Irrigation and Rural Development Project, 2000). There are about 62,262 Hectares or (64.89%) of the watershed's land is dedicated to cultivated land, from this the most suitable areas for irrigation are more than 18230ha (Dugda Woreda Finance and Economic Coopretion Office, 2021). 4.7 million cubic meters per year are diverted to irrigated 388 ha (Shumet and Mengistu, 2016). According to (Makin *et al*., 1976), the irrigable area on the upper Meki river's tributaries such as Meki river, Lebu river and Akomoja river were 2500ha, 85 ha, and 1250 ha respectively.

2.3 Surface Water Resource Potential

Surface water is a natural occurring resource on the surface of the earth that is critical to the survival of humans and other form of life (Kumar *et al*., 2020).

The country is divided into 12 basins; 8 of which are river basins; 1 lake basin; and the remaining 3 are dry basins, with no or insignificant flow out of the drainage system. Almost the entire basin radiated from the central plateau of the country separate into two because of the rift valley(Berhanu, 2014). Rivers drained in the rift valley originate from the adjoining highlands and flow north and south of the uplift in the center of the Ethiopia rift valley (Berhanu *et al*., 2014).

The central rift valley (CRV) of Ethiopia, which has a high potential for the expansion of irrigated agriculture, is blessed with a variety of water sources and water of varying quality for irrigation as well as other agricultural and domestic use (Dejene *et al*., 2018). In the northern rift valley sub-catchment, Meki river is one of the seven major water bodies including Ziway lake, Langano lake, Abijata lake, Kater river, bulbula river, and Horakelo river. And the model shows the simulated mean annual surface runoff was 114.03 mm and the annual stream flow was 9.4 m^3/s (Bunta and Abate, 2021). The meki river before being drained to Lake Ziway, the river joins with its major tributaries, these are including the Meki, the Lebu, the Akomoja, the Weja, and Rinzaf. The amount of water contributes from the three tributaries are (from Meki river 30 Mm^3, Lebu 10 Mm^3, and Akamoja 15 Mm^3) (Makin *et al*., 1976).

2.4 Hydrological and Water Resource Models

Hydrological models have been used in different river basins across the world for a better understanding of the hydrological processes and the water resource availability. Several hydrological models were used for the assessment of surface and groundwater potential at river basins, sub-river basins, and watersheds and at a catchment level. The Soil and water evaluation Tool (SWAT) model are used to quantify and compering, feed river discharge and evaporation (ET) in the basin. This is done in SWAT based hydrological assessment and characterization of lake ziway sub-watershed, Ethiopia (Desta and Lemma, 2017).

The purpose of water resource management is often to mitigate or prevent the adverse impacts of excessive runoff or shortage of water (Legesse and Abiye, 2010). Water managers and policy makers require tools in order to achieve a balance in water supply and demand to ensure equitable use of water resources, protect the environment, promote efficient use of water and develop priority in shearwater resource (Phue and Chuenchooklin, 2020).

Now a day, various physical-based spatially distributed hydrological models are available for the assessment of a water balance. But for this study, Evaluation and Planning (WEAP) model, soil and water assessment tool (SWAT) model was used.

2.5 The Water Evaluation and Planning System Version 21(WEAP21) model

The Stockholm Environmental Institute (SIE) center in the US created the WEAP model in 1990. It is a general, integrated water resource planning tool that offers an allinclusive, adaptable, and easy framework for development, encourages efficient use of water use, and establishes priority in shearwater resource, scenario generation, planning and policy analyses, etc. (SEI, 2016).

WEAP is comprehensive, clear, and simple to use, and it seeks to complement rather than replace the professional plan, as a database, WEAP offers a system for sustaining water demand-supply information. It is also a forecasting tool, used to simulate water demand-supply, flow, storage, and pollution generation, treatment, and discharge. As a policy analysis tool, WEAP, estimate the full range of water development and management option and takes account of multiple computing use of water system (Sieber, 2006).

The rapid increment of population, urbanization, economic development, industrialization, and climate change makes a difficult to distribute water between different water use sectors such as domestic, agricultural, and industrial in the world WEAP model was implemented to assess the current supply and demand situation for Mae Klong basin (Khalil *et al*., 2018).

The sub-basin hydrologic behaviors have been altered by many natural and anthropologic factors such as climate change and land development activity. WEAP model assessment can be used to simulate both natural hydrological processes, human-induced effects, and management strategies on the water resources in the water kater sub-basin in the central rift valley basin, Ethiopia (Abdi, 2021).

The Water Evaluation and Planning (WEAP) model simulated domestic, irrigation, and ecological water consumption in time and space as compared to other allocation models. WEAP model was chosen for assessed the water scarcity of the basin under irrigation expansion and climate change scenario for sustainable availability of water in the future, in order to maximize the economic benefit in the Awash river basin of Ethiopia (Mohammed *et al*., 2019).

The Water Evaluation and Planning (WEAP) model was used to model the current situation of water supply and demand, and also to create scenarios for future water demand and supply. Hence WEAP is used to model the surface water resource in Fincha sub-basin, Ethiopia for effective water allocation which is a key to sustainable water management in order to attain sustainable social, economic, and environmental benefits (Tesfaye *et al*., 2019).

2.6 SWAT Model

Soil and Water Evaluation Tool (SWAT) is a physically-based continuous-event hydrology model developed to predict the impact of land management practices on water, sediment, and agricultural yields in large, complex watersheds with varying soils, land use, and management condition over long periods. For simulation, a watershed is subdivided into several homogenous sub-basin (hydrologic response units or HRUS) having unique soil and use properties. The input information for each sub-basin is grouped into categories of weather; unique areas of land cover, soil, and management within the sub-basin; ponds/reservoir; groundwater; and the main channel or reach, drainage of the sub-basin. The lodging and movement of runoff, sediment, nutrient, and pesticide loading to the main channel in each sub-basin is simulated considering the effect of several physical processes that influence the hydrology (Neitsch et al., 2009)**.**

SWAT is a river basin, or watershed scale model developed to predict the runoff, and impact of land management practice on water, sediment, and agricultural chemical yield in large, a complex watershed with varying soils. SWAT showed to estimate runoff, and sediment yield, determine the spatial variability of sediment yield, and identify the most erosion-prone sub-watershed areas in meki river watershed (Bunta and Abate, 2021).

The current study uses the SWAT (soil and water Assessment Tool) model to measure and compare the computation of the water balance, the discharge of the feeder river, and evapotranspiration (ET) in the study area. Use the input data for the model's calibration and validation periods including the years 1988 to 2000 and 2001 to 2013, respectively. New hydrological information for the area according to the finding, the Meki sub-watershed had substantial ET and lateral flow while the Katar sub-watershed had large infiltration, surface runoff, base flow, and aquifer recharge. Therefore, this is done SWAT-based hydrological assessment and characterization of lake Ziway sub-watershed, Ethiopia (Desta and Lemma, 2017).

Soil erosion is one of the most serious environmental problems since the fertile soil which is rich in nutrients removed. This erosion of soil reduces the capacity and life span of rivers, and reservoirs. Thus, soil resource needs to be conserved for optimal use for maintaining and improving soil productivity. The soil and water assessment Tools (SWAT) model having an interface with Arc view GIS software is used for the estimation of runoff and sediment yield. The SWAT model was used to estimate the runoff and sediment yield of the kesem watershed (Edo, 2021).

2.7 CROPWAT Model Description

The CROPWAT model is a decision-support created by the FAO’s land and water development Division for irrigation planning and management in water resource development (FAO, 1985).

CROPWAT is a practical tool to do standard calculations for reference evapotranspiration, crop water requirements, and crop irrigation requirements, as well as the design and administration of irrigation schemes (Ashenafi, 2016). Calculations of agricultural water requirements and irrigation requirements are carried out with inputs of meteorological, crop, and soil data (FAO, 1985).

2.8 Model Selection Criteria

Thus, so far, to be considered in choosing a suitable model, in general, have been discussed. In most situations, however, absolute objective methods of choosing the best model for a particular problem have not yet been developed, so this choice remains a part of hydrological modeling. (Mills and Prasad, 1992) Four criteria can be used to choose between alternative models, those are; precision of prediction, simplicity of the model, consistency of parameter estimates; and sensitivity of results to change in parameter values. Accuracy of prediction of system output is essential; it is preferred when all other factors are equal, the model with a minimum error of variance would be superior. Simplicity refers to the number of parameters that must be estimated and the ease with which the model can be clarified to clients or public bodies. When all other factors are being equal, one should choose the simplicity model. Reliability of parameter estimation is an important consideration in developing hydrological models using parameters estimated by optimization techniques. If the optimum values of the parameter are very sensitive to the particular period of the record used, or if they vary widely between similar catchments, the model will probably be unreliable.

Based on the above and other model selection criteria, in this study SWAT and WEAP models was chose.

SWAT is a relatively recent model, a physically based, spatial distributed (semi-distributed) model, computational efficient and a variety of management strategies can be performed without excessive investment of time and money. It to assess the watershed hydrology, and it is the best among the hydrological model because of its capability application to large-scale (>100 km^2) and complex watershed. The other advantage is that it is GIS interface model (Jha, 2011). Whereas, WEAP model provide comprehensive, easy-to-use, flexible and user-friendly framework for policy analysis is distinguished by its integrated approach and policy orientation to simulate water demand in a watershed (SEI, 2016).

Generally, the model to be used in this study is passed through (figure 2.2) evaluation process.

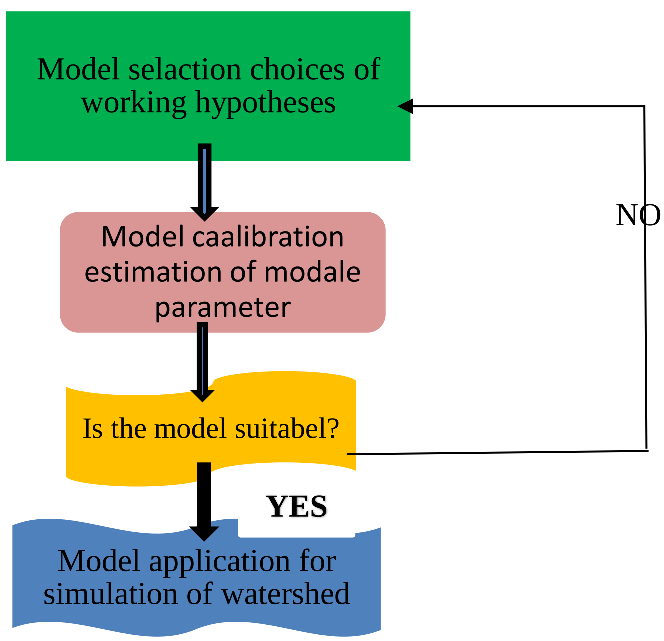


Figure 2.2 Phases of selection and evaluation

Hydrological models require calibration and validation. Model calibration is the process of adjustment of the model parameters and forcing within the margins of the uncertainties to obtain a model representation of the processes of interest that satisfies per-agreed criteria. It is a means of adjusting or a limited range of deviation accepted. It should be checked by the R^2 and NSE statistical procedures (Arnold *et al.*, 2012).

Validation is a comparison of the model outputs with an independent dataset without further adjustments to the values of the parameters. In order to utilize any predictive watershed model for estimating the effectiveness of future potential management practices the model must be first calibrated to measured data and should then be tested against an independent set of measured data. The model predicted capability is demonstrated as being reasonable in the calibration and validation phase, the model can be used with some confidence for future production under somewhat different management scenarios to make sure that the simulated values are still within the accuracy limits (Arnold *et al.*, 2012). The statistical criteria the (the R^2 and NSE) used during the calibration procedure will also be checked here to make sure that the simulated values are still within the accuracy limits.

2.9 Previous Related Study

Soil and Assessment Tool (SWAT) and water evaluation and planning (WEAP) model to assess the impact of climate change on surface water potential and different water allocation scenario (water demand management strategies) within Bilate watershed. These distribution system were designed to satisfy varied sectorial water demands in the event of future climate change (Hussen *et al*, 2018).

The water evaluation and planning (WEAP) tool was to assess the impact of water resource on in-stream and downstream water availability and identify inter-sub-basin location vulnerable to a shortage of surface water in Didisa sub-basin. And also allocate the surface water resource of the sub-basin from existing demand site where collected from the irrigation and water supply sector of the government and the shortage of record data of stream flow supplemented by the output of the SWAT hydrological model (adgolign *et al*, 2016).

Assessed water availability using SWAT and WEAP model on Dwarakeswar-gandherwari river basin, Indian the model to integrated framework evaluated the local water resource system for the impact of the proposed hydraulic structured under the changing climate and integrated into the water evaluation model (Sahoo *et al.*, 2020)

The water evaluation and planning (WEAP) model coupled with the soil and water assessment tool assess the impact of climate change on surface water availability on upper Pangani River Basin, Tanzania. This study was design to investing the dynamic of current and future and assess scenario(Kishiwa *et al.*, 2018)

Assessment of water shortage in Sesan river basin by integrating the SWAT and WEAP model. Therefore, SWAT model was used to identify the surface water potential and the WEAP model was used to distribute these water source in order of priority to different subjects for water use(Do *et al*, 2018).

The Ali Efenti catchment is a rural upstream sub-catchment of the pinios river basin that suffers from seasonal water shortages due to the rapid increase of the total water abstraction in the summer months, which is mainly attributed to local crop irrigation catchment modeling is being implemented using a conceptual model based on water balance the WEAP model and a physical based modelling approaches coupled with routines for irrigation and crop growth, SWAT model(Psomas *et al.*, 2016).

The two model the Soil and Water Assessment Tool (SWAT) for future climate prediction, and Water Evaluation and planning (WEAP model for the simulation of water quantity in the Hongshui River Basin (HRB), to evaluate the impact of climate change, which plays a significant role in the lives of inhabitants downstream of the basin(Touseef *et al.*, 2021).

3 MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location of the Study Area

The Meki watershed, which is part of the central rift valley basin of Ethiopian is located in the Oromia reginal state and southern nation and nationalities and peoples region (SNNPR). The area extends from a chain of mountains called the Guraghe Mountains, to the low-laying Ziway Lake (Legesse *et al*., 2020). It is located between 7°50'0"N to 8°20'0"N latitudes and 38°20'00"E to 38°50'00"E longitudes shown (figure 3.1).

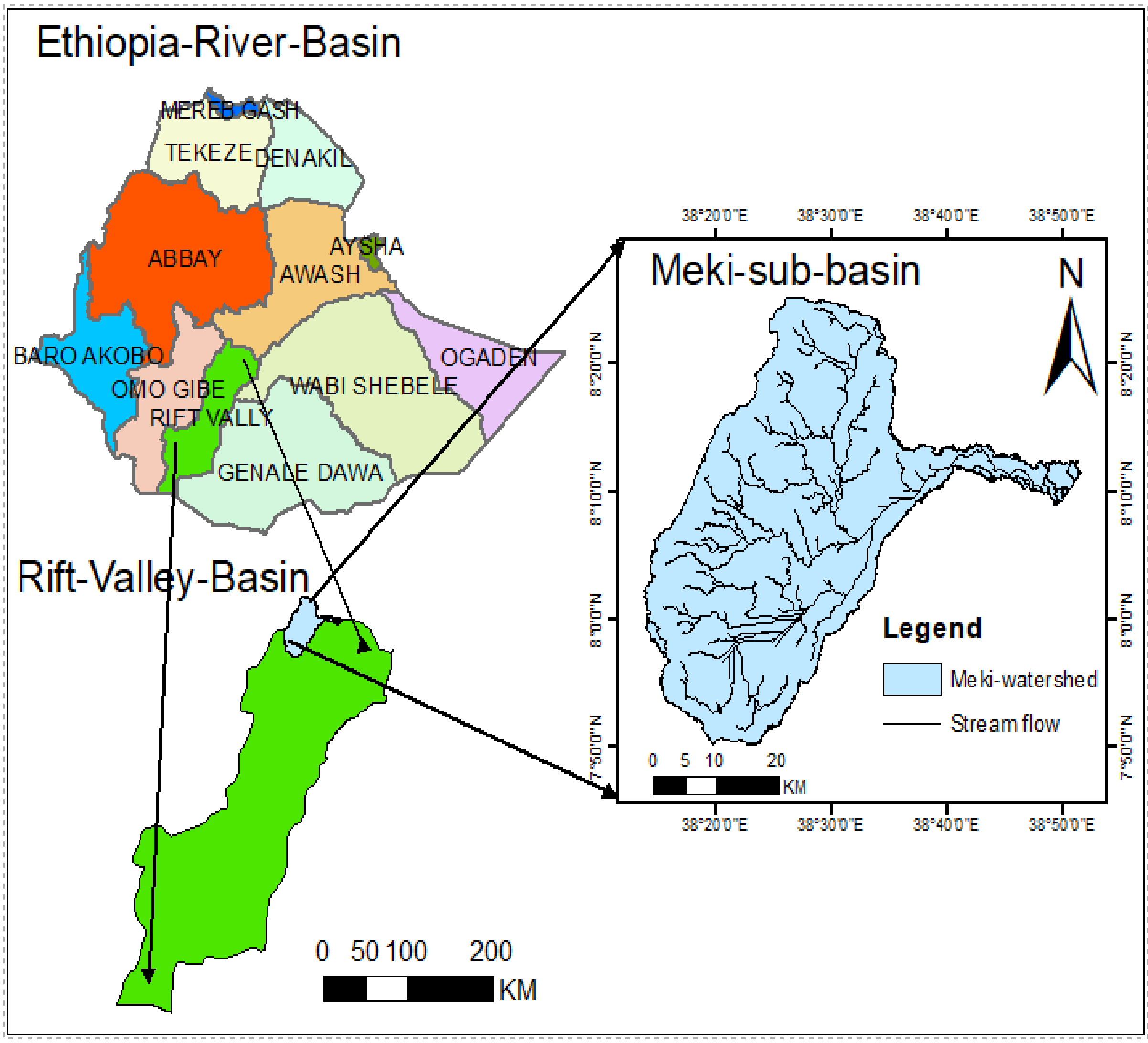


Figure 3.1 Geographical location of the study area

3.1.2 Topography and Drainage

The present land configuration of Meki river watershed was the result of tectonic and denudation activity. The relief feature of the watershed is dominated by flat land that has a few hills. The land form of the watershed relief elevation ranges between 1,600-2,300-meter a.s.l. (above sea level). The upper reach of the basin (above Adis ababa-Butajira-Hosaina rode) area steep and mountainous, while the lower basin is flat with a broad valley. The topography of the area is primarily determined by the rift system of faulting. The western Plato of Gurage highlands with elevations ranging from 2933 to 3612 m a.s.l. that lies to the eastern part of the district is over 1636 m a.s.l. (above sea level) found on the floor of Rift Valley. The Meki river drains an area of 2434 km^2 of the Guraga mountain to the west and north-west of lake Ziway. This River basin drains the Western mountain and an escarpment including a vast swampy area travel for about 1000 km before draining to Ziway Lake (Legesse *et al.*, 2020). Meki river sources are streams that start from the Gurage highland with major tributaries, such as the Lebu, the Akomoja, and Rinzaf, and its final destination is the lake Ziway (Makin *et al.*, 1976). Now the river plays a great role in the promotion irrigation activity along its course of the river.

3.1.3 Climate

Meki river watershed is characterized by three ecological zones: humidity to dry humidity, dry sub-humidity, and semi-arid or arid lands. Temperature and rainfall in the area show a strong variation with altitude. Ethiopian meteorological service agency data analysis shows the average annual rainfall of 650 mm on the rift floor to 1200 mm in the highland. The mean annual temperature range in the high land less than 15^0C; and 29^0c in the rift, with the mean relative humidity of 60%, average wind speed of 1.66 m/s, and average sunshine of 7.3 h. time (Mesele and Mechal, 2020). The Meki watershed is characterized by three main seasons, during the long rain season in the summer (June to September; summer monsoon rainfall, locally known as Kiremt), the rain represents 50%-70% of the mean annual total. The dry period extends between October to February (Baga); this season occasionally rains during this period bringing 10-20.5% of the yearly average. The bega season is known as the main harvest season in the area. The third season, which is locally known as belg is one of a small rain season accounting for 20-30%. Some irrigation activates are practiced along the course (Legesse *et al*., 2010). There is almost no cultivation activity in Belg season in the area, other than Fruit and Vegetable cultivation using irrigation practice (Mesele and Mechal, 2020).

3.1.4 Soil Type

The study area has soils closely related to the parent material land and the degree of weathering. Basalt, ignimbrite, acidic lava, volcanic ash and pumice, and riverine and lacustrine alluvium are the main parent materials. Soil types in the area could be grouped into three. The first group is a well-drained deep radish brown to red friable clay to loams with a strong structure. The second group of soil is well-drained, moderately deep-to–deep dark gray or brown, friable silty loam to sandy loam soil with moderate structure and good moisture strong properties. The third group of soil is dark grayish, free draining friable silty loam to sandy loam with moderate structure and good moisture properties (Legesse *et al*., 2020).

Generally, the two major soil types in the district are clay loam 33% and sandy loam is 67%. It has a light texture, which is vulnerable to both wind and soil erosion. The soil types are characterized as saline and alkaline thought the degree of salinity is much lower and is being utilized for irrigation farming (Dugda Woreda Finance and Economic Coopretion Office, 2021).

3.2 Tools used for this study

For assessing any research, data is the basic and taken as an input for analyzing the research. The following are tools that were used for analyzing the research data.

3.2.1 Arc View GIS Software

ArcGIS version 10.4.1 was used for locating the study area, for delineating the watershed and used as a basic inter face to the SWAT model. Clip and projection of the Digital Elevation Model (DEM), Land use and Land cover (Lulc), and soil map of the Meki watershed from central rift valley main basin.

3.2.2 Microsoft Excel

Particularly, Microsoft Excel was used to import and export necessary data to and from

WEAP, SWAT model, CROPWAT8, and SWAT-CUP. When importing data, the WEAP was also imports and update the scale and units associated with key assumption and demand annual levels. Thus, Excel was used both to edit data and units. It also used for arranging and processing meteorological data.

3.2.3 Xlstat2019

The meteorological data collected from National Meteorological Agency (NMA) used as input in this research were rain fall, minimum and maximum temperature, wind speed, solar radiation, and relative humidity. A certain portion of the collected data were missing. Accordingly, Xlstat2019 software was used to fill the missing data.

3.2.4 SWAT Weather Data Base Software

It was used to calculate weather generator statistics of the weather data which was collected from national meteorological agency (NMA) change in to excel and text format. This data again used as input data of WGNE-user in the SWAT database.

3.2.5 Hydrological Models

Hydrological models have been used in different river basin across the world. In this study basically three hydrological models were used such as SWAT, WEAP and CROPWAT model. Additionally, SWAT-CUP software was used for calibration and validation of SWAT model.

3.2.6 Water Evaluation and Planning (WEAP) Model

It was used to calculate the different water demands and for effective allocation of water demand. It is also used to determine the supply requirement, unmet demand, and scenario development.

3.2.7 Soil and Water Assessment Tool (SWAT) Model

The SWAT model in this study was used to assess the surface water resource of the watershed. It would be used to simulate the quantity of surface water (water balance) in the watershed.

3.2.8 CROPWAT8 Model

CROPWAT8 is a decision support tool developed by the land and water development division of FAO. It was used to calculate the Crop Water Requirement (CWR) and Irrigation Water Requirement (IWR) for crops cultivated in the watershed. The input data were relative humidity, solar radiation, wind speed, minimum and maximum temperature, precipitation, and types of crop.

3.2.9 SWAT-CUPS Software

SWAT-CUP is a computer programing for calibration and validation of the SWAT model. It is a public domain program and can be used for free. In this case, it was used for calibration, validation, and sensitivity analysis of the SWAT model.

3.3 Methodology

3.3.1 Data Collection and Source of Data

The necessary data for this study was secondary data such as Digital elevation Model (DEM), land Cover and Land Use (LULC), soil data, meteorological data, hydrological data, population data, irrigation data, and stream flow were discussed in (table 3.1).

Table 3.1 Data and source of data

Data type	Source of data	Scale/period	Description of purpose
DEM	Ethiopia ministry of water and energy	30X30	For SWAT model processing
Land cover	Ethiopia ministry of water and energy	2015	Land use classification map
Soil map	Ethiopia ministry of water and energy	2015	Soil classification of map
Meteorological data	National meteorological agency	1996-2021	1, daily rainfall (mm) 2, daily minimum and maximum temperature (C^0) 3, Daily wind speed (m/s) 4, daily sunshine (hr.) 5, daily relative humidity (%)
Stream flow	Ethiopia ministry of water and irrigation	1996-2013	Daily stream flow of Meki watershed for calibration and validation
Population	Central Statistical Agency (zonal and woreda level)	2015	Number of populations
Irrigation data	Physical and socio-economic profile of Dugda woreda	2019-2021	Irrigated lands in hectare and types of crops

3.3.2 Meteorological Station

It is important to identify the location of meteorological data. Figure 3.2 indicate the four meteorological location, those were Buie, Butajera police station, Fato, and Meki. Table 3.2 describe the meteorological station and the data that was collected from Ethiopian national meteorological service agency. This collected data was used to simulate surface water using SWAT model and used to estimate Crop Water Requirement (CWR) and Irrigation Water Requirement (IWR) using CROPWAT8 model. Meteorological data (rainfall, minimum and maximum temperature solar radiation, relative humidity, and wind speed) of four station wear acquired from national meteorological service agency of Ethiopia. But Solar radiation, relative humidity, and wind speed data were available only for Buie station. The SWAT weather generator model was used to fill missed value in weather data of relative humidity, wind speed and solar radiation.

Table 3.2 Meteorological station

Metrological station	Latitude	Longitude	Elevation	Record period	Missed%
Buie	8.33	38.55	2054	1996-2021	25%
Butajira police station	8.12	38.38	2027	1996-2021	25%
Fato	8.37	38.51	2520	1996-2021	35%
Meki	8.15	38.82	1662	1996-2017	45%

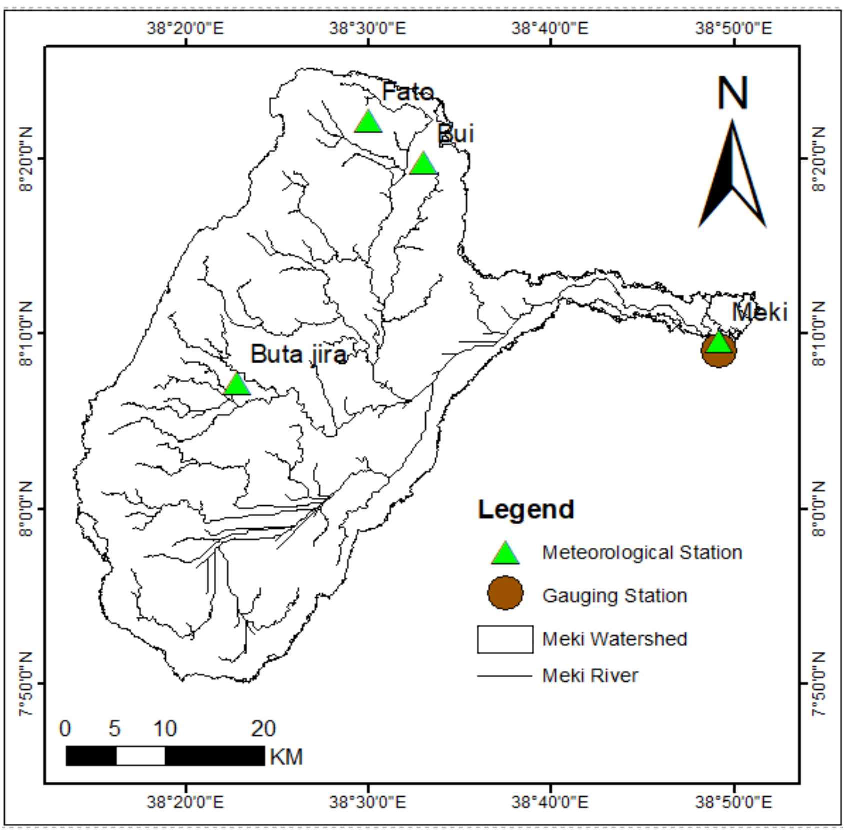


Figure 3.2 Meteorological station

3.3.3 Hydrological Data

Stream flow data was collected from Ethiopian minister of water and irrigation. There was only one main stream flow gaging station in the meki watershed at the entry lake Ziway particularly 8°09' N latitude and 38°50' E longitude (figure 3.2). It was used to calibrate and validate of the SWAT output using a separate software SWAT-CUP.

3.3.4 Missing Data Estimation

I. Filling Missing Rainfall and Temperature Data

The instrument used to record the meteorological data may be stop due to different reasons such as change of position, damaging or broken of the instrument, observation error, change of ecosystem due to fire, land slide etc. At this time missing data were developed. To fill these missing data varies techniques are used. In order to use the data, for this study the missed data were filled by Xlstat2019 software by nearest-neighbor estimation method. After the missing data were filled their consistency and homogeneity were checked (figure 3.6 and 3.7).

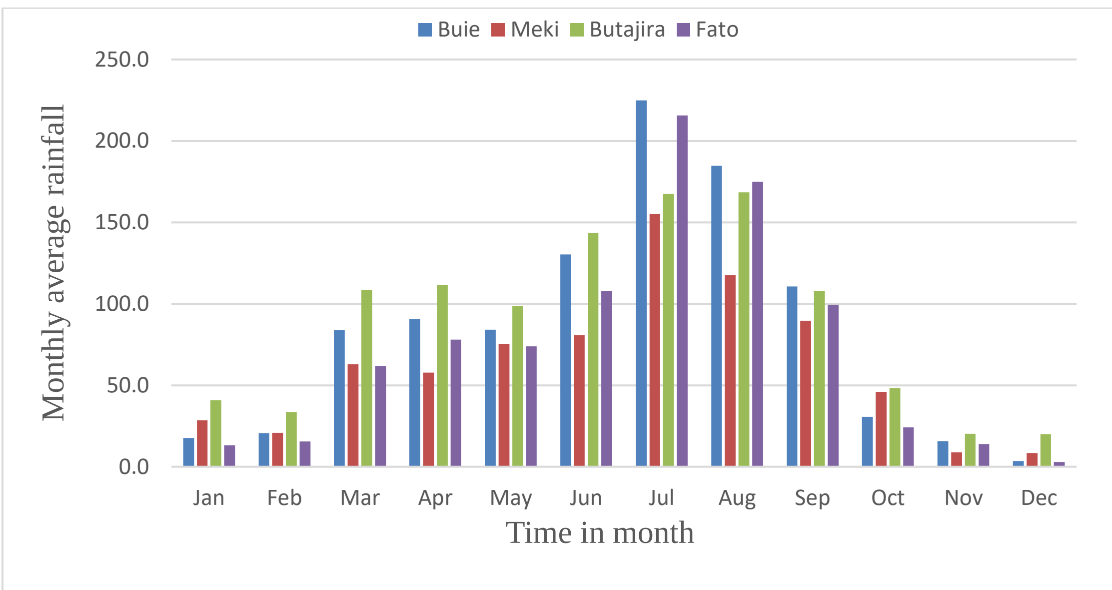


Figure 3.3 Average monthly rainfall data series

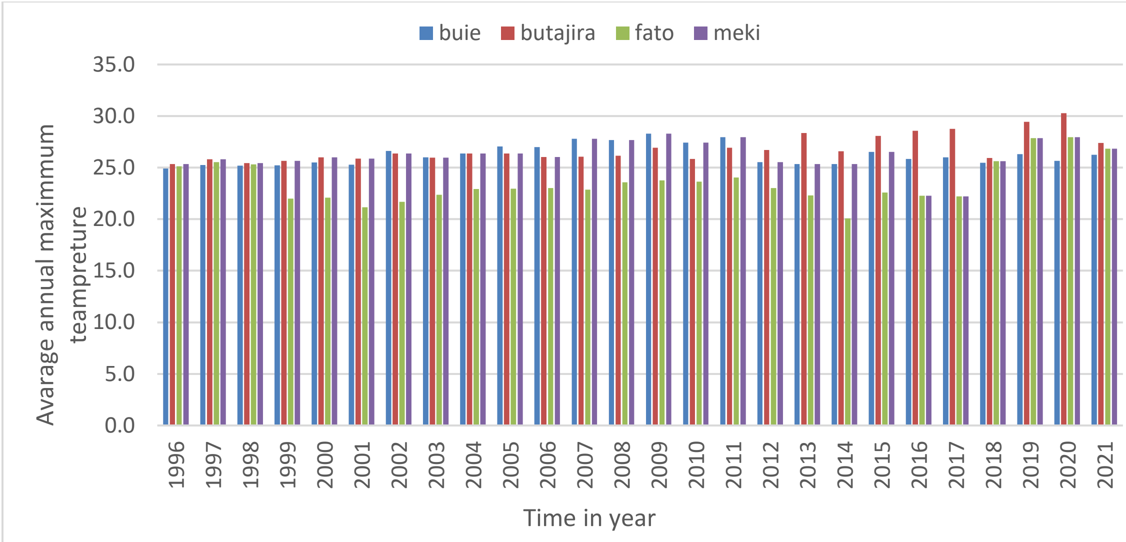


Figure 3.4 Average annual maximum temperature

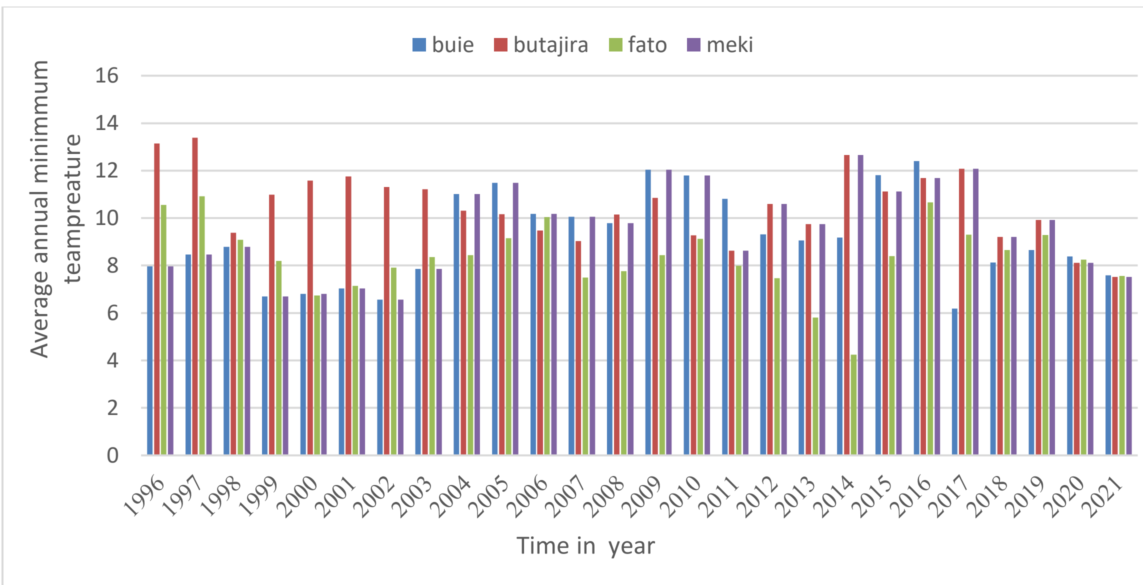


Figure 3.5 Average annual minimum temperature

I. Consistency Test

The double mass curve method was used to adjust the inconsistency data by arranging it in reverse chronological order (cumulative rainfall of selected rainfall station in the neighborhood) verses (cumulative rainfall of test station X). If the difference in slop is low, data is considered as consistence. On the other hand, inconsistent data will exhibit a change in slope or break at the point where the inconsistency occurred. To check the in consistency of data double mass curve was used to correct rain gauge data for the station.

In this method the accumulated annual rainfall of uncertain each station has been compared with the concurrent accumulated value of mean rainfall of group of neighbors surrounding station.

$$p_x^c = p_x^o * \frac{k^c}{k^o} \qquad 3.1$$

Where p_x^c =corrected precipitation at station x, p_x^o= original recorded precipitation at station x, k^c = corrected slope of the double masse curve, and k^o= original slope of the double masse curve

The double masse curves for all station are presented in figure (3.6) while for the individual stations are listed in appendix A (figure1-4).

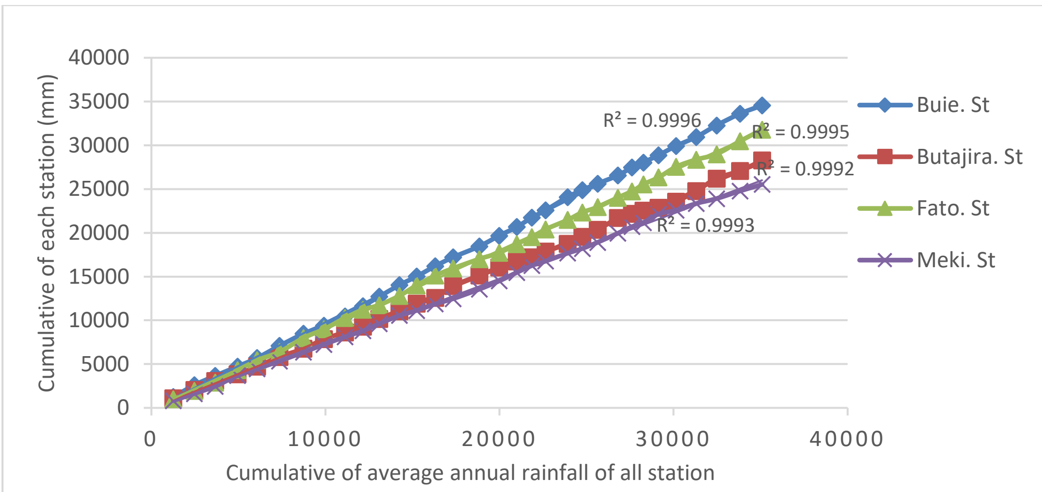


Figure 3.6 Double mass curve of Meki watershed

II. Homogeneity Test

Homogeneity analysis was used to separate a change in the statistical properties of the time series data. The cause can be either natural or man-made. These include alteration of the land and relocation of the observation gauging station. Therefore, in order to select the representative metrological station essential, the homogeneity of the selected gauging station's daily rainfall recorded was carried out by a non-dimensional equation (3.2) homogeneity test on metrological stations (precipitation) are discussed in appendix (table5).

$$p_i = \frac{\bar{p}i}{\bar{p}} \qquad 3.2$$

Where $p_i =$ Non-dimensional value of precipitation for the month i, $\bar{p}\,i =$ over year average monthly perception of station i, $\bar{p} =$ over year's average yearly precipitation of the station.

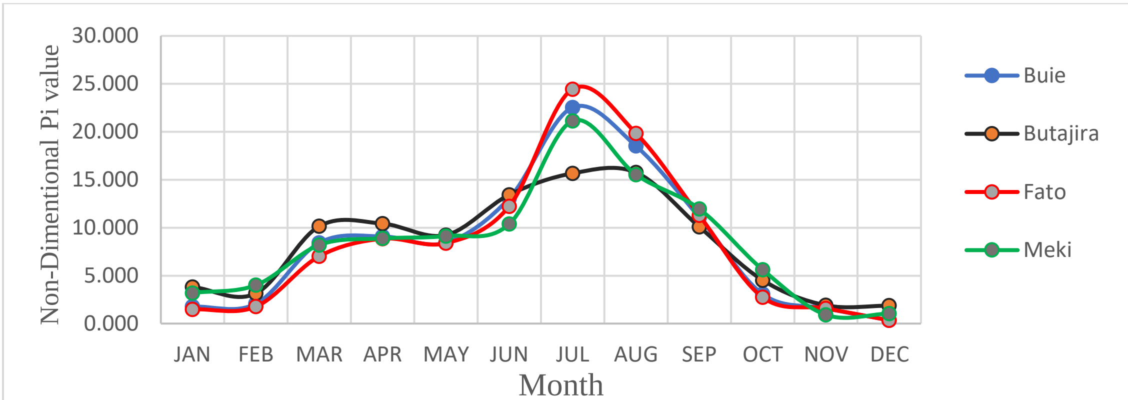


Figure 3.7 Homogeneity test

II. Filling missing Stream Flow Data

The missed stream flow data of the study area was filled by using nearest neighbor method by XLSTAT2019 which corelates long term flow rate records with other hydrological stations. For this study Awash and Gedamso river stream flow data was used For filling the missing data.

3.4 Population Projection and Water Demand

3.4.1 Population Projection

In designing of water supply scheme, population projection is essential. In this study population projection was a very important element in scenario development in order to manage varies integrated water resource management planning projects by considering "what if" population growth in distributing water between different sectors. The population data was the basic input in the WEAP model.

The common methods by which the population projection can be done are the geometric increase method, incremental increase method, decrease rate method, simple graphical method, master plan method, logistic curve method, and Ration and correlation method.

The projected number of populations for the study was taken from the 2015 population and housing census for each of the regions and woreda level (CSA, 2015), and the population growth rate was extrapolated based on (OWWDSE, 2010). For the future case of projection geometric increase method was used up to the base year of study since this method assumes that the percentage of increase in the population remains constant and it is appropriate for growing towns and rural having a vast scope of expansion. The equation for the geometric growth method in the equation (3.3).

$$P = Po \times (1 + p)^{(T - T_o)} \qquad 3.3$$

Where; P = projected population in number, P_o = baseline in population in number, T = projected year, T_o = baseline year and p = growth rate in percentage.

To project a population by a WEAP the expression builder has a function and a branch.

The expression builder is a "growth form" function built into the WEAP model. It is a general-purposes tool to construct WEAP expression by dragging and dropping the function and WEAP branches in to an editing box (SEI, 2015). That helps project the population of the reference period (2022-2051). The input data in growth form field within WEAP for projecting the population are year of last census, population of current and estimating growth rate.

Table 3.3 Percentage of rural and urban population growth rate

Year	Growth rate			
	SNNPR		OROMIA	
	Urban	Rural	Urban	Rural
2000-2005	4.94	2.8	4.88	2.65
2006-2010	4.7	2.57	4.74	2.48
2011-2015	4.46	2.31	4.53	2.24
2016-2020	4.25	2.08	4.32	2
2021-2025	4.02	1.82	4.08	1.72
2026-2030	3.77	1.56	3.84	1.43
2031-2035	3.54	1.326	3.632	1.222
2036-2040	3.3	1.078	3.424	1.014
2041-2045	3	0.83	3.216	0.806
2046-2050	2.8	0.582	3.008	0.598
2051-2055	2.6	0.334	2.8	0.354

Source: - Oromia water resource design and supervisor enterprise (OWWDSE, 2010)

3.4.2 Water Demand

Water demand is the amount of water used by the user to satisfy their needs including domestic and non- domestic (industrial, commercial, institutional, and public needs), and irrigation water demand. as discussed below.

I) Domestic Water Demand

It includes the quantity of water requirement in the house for drinking, bathing, washing clothes, floors, utensil, flushing toilets, etc.

The quantity of domestic water demands is determined based on collecting information on how many people are livening and how much amount does an individual need in the watershed. But, obtaining a proportional figure on the amount of water used by each individual user is a difficult task because people's needs are not always predictable. To establish how much an individual need, standard quantity has been established as guidelines in different literature in liters per second per person (capital) per day (lpcd).

As the first growth and transformation plan (GTP-I) was finalized on the mid of 2015 the second growth and transformation plan (GTP-II) covering the period from 2016 to 2020 was prepared. As per the GTP-II water supply service level standard, it is required to provide safe water in minimum 25l/c/day within a distance of 1km for rural, while in an urban area it is required to provide safe water in minimum 100l/c/day for category-1 towns/cities (towns/cities with a population more than 1million), 80 l/c/day for category-2 towns/cities (towns/cities with a population in range of 100,000-1million), 60 l/c/day for category-3 towns/cities (towns/cities with population in the range of 50,00-100,000), 50 l/c/day for category-4 towns/cities (towns/cities with a population in the range 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) with a distance of 250m (MoWIE, 2015).

Therefore, the current population size of the Meki sub-basin in 2021 was 870254 that exist in the range of 100,000-1million. But the water demand forecasted up to the year 2051 which lies in the third Growth and transportation plan (GTP-III). So, the per capital demand will increase beyond 80 l/c/day for urban and 25 l/c/day for rural as per (Wallingfored, 2003) period of (2021-2051). Its quantity variation depends on the living standard of the user, the range usually being 75 to 380 l/c/day, average 190 to 340 l/c/d

II) Industrial Water Demand

The water required in the industry mainly depend on the type of industries, which are existing in the area. Industries can be grouped under small, medium, and large-scale industries. In the watershed and nearby, there is small-scale industry but, none of them have recorded water use/consumption information. Due to this which consider under domestic water demand. on the other hand, the industrial sector in the sub-basin is small-scale industries with low water consumption rate, which was considered under domestic demands (Hussen *et al*., 2018). According to (OWWDSE, 2010) the following assumption are used for this study.

a) **System losses:** in estimating water losses in the water supply system a percentage of15% to 20% of the total domestic, commercial, institutional, and industrial demands are assumed in the basin. But for this study use 20%.

b) **Average daily demand**: the average daily demand is taken to be the combined total of the domestic, industrial, institutional and commercial demand and the system losses.

c) **Maximum daily demands**: the daily water consumption in a town varies depending on the time of day, season, and climate conditions. Therefore, the Maximum daily demand has been taken as 1.5 times the Average Daily Demand.

I. Livestock and Wilde Life Water Use

Livestock water use is water associated with livestock watering, feedlots, dairy operation and other on farm needs. Ethiopia's livestock population is one of the largest in Africa and puts additional pressure on water and land resource. The water requirements of livestock population are influenced by several factors, including: types of livestock, location, types of diet, feed intake, and temperature. The productivity of livestock in the district is affected by the prevalence of diseases. Varies diseases, and shortage of feed, and water are the major reason for diminishing the productivity of livestock population. Because of these cumulative effects, the production obtained from livestock rearing activity remain low.

II. Environmental Flow Requirement

Environmental flow is the flow that is left in or released into a river system with the specific purpose of managing some aspect of its condition. Their purpose is the maintenance of a healthy riverine ecosystem (Tennant, 1976). According to Tennant, for the environmental requirement for this study was allocated to be 20% of the mean annual runoff to maintain the ecosystem of the river such as river water quality, fish, wildlife, and the level of ziway lake.

III. Irrigation Water Demand

Water can be involved in all aspect of development such as food security, health care, and poverty reduction and also essential for economic growth, and sustains the natural ecosystems on which everting else depends. But, Ethiopian's annual rainfall is not distributed evenly throughout the country, which prevents the availability of the necessary water when it is needed. Since most farmers depend on rain, poverty cannot be eliminated by this alone. Due to uneven distribution of rainfall, (MoWR, 2010) created the Ethiopian Water resource Management Policy to effectively and sustainably develop the huge irrigated agricultural potential for the production of food crops and the raw materials required for agro-industries.

Consideration should be given to the availability of water in an acceptable amount and quality when planning and implementing irrigation. Knowing how much water is necessary for a crop root zone to be kept at field capacity is essential for the proper design of any irrigation system. For irrigation water demand and irrigation water management in the field, it was essential to understanding fundamental parameter like evaporation and transpiration.

The total area irrigated and the water needed for irrigation for each cropping types were multiplied to determine the overall water demand for irrigation. For calculating irrigation water demand in the catchment important data was collected such as relative humidity, solar radiation, wind speed, minimum and maximum temperature, precipitation, and types of crop. Additionally, the area of the land in hectares under cultivation was estimated, and then the collected data was put into CROPWAT8 software in order to estimate the irrigation water demand in the watershed. Therefore, the method to calculate the irrigation water demand in the study was mentioned as follow.

i. **Crop evapotranspiration (ETc)**:

it is the crop water requirement (CWR) for a specific cropping pattern over a specific time frame. Crop evapotranspiration was calculated by multiplying Kc values for each growth stage of the particular crop by the corresponding reference evapotranspiration (ETo) values(FAO, 1998). The following equation (3.4) was used to compute CWR for varies crops.

ETc=Kc x ETo 3.4

Where ETc- crop evapotranspiration (mm/period), kc–is crop coefficient, ETo- reference evapotranspiration (mm/day).

ii. Reference crop evapotranspiration (ETo)

Reference evapotranspiration is the estimation of evapotranspiration rate from a reference surface. This rate represents the reference evapotranspiration for non-water-stressed plant like grass. Crop coefficient (Kc), crop growth stages, rooting depth, critical depth fraction, yield responses factor, maximum crop height and length of growth stage were fixed for crop. The only factor that affect was the ETo are climate parameter that were planned in the watershed according to local condition of study area and using literature (FAO, 1998).

Reference evapotranspiration was calculated using the Penman-Monteith method equation (3.5) with the use of the computer application, CROPWAT8 software and input metrological data (minimum and maximum temperature, wind speed, solar radiation, relative humidity) appendix E (table 8).

$$ETo = \frac{0.408\Delta(Rn-G)+\Upsilon\frac{900}{T+273}U2(es-ea)}{\Delta+\Upsilon(1+0.34U2)} \qquad 3.5$$

Where: ETo Reference evapotranspiration (mm); R_n = Net radiation at the crop surface (MJ/m^2 per day); G= soil heat flux density (MJ/M^2 per day); T= mean daily air temperature at 2 m height (C^0) ‘u_2 wind speed at 2 m height (m/sec); e_s = Saturation vapor pressure (KPa); e_a= actual vapor pressure (KPa); e_s-e_a = Saturation vapor pressure deficit 9KPa); Δ = Slope of Saturated vapor pressure curve at temperature t (KPa/ C^o γ= Psychometric constant (KPa/C_0).

Effective rainfall: it is the difference between the total rainfall and the losses (runoff, evaporation, and deep percolation), that was retained in the root zone and used by the plants. The effective rainfall affected by climate, soil texture, soil structure and depth of the root zone. Effective rainfall was used for estimation of irrigation water demand. There are different approach that were used to calculate effective rainfall. In this study, according to FAO fixed percentage method was used (FAO, 1998).

Peff = P mm x Z

Were Peff is the effective rainfall; Z is a fixed percentage coefficient (specified by the model user), with atypical range of value from 0.7 to 0.9; and P mm is the mean monthly rainfall that input for CROPWAT8.

The procedure to select the rainfall that was used to calculate the effective rainfall that input for CROWAT8 are as followed.

1, Rank of the precipitation from highest to lowest

2, The probability of exceedance (p) of 65 % was used to calculate the return period (Tr)

P= 1/Tr; =1/P= 1/0.65= 1.5

3, The rank of rainfall with 65% probability of exceedance was calculated and the corresponding monthly value were taken as dependable rainfall.

Tr = (n+1)/m; n=no of event (26 year) m = (n+1)/Tr, m= (26+1)/1.5 = 18 ~ 18. Therefore, 18^{th} order rainfall is taken to calculate the monthly effective rainfall appendix (table 4).

The total effective precipitation was 374.3 mm and the maximum effective rainfall occurs during high rainfall time (summer season) from July up to September, with 122.7mm, 105.4mm, and 69.7mm, respectively appendix (table 8).

Irrigation water requirment (IWR): using the climate data (minimum and maximum temperature, wind speed, solar radiation, relative humidity), rainfall data, crop type, and soil data input into CROPWAT8 software. And then the crops water requirment and irrigation water requirment of each crop were calculated in appendix (table 9-14) .

IWR = ETc – Peff 3.6

Where IWR-is irrigation water requirement (mm/period), ETc- crop- evapotranspiration (mm/period) and Peff- is effective rainfall (mm/period)

3.5 SWAT Model Setup

In this study Soil and water assessment tool (SWAT) model was used to determine the surface water resource of Meki watershed. For the assessment of water balance, the SWAT model was used different data such as DEM of the Meki watershed, land use, land cover, soil, and slope. metrological data (daily rainfall, minimum, and maximum temperature, relative humidity, solar radiation, and wind speed).

3.5.1 Watershed Delineation

The digital elevation model (DEM) data was available in the form of GCS-WGS-1984 raster form. First the DEM was converted into the Universal Mercator (UTM) projection raster form by considering zone of the study area which is Adindan UTM Zone 37 by using ArcGIS software. The watershed delineation part comprises five main steps, DEM setup, stream definition, outlet and inlet definition, watershed outlet selection, and definition and calculation of sub- basin parameters.

The digital elevation model (DEM) of Meki river sub-basin (figure 3.8A) was extracted from the 30mx30m projected Rift-valley basin DEM that was collected from the Ethiopia Minster of Water and irrigation in the GIS department. The maximum and minimum elevation of meki watershed was 3612m and 1632m respectively. It was used for water delineation presented as follow.

Properly projected DEM of meki watershed was delineated by using GIS and loading to Arc SWAT and saved in the created folder in the SWAT project setup for further processes. The DEM property (X-Y, Z) was set in meter in DEM project setup and then the flow direction and accumulation were done by DEM-based. After the end of DEM grid preprocessing, the stream network and sub-basin outlets were defined based on the drainage area threshold approach. In this study, a 3595.99 ha threshold area was used based on the minimum and maximum area suggested. Finally, watershed delineation was done by selecting the outlet point of Meki watershed and then calculating the sub-basin parameter.

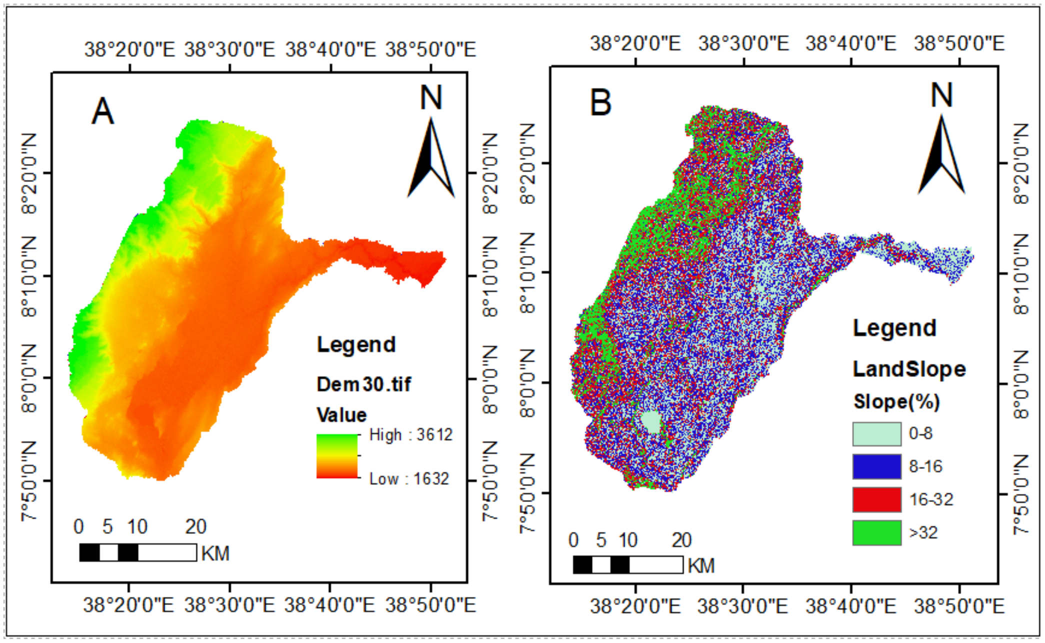


Figure 3.8 A) DEM and B) slope of meki watershed

3.5.2 Hydrological Response Units

In the process of SWAT rainfall-runoff modeling, the watershed was divided into multiple sub watershed, which are then further subdivide into hydrologic response unit (HRUs) that consist of homogeneous land use, management, topographical, and soil characteristics and it represent as percentage of the sub watershed area in SWAT simulation (Arnold *et al.*, 2012). In simulation process HRU analysis tool was helped to call land use and soil raster data with their respective lookup table that interconnect with the SWAT database and the slope map to the project. For slope, the multiple slope option (an option that considers different slope classes for HRU definition) was selected. in so doing this the land use and soil data have been successfully loaded and clipped to the watershed boundary. The LuLc, soil, and slope map were re-classified in order to match with the parameters in the SWAT database. After reclassifying the land use, soil, and slope in the SWAT database, all these physical properties are made to be overlaid for HRUs definition as shown in (figure 3.10A). All Land cover, soil, and slope map were required to create HRUs. Finally, multiple HRUs were assigned to each land use/cover and soil, in order to determine HRU definition which is the final stage in HRU analysis. In this case, the meki watershed HRUs was defined by giving 10%, 10%, and 10% for land use, soil, and slope respectively. Therefore, in this study, the number of sub basin and HRUs was 33 and 281 (figure 3.10A and B) respectively. Sample results for HRU statistics are presented in appendix B (table 7).

i. Land cover map

The land use and land cover map of Meki watershed were gathered from Ethiopia minister of water and irrigation. The land cover of Meki watershed was clipped from the projected Rift valley river basin land cover map (figure 3.9A). The land cover data in a projected shape file format was loaded into the Arc SWAT interface to determine the area and the hydrologic parameter of each land-soil category simulated within each catchment. The land cover classes were defined using the look-up table. A look-up table that identify the four-letter. SWAT land use and land cover were prepared to related the grid value to SWAT land cover/land use classes. The Meki watershed consists of eight major land use/land cover classes (table 3.5) agricultural land was the most dominant (71%).

Table 3.4 Land cover types of Meki watershed

Coverage type	SWAT-CODE	Area (ha)	Area covered %
Range-Brush	RNGB	1156.2423	0.6
Forest-Evergreen	FRSE	27547.9544	15.3
Barren	BARR	1299.4801	0.7
Agricultural land	AGRL	122688.0373	71.0
Residential-High density	URHD	19225.7417	10.7
Wetlands-Mixed	WETL	5137.495	2.9
Water	WATR	1709.2731	1.0
Pasture	PAST	1035.4862	0.6

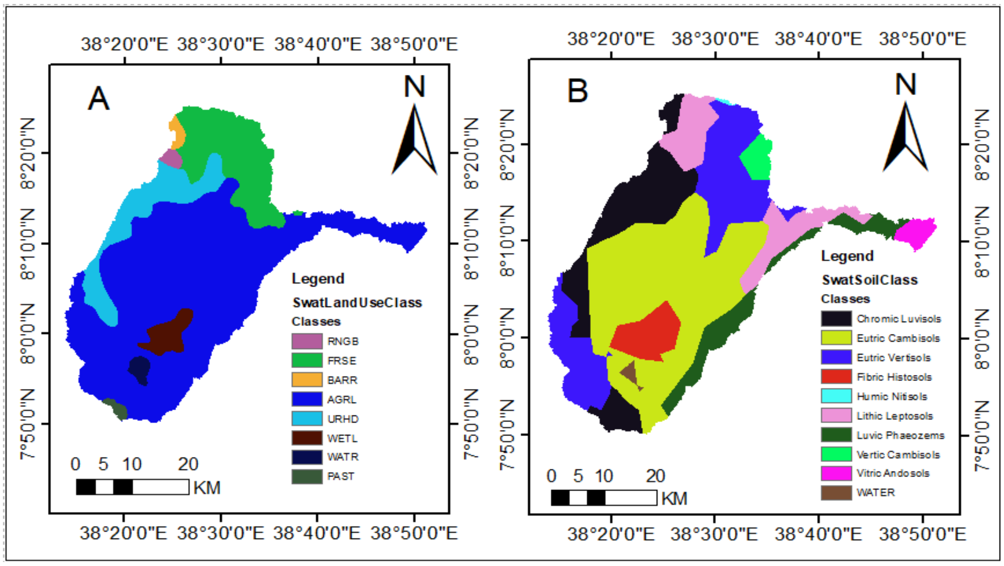


Figure 3.9 A) Land use and B) soil class map of Meki watershed

ii. Soil map

The raster soil map of Meki watershed was also collected from the Ministry of Water and Irrigation. Based on FAO classification in this study area there were ten major soil groups such as Chromic Luvisols, Eutric Cambisols, Eutric Vertisols Fibric Histosols, Humic Nitisols, Lithic Leptosols, Luvic Leptosols, Vertic Cmbisols, Luvic Phaeozems Vertic Cambisols, Vertic andosols, and water Bodies table (table 3.6). from this Eutric Cambisols, Vertisols and Chromic Luvisols are the most dominate soil types and covers about 70.45% of the total area in combination (figure 3.9B). The properly projected soil map was required to create HRUs in SWAT simulation. However, the SWAT database has no FAO soil data. In order to add FAO soil in to SWAT database, Map Wind SWAT (MWSWAT) was download from (http://www.waterbase.org/) and installed. And then the FAO soil was imported from MWSWAT2012 database into a new Arc SWAT database for further process. The soil layer in the map was linked to the user soil database information by constricting the soil look-up table for the SWAT model and reclassification was done.

Table 3.5 Meki watershed soil types

No	Soil types	Area (ha)	Area coverage (%)
1	Chromic Luvisols	28124.1	15.64
2	Eutric Vertisols	36603.0	20.35
3	Lithic Leptosols	18033.6	10.03
4	Eutric Cambisols	68782.5	38.25
5	Vertic Cambisols	3303.1	1.84
6	Luvic Phaeozems	13198.3	7.34
7	Vitric Andosols	3181.3	1.77
8	Fibric Histosols	7589.7	4.22
9	Humic Nitisols	228.2	0.12

iii. slope map

The land slope classes were also integrated with defining the hydrological response units in addition to land use and soil input parameter. The DEM data used during the watershed delineation was also used for slope classification (figure 3.8B). The slope is also an important characteristic of a catchment as it gives an indication of the kinetic energy available for water move toward the basin outlet, and it has been found to be related to total runoff (Bullock *et al*., 1990). Arc SWAT has single and multiple slope classes. In this study, the multiple slope discretization operation was preferred over the single slope discretization. The watershed to classify the slope into four slope classes such as flat land, gentle, intermediate, and step land (0-8%, 8-16%, 16-32 and >32%) respectively as shown below (table 3.7).

Table 3.6 Areal distribution of slop in Meki watershed

Slop classes %	Area (ha)	Area coverage (%)
0-8	638.629	8.92
8-16	1383.654	19.32
16-32	2685.136	37.5
>32	2452.67	34.26

Finally, the land use, soil, and slope grids were reclassified, and then an overlay operation was carried out. The watershed was classified into HRUs after the project was completed based on the soil type, land use, and slope classes (figure 3.10A).

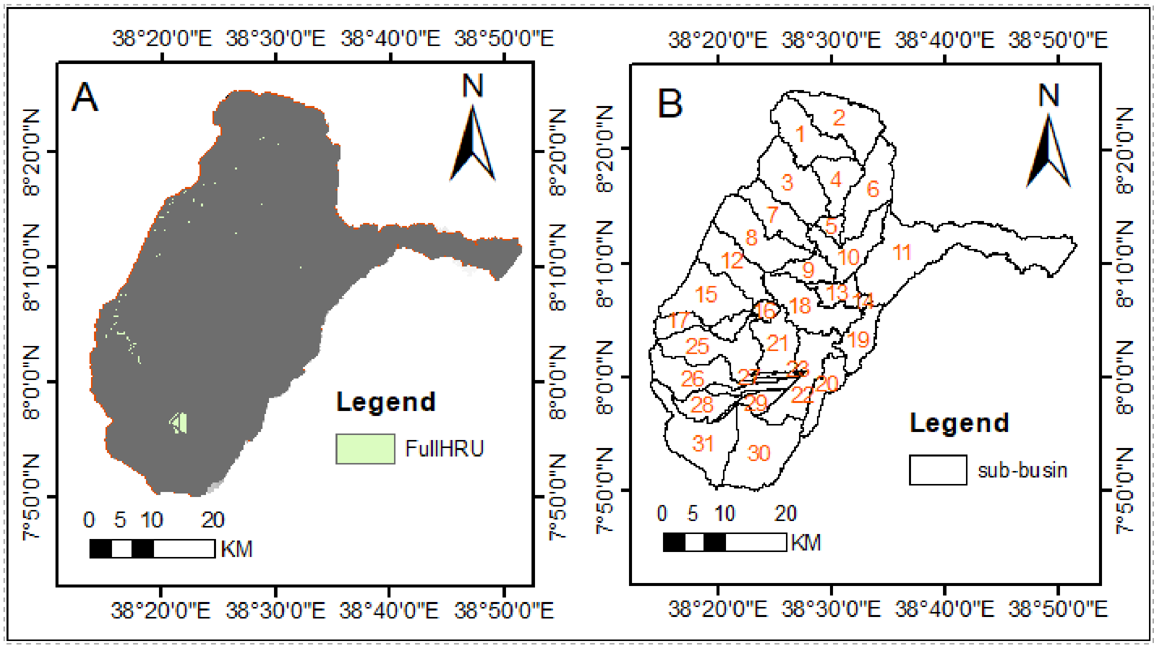


Figure 3.10 A) HRU and B) Sub- basin number of Meki watershed

The HRU definition came as the final stage in the HRU analysis. It is determined by assigning multiple HRUs to each land use/land cover, soil, and slope. In this case, an HRU threshold level was used to remove minor land use, soil, and slope classes in each sub-basin. Land use or slope classes that cover less than the threshold levels were eliminated. In order to model 100% of the land area in the watershed, the area of the remaining land use, soil, and slope classes was prepared. finally, the SWAT model was run after adding the meteorological data including precipitation, minimum, and maximum temperature, relative humidity, solar radiation, and wind speed organized daily as per the requirement of the SWAT model.

3.6 SWAT Hydrological Process Analysis

SWAT divides the hydrology of the watershed into the two-stage of the hydrological cycle: the land and the water (routing) phases. The land phases of the hydrological cycle regulate how much water, sediment, nutrients, and pesticides are loaded into the main channel. The water (routing) phase controls the movement of water, sediment, and nutrients via the channel to the sub basin's outlet. The following water balance equation (equation 3.7) was to simulate the hydrological cycle within a watershed (Neitsch *et al.*, 2005).

$$SWt= SWo + \Sigma^{t}_{i=1} (Rday – Qsur – Ea - Wseep - Qgw) \quad 3.7$$

Where: SWt - is the final soil water content (mm), SW_O- the initial soil water content, R_{day-} precipitation, Q_{sur-} the amount of surface runoff, Ea- the amount of evapotranspiration, W_{seep-} the amount of water entering the vadose zone from the soil profile and Q_{gw-} the amount of return flow on the day I (mm), and t – is time (days).

3.6.1 Runoff Simulation

As the rain is falling, water get stored or flow as stream or river over the land, this because the difference between rainfall and infiltration is excess (surface runoff). So, surface water is water stored or flowing on the earth's surface. Using different hydrological model assess the surface potential and quantify runoff generated in the watershed (Daniel., 2011). SWAT has the soil conservation service curve numbers equation and the Green and Ampt infiltration method. Green and Ampt infiltration method to estimate the surface runoff volume which assumes that there will be excess water at the surface at all times which was an invalid assumption in the study area, and also this method requires sub-daily precipitation data which was the other limitation use this method. Therefore, in this study, the SCS curve number equation (equation 3.10) were used to determine runoff depth (USDA, 1972).

$$Qsurf = \frac{(Rday-Ia)}{(Rday-ia+s)} \quad 3.8$$

Where Qsruf – is the accumulated run off or rainfall excesses (mmH_2O), Rday–is rainfall depth for the day (mmH_2O), Ia – is the initial abstractions which includes surface storage, ia - interception and infiltration prior to runoff (mmH_2O) and S – is the retention parameter (mmH_2O).

Varies spatially due to change in soil, land use, management and slope and temporarily due to changes in the soil water content and it was defined as:

$$S=25.4 \left(\frac{1000}{CN} - 10\right) \quad 3.9$$

Where, CN – is curve number

The initial abstraction is commonly approximated as 0.2S and equation (3.8) become

$$Qsurf = \frac{(Rady - 0.2S)^2}{(Rday + 0.8S)}. \quad 3.10$$

To determine the total runoff for the watershed, the runoff will be routed after being simulated independently for each HRU. This improves precision and describes the water balance physically. The rainfall-runoff processes consist of simulation, calibration, sensitivity analysis, and validation phases. However, in this instance, SWAT-CUP, a separate piece of software from the simulated watershed scenario, was used to examine the calibration, sensitivity analysis, and validation of the simulated model (Txtinout).

3.7 SWAT-CUP software

The Soil and Water Assessment Tool Calibration and Uncertainty Program (SWAT-CUP) was recently developed and provide a decision-making framework that used to calibrate and validate the model. The Sequential uncertainty fitting (SUFI-2) is an algorism of SWAT-CUP that a multi-site, semi-automated invers modeling technique that uses the latin hypercube, scheme using both manual and automated calibration and incorporating sensitivity and uncertainty analyses (Mengistu *et al*., 2020).

3.7.1 Sensitivity Analysis

The hydrological model sensitivity analysis is the process of defining the model parameter that has been the highest effect on model calibration and model estimation. The significant objective of the parameter sensitivity was invented with the potential to reduce the number of times needed to compute the amount for model calibration. In SWAT-CUP there are two ways to identify the most sensitive parameter. The first one is a Global sensitive analysis and the other one is a one-at-a-time sensitive analysis. In this study, the Global sensitive analysis was used to determine, evaluate and rank parameters that have more influence on the output of the model by using P-value and t-states in the SWAT-CUP. In this case the parameter has t-stat large in absolute value and a p-value approach to zero were more sensitive parameter.

3.7.2 SWAT Model Calibration and Validation

Model calibration is a process of changing the values of model input parameter or it is an iterative exercise used to establish the most parameter in modeling studies, in order to match the model output with observed data within some acceptable criteria. It is to better parameterize the model to a set of given local conditions, thus reducing the uncertainty of the prediction. After calibration, validation is takes place it is the process of demonstrating that a given site specific model is capable of making sufficiently accurate simulation. validation use the same calibration parameter and an independent set of measured flow data that was not used for model calibration. It was the continued process from calibration processed was stopped till simulation of validation period stream flows confirmed that the model performance satisfactory. The minimum recommended value of calibration and validation were (R^2>0.6, NSE>0.5 and PBIAS<±25) (Arnold *et al*., 2012).

The SWAT model for Meki watershed was calibrated and validated using observed streamflow data from 1996 to 2013 at Meki stream gauging station in (m^3/s) set at Meki town. From 1996 to 1997 was used for the Warm-up period for the model to generate a sensible initial value. The data from 1998 to 2007 and the data from 2008 to 2013 wear used for calibration and validation respectively. The determination coefficient R^2 and NSE was used as objective function to calibrate and validate the model using the flow sensitivity parameters. The model was calibrated and validated using (SUFI-2) algorithm of SWAT-CUP.

3.7.3 Model efficiency/performance evaluation

The three statistics criteria that determine the performance of the model are the determination coefficients (R^2), the Nash-Sutcliffe efficiency NSE and percent of bias (PBAIS) were used to estimate the SWAT model efficiency or the goodness-of-fit between observed and simulated data (Singh *et al.*, 2014). During calibration and validation, the regression coefficient (R^2) was determined the strength of the relationship between observed and simulated values. R^2 range from 0 to 1

Where 0 indicate no agreement, 1 represent a perfect agreement, and greater than 0.5 are acceptable (equation 3.11) (Van Liew *et al.*, 2003).

$$R^2 = \frac{\left[\sum_{o=i}^{n}(Q_{Si}-Q_{siav})(Q_{ob}-Q_{obav})\right]^2}{\sum_{i=1}^{n}(Q_{si}-Q_{sibav})^2\,(Q_{ob-}\ Q_{obav})^2} \qquad 3.11$$

Where, Qob- is observed value (m3/s), Qobav -is the average observed value (m3/s), Qsi -is simulated value (m3/s), Qsiav -average simulated value (m3/s).

NSE indicates the degree of fitness of observed and simulated data and was given by (equation 3.12). The NSE (Nash and Sutcliffe, 1970) is the ratio of the residual variance to the measured data variance. It indicates how well the simulated data and the measured data fits the 1:1 line. It ranges -∞ to 1 with NSE of 1 show a perfect fit, values between 0 and 1 are generally acceptable level of performance whereas values < 0 are not acceptable and indicate that the mean of the measured values a better predictor than simulated.

$$NSE = 1 - \frac{\sum_{(Qob-Qsi)}2}{\sum_{(Qob-Qobav)}2} \qquad 3.12$$

Where, Qob-is observed value (m^3/s), Qsi-is simulated value (m^3/s), Qobav -is the average observed value (m^3/s)

PBIAS measure the average of the simulated value to greater than or smaller than the observed value. It was computed as shown in equation 3.13.

$$PBIAS = \left[\frac{\sum_{i=1}^{n}(Q_{ob,i}-Q_{sim,i}}{\sum_{i=1}^{n}Q_{obav,i}}\right] * 100 \qquad 3.13$$

where: Q_{ob} = observed flow rates, Q_{sim} = simulated flow rate model results and Q_{obav} = Average observed flow rate. The PBIAS is the measure of the mean value of the simulated flow to be greater than or smaller than their observed data. Positive values that show model underestimation bias and negative value also show overprediction bias. A value close to zero percent is best for PBIAS and the recommended range for percent bias is between positive 25 and negative 25 (Singh *et al.*, 2014).

3.8 WEAP Model setup and Sharing of Water

3.8.1 WEAP Model setup

WEAP consists of five main views: Schematic, Data, result, Scenario Explorer and notes are Mentioned as follow.

a) **Schematic View:** This view contains GIS- based tools for easy configuration of the system. Objects (e.g., demand node tools, reservoirs) can be created and positioned within the system by dragging and dropping items from a menu. So, the study area was defined and set its boundary by adding the vector layer of Meki catchment which has been prepared using ArcGIS 10.4.1 to the WEAP reads vectors shape files format of WGS1984 projection (figure 3.11).

b) **The Data View:** All required data including annual activity level (population data, irrigation data…), annul water use rate, consumption rate, and monthly variation have been added to the demand site. Data inter into the WEAP model by data entry view of the current data or by pers right mouth baton on the schematic view elements (river, agricultural site or big city).

c) **Result View**: Show all model results or outputs, in the form of charts, tables, and maps. In this view the water demand, coverage, unmet demand and etc. demonstrate in terms of current account, reference, and "what if" scenario.

d) Scenario Explorers View: In this view the "what if" question was defined so that the process of determining an independent collection of data and an assumption about a system of connected demand and supply was derived. This information was divided into the current account and the alternative future scenario that was modeled. The data entry table on the right is used to enter expressions that defined current account and scenario values.

e) **Notes View:** Provides a place to document the data and assumptions.

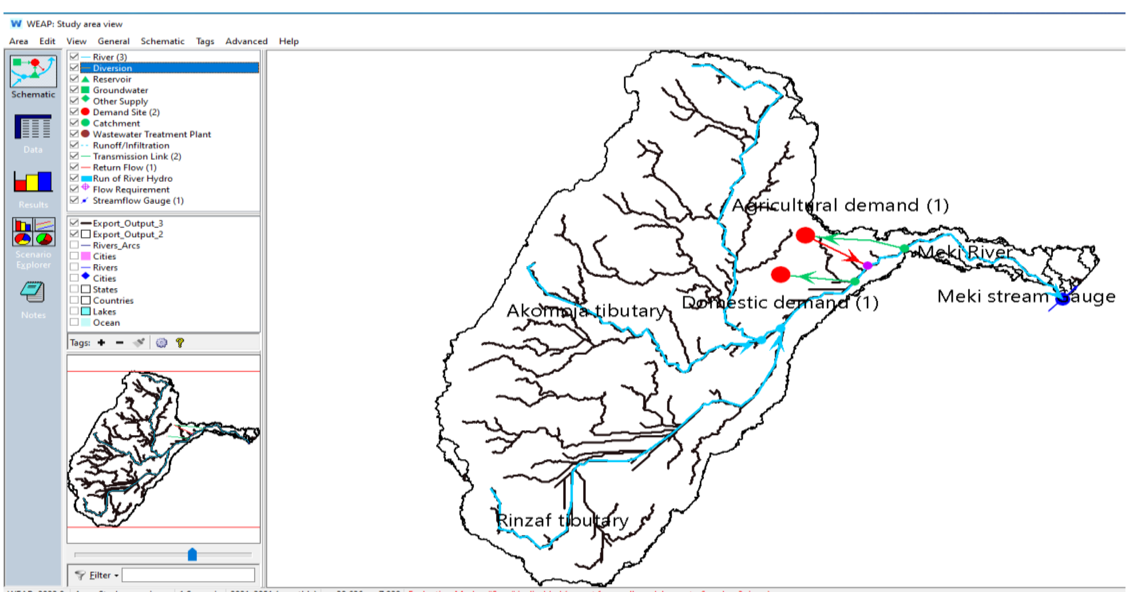


Figure 3.11 Schematic of WEAP21model configuration Meki watershed

3.8.2 Schematic of WEAP21model

Schematic of WEAP21 model consists of demand site and connecting link (transmission link)

a) **Demand site**

A demand site is defined as a set of water user that share a physical distribution system that are all within a defined region or that shar an important withdrawal supply point (Sieber, 2006). Domestic and agricultural sites were major demand sites in this study.

b) **Transmission link**

Each demand site has a transmission link to its source and where applicable a return link directly to a river. To run the model the demand site should be connected with the supply of respective source this is done by connecting a supply resource to each demand site which was accomplished by dragging and dropping the transmission link from each source to the respective demand sites. The return flow routing is the percent of total outflow from a demand node, and then the return flow routing for that link must be 100%. Return flow from irrigation sites were configuration downstream of the source. But, return flow from domestic water supply was not included since the quantity is insignificant it is preferred to overlook.

3.8.3 Sharing of Surface Water

Water allocation is the mechanism for determining who can take water, how much they can take, for which location, and for what purposes (Robert et al., 2013). Water allocation refers to the rules and procedures through which access to water is decided for individual or collective use, and in relation to availability (Roa-garcía, 2014). The aim of optimal water resource allocation is to reallocate the limited water resource scientifically among different water user sector based on a fair, effective, and sustainable principle in a given region through measures such as restraining water demand reasonably, increasing water supply effectively and protecting the ecological environment positively (Niksokhan et al., 2009). So, in this study WEAP used a liner programming technique to distribute the water to various consumers after assessing the surface water potential with the use of the SWAT model. SWAT was more effective at simulating the full hydrological cycle, while the WEAP model offers a more user-friendly and thorough option for scenario analysis that can estimate and predict demand in a watershed.

The SWAT hydrological model outputs, which represent the water budget for the Meki watershed, that must calibrate and validate using SWAT-CUP software and then entered as the mean monthly stream flow or head flow on the WEAP model river networks. Then all demand data were entered into WEAP as consumption, but irrigation demands were entered as a gross requirement because it has return flow back to the supply source. Finally, annual demand was calculated using the WEAP algorithm by multiplying the total activity level in each branch by the water use rate of the branch and adding the total demand (SEI, 2015).

3.8.4 Scenario Development

Scenario analysis is vital to WEAP. Scenarios are used to explore the model with an enormous range of “what if” questions (Sieber, 2006). It is the model of an expected order of the event.

Due to a lack of future planning in a water supply project, different problems are rise for example damage to the project, insufficient/excess demand in the demand site (less than or greater than planned), etc. Therefore, scenario analysis is the basic issue in preparation of different water resource management planning project.

The scenario can answer several “what if “question, such as: what if a pattern of economic and population growth change? what if water conservation is implemented? what if ecosystem requirements are tightened? What if a more efficient irrigation technique is implemented? (Sieber, 2006).

The WEAP model is used to create a scenario that can be compared to determine water requirements, costs, and environmental effects. Every scenario begins with the same year that the current account data was established.

The typical scenario modeling process in WEAP software consists of three parts. First, a current account year, is chosen to serve as the base year of the model; next, a reference scenario year, it was created from the current account to simulate how the system would like to be evaluated in the absence of intervention. Finally, a “what-if” scenario was created to modify the "reference scenario" and assess the effects of change on policies and/or technologies (Mounir et al., 2011).

Meki sub-basin is one of the strategic river basins for irrigation, tourism development, new potential irrigable land, infrastructure, urbanization, increment in population and rapid economic growth are basic issue in the river basin. Rapid water demand growth and environmental flow consideration are a critical matter in the basin, therefore the following scenario were likely observed (figure 3.12).

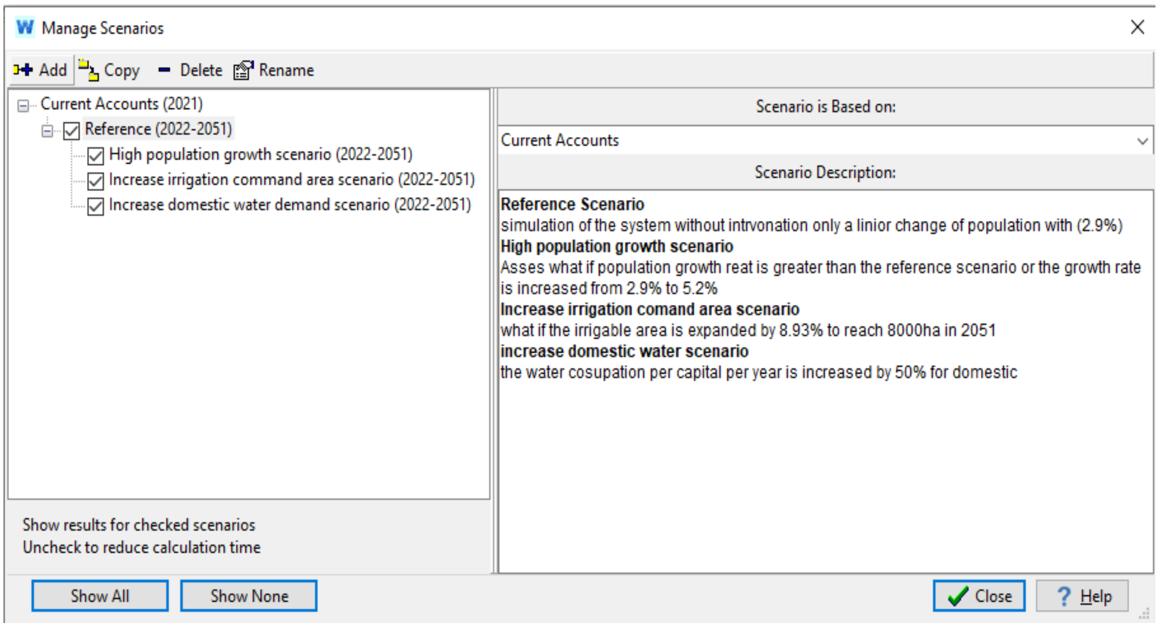


Figure 3.12 Scenario development by a WEAP model

I) Current Account year

The current account serves as the foundation of all scenario analysis. The current account used in this study was 2021 and used as a base for the creation of scenarios and scenario analysis, which was viewed as a reference step in the development of an application, and provided a base of the actual water demand, resources and supplies for the system. Generally, in the current account year, the watershed major demands were irrigation and domestic demand have been estimated.

II) Reference Scenario:

A "reference" scenario is established from the current account to simulate the likely evaluation of the system without intervention. In this study current scenario was applied to analyze the condition of Meki watershed without any development change in the system except for the population growth rate. For the reference scenario, in the next 30 years from 2022-2051 the population growth rate was 2.9% as recommended by central statically agency of Ethiopia (CSA,2007). Hence, the total population within the base year was 870254 for the year 2021 projected over (CSA, 2015) regional, zonal, and woreda level data appendix A (table 6). The current account data (the year 2021) was extended to the future for about 30 years (2022-2051).

III) High Population Growth Scenario

This scenario was the first key assumption in WEAP. This scenario was developed to evaluate the effect of high population growth on the future water demand of Meki watershed. In this scenario answered “What if” the population growth rate increased or is greater than the reference scenario? In this case, based on the past population growth rate trend (OWWDSE, 2010) and further extrapolating the population growth rate up to the year 2051 was 5.2%. Hence, what if the population growth rate that increased from 2.9 % to 5.4 % per annum.

IV) Increase in Irrigation Area Scenario

The irrigation water demand is one of the key assumptions in scenario development when evaluating the impact of future water use in the study watershed. Because it is highly related to investment activity in the area, so it requires so much quantity of water as it is expanding. In this study, the major source of water supply for irrigation were borehole, river and ziway lake. But river was only considered water supply for irrigation purpose. In order to model the irrigation water demand in the future; annual activity level, annual water use rate, consumption rate, and monthly variation were used. The annual water use rate, conception rate and monthly variation were determined by using the CROPWAT and the annual activity level were 615 ha (Dugda Woreda Finance and Economic Coopretion Office, 2021). The water demand varies inter-annually, depending on the type of crops grown and evapotranspiration. In this study, the irrigable area was expanded by 8.93% along meki river per annual to reach 8000ha on the 2051 in the watershed. Therefore, this study has model the irrigation demand in WEAP with annual crop water requirement around 12299 m3/ha per annum appendix B (table 16).

V) Increase Domestic Water Demand Scenario

The increment of irrigation activity that was more related to the dramatically increase the number of populations to reduce the poverty, this interchange economy and urbanization development; which are the reason to increase the water demand. Therefore, to satisfy the water requirement of the water user in the watershed; the water conception per capita per year is increased by 50% from the current per capital water demands for domestic water use as per (Wallingfored, 2003).

3.9 Flow Chart Representation of Methodology

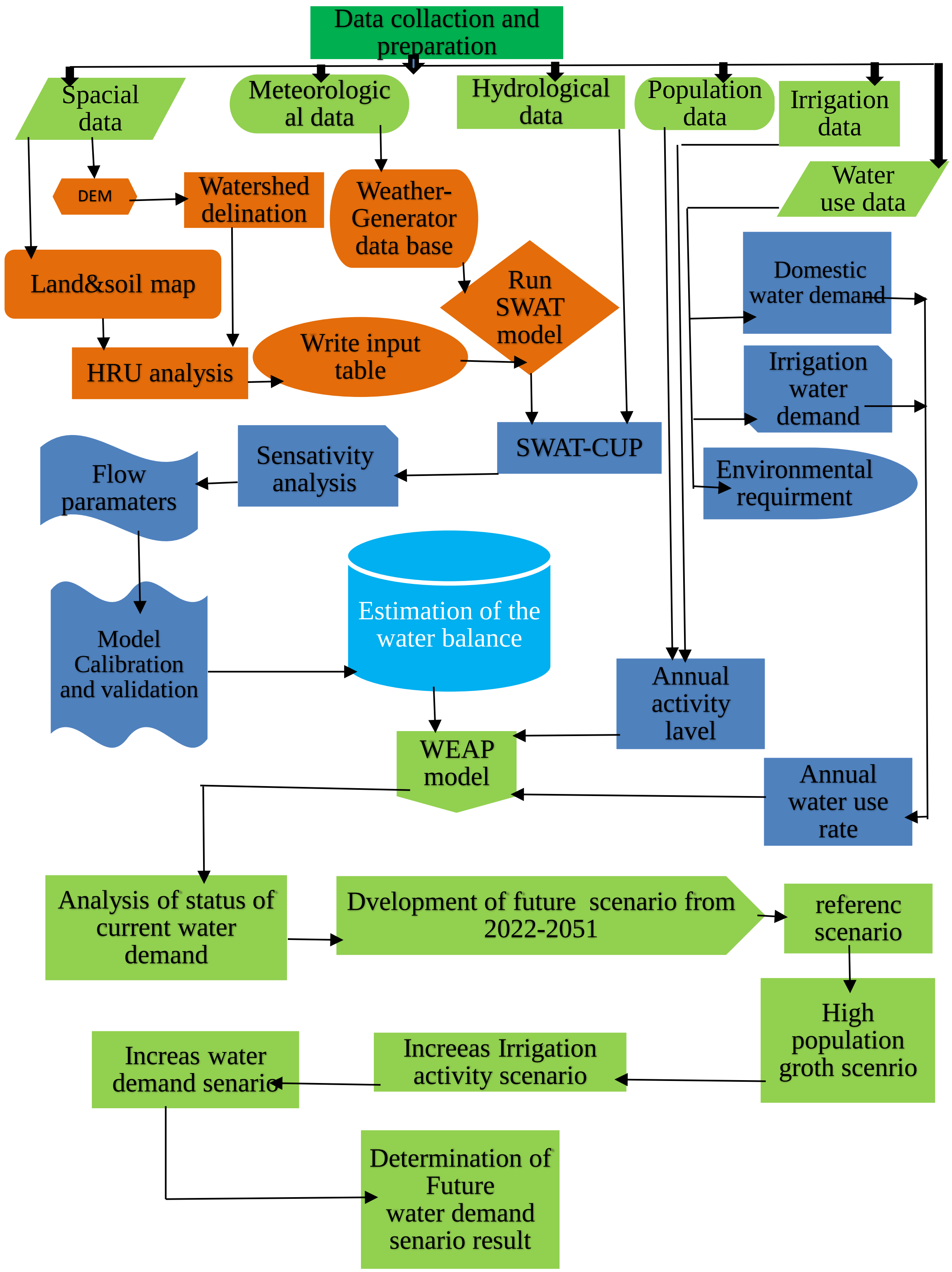


Figure 3.13 Flow chart representation of methodology

4 RESULTS AND DISCUSSIONS

4.1 Sensitivity Analyses

Sensitive analysis is the process of identifying the model parameters that exert the highest influence on model calibration or model predications. The SWAT-CUP has Global and One-at-a time sensitive analysis method that help to identify the most sensitive parameters in the process of calibration and validation. In this study the Global sensitive analysis was selected that help to identify the most sensitive parameter by the help of t-state and p-value in SWAT-CUP SUFI2. The nine parameters to characterize the Meki watershed were curve number (CN2), base flow alpha factor (ALPHA_BNK), depth from the soil surface to bottom of the layer (SOL-Z), saturated hydraulic conductivity (SOL-k), soil evaporation compensation factor (ESCO), Average slope length (SLSUBBSN.hru), and Manning's value for overland flow (OV-N) and threshold depth of water in the shallow aquifer for return flow to occur (GWQMN.gw), and available water capacity of the soil layer (SOL-AWC).

A t-state and P-value are used to identify the most sensitive parameter in the calibration and validation processes. The t-stat is the coefficient of a parameter divided by its standard error that was used to identify the relative significance of each parameter that was a value large in absolute value was most significant whereas the p-value close to zero (i.e. $p<0.05$) is more significant and it indicate that the parameter is more sensitive also see appendix (figure 5). Therefore, from the model output, the most sensitive parameters were SCS runoff curve number (CN2), and saturated hydraulic conductivity (SOL-Z) (table 4.1). This result suggests that, accurate estimation of theses parameters is important for stream flow simulation in the basin.

Table 4.1 Fitted and most sensitive parameter of the best value of objective function

Rank	Parameter Name	t-Stat	P-Value	Fitted value	Min-value	Max-value
1	R__CN2.mgt	-13.6275738	0.000001	-0.116	-0.2	0.2
2	R__SOL_Z(..).sol	-4.1821431	0.000153	-0.305	-0.5	1
3	R__SOL_K(..).sol	1.86939354	0.068901	0.035	-0.25	0.25
4	V__ESCO.bsn	1.790852259	0.080886	0.15	0	1
5	V__ALPHA_BF.gw	1.582773164	0.121348	0.57	0	1
6	V__OV_N.hru	1.112023157	0.272767	5.781	0.1	30
7	R__SOL_AWC(..).sol	-0.80155424	0.427547	0.1217	-0.07	0.2
8	V__GWQMN.gw	-0.56231248	0.577041	1.78	0	2
9	V__SLSUBBSN.hru	-0.27968676	0.781159	31	10	150

Where r and v are the method of variation which represent relative and replace respectively.

4.2 Calibration and Validation of the Model

After running (simulating) the SWAT model calibration and validation were takes place using SUFI2 algorithm of SWAT_CUP. The 18 year (1996-2013) observed flow data at Meki gauging station was used for calibration and validation. From this observed flow data for 10 year (1998-2007) used for calibration (figure 4.1) and for 6 year (2008-2013) used for validation (figure 4.2) and the remaining two year used for warm up period. The calibration and the validation results were performed until a good agreement and fitness between the simulated and observed monthly flow at the outlet of the watershed. Therefore, after a number of iterations the objective function of R^2, NSE, and Bias result were collected and illustrated in (table 4.2).

Table 4.2 Numerical value of calibration and validation of objective function

Parameter	R^2	NSE	PBIAS
calibration	0.83	0.69	-19
validation	0.86	0.76	-18

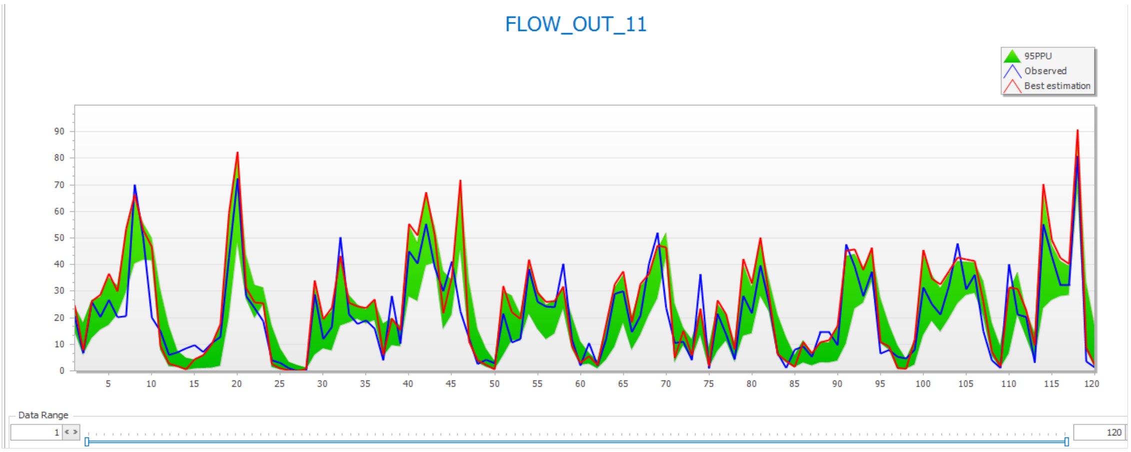


Figure 4.1 Observed against simulated monthly flow in model calibration (1998-2007)

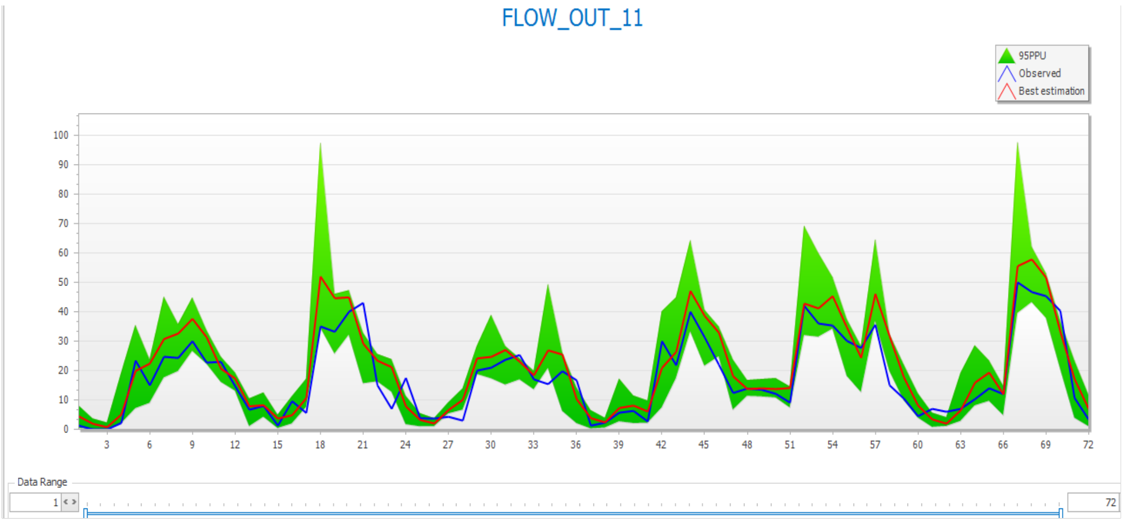


Figure 4.2 Observed against simulated monthly flow in model validation (2008-2013)

4.3 Current Surface Water Potential Assessment

In rainfall-runoff modeling, soil and water assessment tool (SWAT) was very essential to determine the surface water potential. After running the SWAT model, the result must calibrate and validate and then check the R^2, NSE and PBIAS. After these processes the following result would be collected such as precipitation, surface runoff(Q), lateral soil (Q), total water yield, evapotranspiration, potential evapotranspiration, recharging to deep aquifer, percolation to shallow aquifer, and re-evaporation from shallow aquifer and. The whole model output type, which have average monthly and annual water balance of the watershed value were shown in (table 4.4) and (table 4.3) respectively.

Around 696.3mm, rainfall falling on to the ground surface of the watershed. Surface water runoff depth of Meki river watershed was 144.11 mm which was 20.7% of annual mean precipitation (figure 4.3). The estimated mean annual surface runoff volume flowing the entire total watershed area of 243400ha, a total of 350.76 million cub meter (Mm^3) surface runoff was produced by the model from the catchment annually in the year 2021. The watershed has minimum surface run of 6.03 million cub meter ($Mm^{3)}$ and maximum surface runoff 56.3 Mm^3 in August. As the rainfall falling the ground some portion of the rainfall penetrates into the ground and flow on the side of the soil and reach the ground surface again and then mix with surface water was known as lateral soil was 29.9 mm and which was 4.3% of mean annual rain fall (table 4.3).

The contribution of the rainfall during "Kiremt" season (June, July, August and September) were 94.17mm, 100.73mm, 110.9mm and 95.74mm respectively with a total surface runoff depth of 95.85mm which was the sum of 16.79mm, 18.9mm, 21.53mm, 18.66mm, and 19.97mm during kiremt season (June, Aguste, September, and October) (table 4.4). During this season the mean rain fall contribution was 57.7% of the annul mean precipitation. The rainfall during "Bega" season (November, December, January, and February) were 14.37mm, 11.02mm, 8.99mm, and 17.12mm respectively which cover only 7.4% of total annual rainfall (table 4.4). The total surface runoff during this season (November, December, January, and February) were 19.97mm, 3.04mm, 3.08mm and 2.48mm respectively with a total surface runoff 69.5 million cub meter (Mm^3). The remaining months were "Belg" season (March, April, and May) has 36.24mm, 61.02mm, 73.91mm with a surface runoff depth 9.07mm, 13.23mm, and 12.6mm respectively (table4.4). (Table 4.3) and (figure 4.3) show A few portions of precipitation that percolate into the soil layer (shallow aquifer) estimated about 269.3mm, recharge deep aquifer account 13.47mm contribute to base flow, and out of annual rain fall about 20.68mm as Revap flow from shallow aquifer. The part of precipitation that evaporate from the soil and transpiration from the plant is called evapotranspiration that account about 254.3mm (36.53%) of mean annual precipitation (table 4.3).

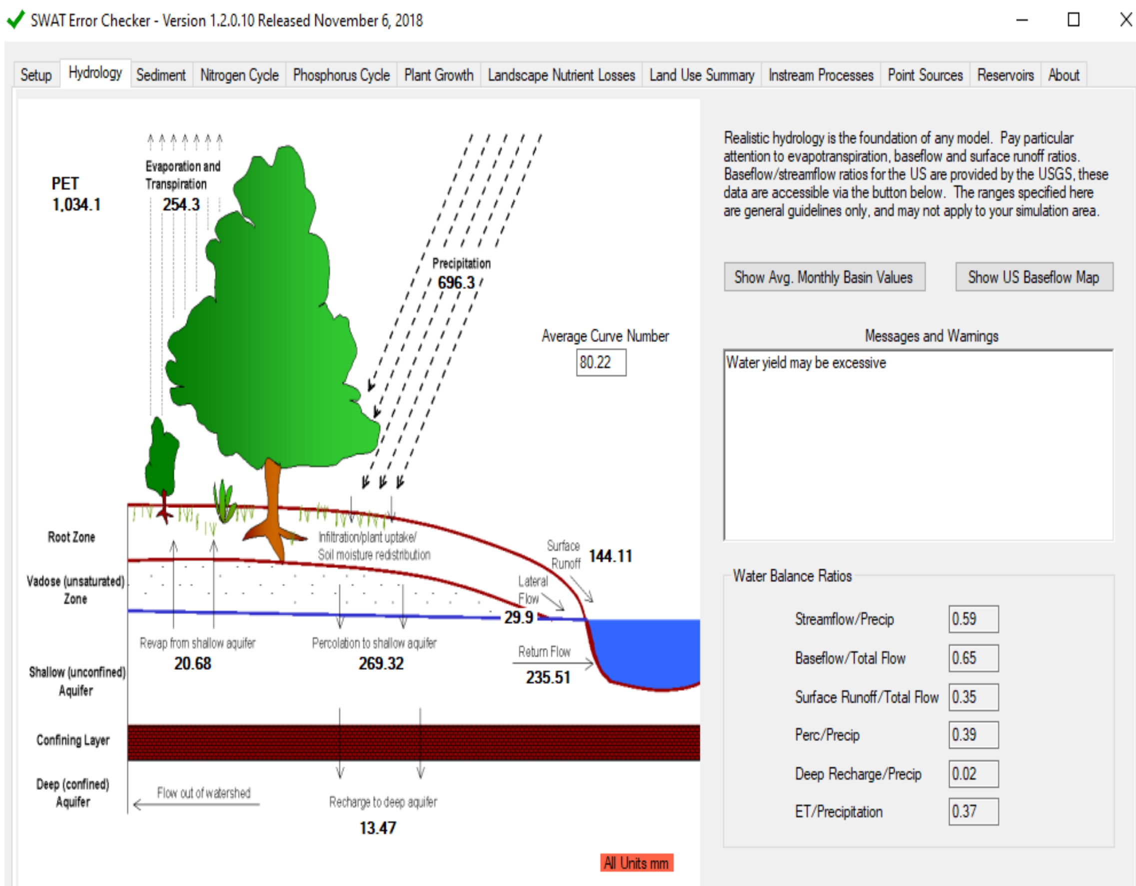


Figure 4.3 Meki watershed water balance

Table 4.3 Average annual water balance value of the watershed

No	Water Balance	Depth (mm)
1	Precipitation	696.3 mm
2	Surface runoff(Q)	144.11mm
3	Lateral soil (Q)	29.9 mm
4	Total water yield	389.5 mm
5	Evapotranspiration (ET)	254.3 mm
6	Potential Evapotranspiration (PET)	1034.1 mm
7	Re-evapotranspiration from shallow aquifer	20.68 mm
8	Return Flow	235.51 mm
9	Percolation to shallow aquifer	269.3 mm
10	Recharge to Deep aquifer	13.47 mm

Table 4.4 Average monthly water balance values of the watershed

MONTH	RAIN FALL (MM)	SURF Q (MM)	LAT Q (MM)	WATER YIELD (MM)	ET (T/HA)	PET MM
January	8.99	2.48	0.55	11.26	1.27	83.47
February	17.12	4.71	0.76	10.42	3.94	84.97
March	36.24	9.07	1.37	17.82	16.99	102.18
April	61.02	13.23	2.41	26.49	27.47	101.47
May	73.91	12.6	2.9	31.34	33.75	100.22
June	94.17	16.79	3.54	39.62	38.59	94.2
July	100.73	18.9	3.85	49	39.91	88.12
August	110.9	21.53	4.86	58.63	37.45	88.89
September	95.74	18.66	4.53	60.08	28.52	75.34
October	71.93	19.97	3.25	62.78	18.41	72.66
November	14.37	3.04	1.16	35.02	5.75	68.18
December	11.02	3.08	0.72	20.61	2.25	73.67

4.4 Water Demand in the Current Account Year

The current and future states of water potential analysis focus on annual water demand, monthly supply requirement, demand coverage and unmet demand calculation. Total demand site's for water was calculated as the sum of the demands for domestic and irrigation at annual basin in the watershed.

4.4.1 Current Domestic Water Demand

In order to model the current and the future domestic water demand among multiple water users, annual activity level (total population for the base year), annual water use rate, consumption and monthly variation are necessary.

The current (2021) population number of the study area was 870254 (table 3.4) which exist between 100,000-1 million and it use 80l/c/day for urban and 25l/c/day for rural. But this study lies in the third Growth and Transformation plan (GTP-III). Due to this, the per capital water consumption increase beyond 80l/c/day and assuming 25% increment from GTP II to GTP III, it become 100l/c/day for urban and 32l/c/day for rural was used. So, the current domestic water demand was the product of current total population (870254) with per capital demand (36.5m^3/c/day) which is equal to 31.76 Mm^3 in the watershed as shown in (table 4.5).

In estimating monthly variation for a demand site, historical pattern can be revised. If such record is unavailable. The user can reference demand sites with similar properties the twelve-monthly coefficient must sum to one hundred percent. If demands des not vary, all month are assuming to use the same amount according to the number of days in the month (SEI, 2011). For this study there is no historical record of monthly variation all month are assume to use the same amount, according to the number of days in the month. For example, the default annual share for January is 31/365=8.47% whereas February is 28/365= 7.67%. The consumption rate is deepened on household metering. But household metering is not widely used in developing country. Therefore, a default consumption rate provide by the WEAP model was used.

4.4.2 Environmental flow Requirement

For the environmental requirement for this study was allocated to be 20% of the mean annual runoff to maintain the ecosystem of the river such as river water quality, fish, wildlife, and the level of Ziway lake (Tennant, 1976).

4.4.3 Current Irrigation Water Demand

The major crops in the watershed are limited to 'MEHER' season and the major types of crops that are produced including maize, wheat, teff, barley, and sorghum from cereals, and horse beans, chickpeas, and filed peas from pulses. Few smallholders are engaged in the irrigation agriculture using water from Meki river and lake while the other ret out water from the ground by using their diesel generator. The major crop in the study area were onion, tomato, cabbage, maze, potato, and pepper (Dugda Woreda Finance and Economic Coopretion Office, 2021) and (Legesse *et al*., 2020). Calculation of current irrigation and domestic water demand were resulting from feasibility studies and design document. Hence, in this study 2021 data and CROPWAT was used to estimate the crop water requirement for existing and proposed irrigation schemes. Using the above data, the calculated the annual water use rate (crop water requirements) for the irrigation projected, the total current irrigation water demand, and monthly variation were described in appendix (table 9-15).

The amount of water consumed by domestic and agricultural water demand was 31.76 Mm^3 (84.9%) and 7.56 Mm^3 (16%) respectively. Therefore, the total current consumptive water demand was 39.32 Mm^3 and the non-consumptive water user (environmental flow requirement) was 70.15 Mm^3 as mentioned in (table 4.5)

Table 4.5 Current water demand in the watershed

No	Water demand	Quantity (Mm^3)
1	Domestic water demand	31.76
2	Irrigation water demand	7.56
3	Environmental flow requirement	70.15

4.4.4 Unmet Water Demand in the Current Account year (2021)

Unmet water demand is the difference between supplies required and supply delivered to a particular demand site in a WEAP algorithm. Unmet demand is demand which was not fulfilled or unavailable in a month or a year. The demand coverage for demand site ranging from 0 to 100% it cannot more than 100%. The WEAP model calculate the magnitude of shortage of (un-covered) for demand site by subtracting the coverage in the demand site from 100. In this study, the total water demand in the current was 39.32 Mm^3 excluding the minimum environmental flow requirement and the total available water resource is greater than the requirement for the current year for the selected demand site. So, the overall unmet demand of all demand sites in the current account years found to be 0.00%, this implies that the overall coverage of supply is 100% in the current account year.

4.5 Future Water Demand and Allocation under selected Scenarios

Scenario were developed to see what will happen on the water resource in the future. Scenario can solve variety of “what if” question on demand amount, coverage of water for each demand site and in overall balance of water in the watershed. Different scenarios were developed by considering with and without the effect of technological change in the future water demands. Thus, the reference scenario consider on the future water demand without the effect of technological change on water demands but only consider population growth; and the other scenario consider the effect of technology change on water demands. Therefore, for this study scenario were established in WEAP based on reference scenario, population growth rate, increase irrigation activity, and increase water demand scenario from 2022 up to 2051.

4.5.1 Reference Scenario (2022-2051)

Reference scenario show the change that are likely to occur in the future without new interference or new policy measures. In this scenario, no change was made except the increment of population with an average growth rate 2.9% as recommended by CSA of Ethiopia 2007 and the maximum water demand per person per year in the watershed was 36.5 m^3/year.

figure 4.5, show the net water demand for each sector and the projected water demand for the year of 2022-2051. From the simulation, it was projected that in the year 2051, the total water demand will be increase from 39.32 Mm^3 to 82.44 Mm^3 due to population growth. In this scenario the domestic water demand was 74.89 Mm^3 which is 90.8% of total water demand. The agricultural water demand was 7.56 Mm^3. As no change in policy measures, agricultural demand and consumption rate were still constant.

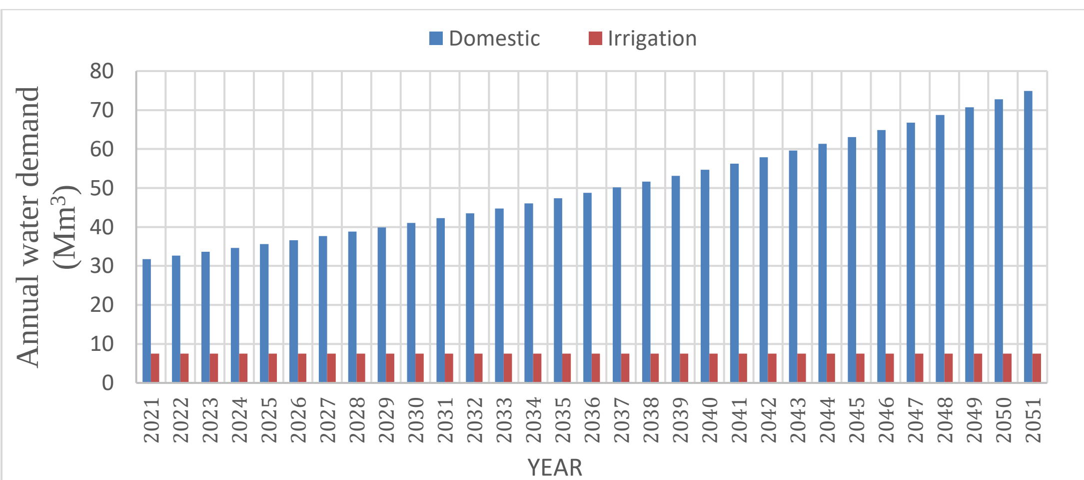


Figure 4.4 Annual water demand for reference scenario

4.5.2 Scenario 1: High Population Growth Scenario

What happen if the population growth rate is set to a higher growth rate than the reference scenario population growth rate? In this case, the population growth rate was raised from 2.9% to 5.2% to simulate the water demand in the future.

The total water demand reaches 161.4 Mm^3 in the watershed in 2051 as shown below in (figure 4.6). The expected total domestic water demand will be increased from 74.86 Mm^3 to 153.8 Mm^3 with 95.3% of total water demand in the 2051 which is increased from the reference scenario, this is due to high population growth rate. The projected total irrigation water demand was the same as reference scenario it was 7.56 Mm^3. Figure 4.7 portrayed, the total annual unmet water demand under this scenario was 2.8 Mm^3 (2%) in the dry period (January) throughout the year. The coverage in this scenario was 98% shown in appendix C (figure 16).

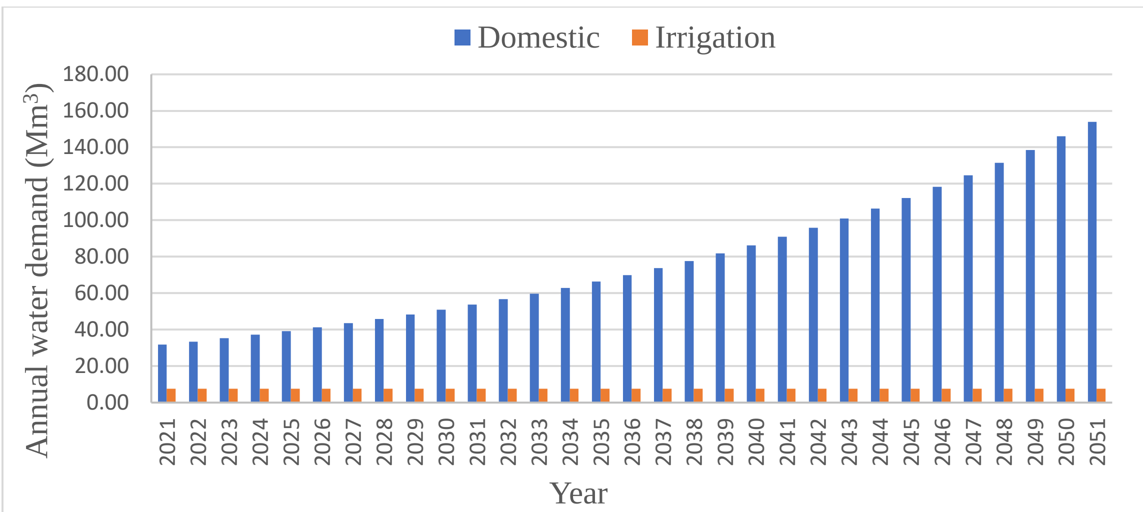


Figure 4.5 Water demand for scenario one (High population growth scenario)

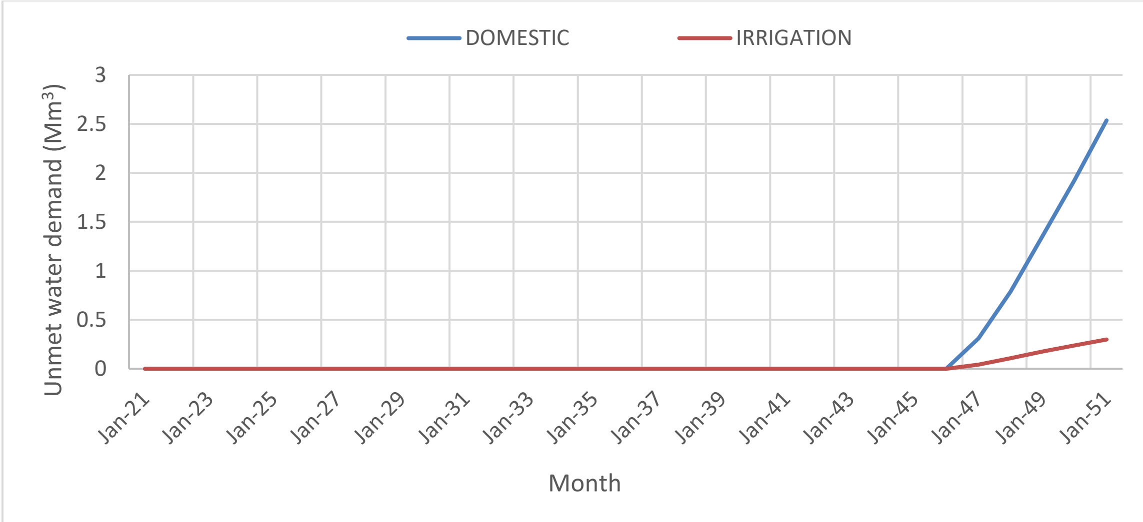


Figure 4.6 Unmet water demand under high population growth scenario

4.5.3 Scenario 2: Projection in Irrigation Command Area

In this sub-basin the irrigation activity increase year to year this helps to reduce the poverty. This increment will continue further, therefore, the area to reach 8000ha in the year 2051 by the estimated growth of 8.93% from the current available command area of 615ha of the watershed.

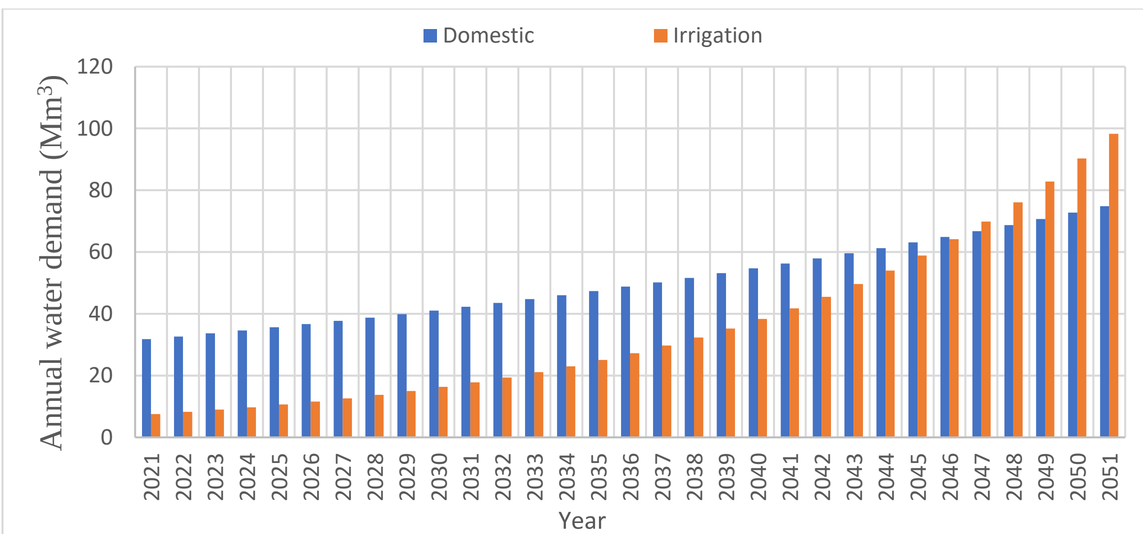


Figure 4.7 Water demand for scenario two

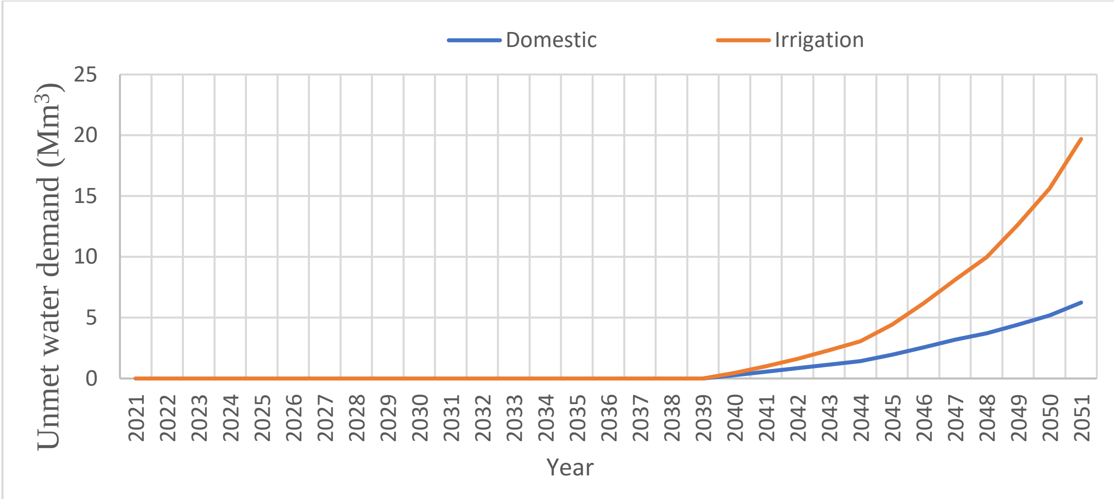


Figure 4.8 Unmet water demand under increase irrigation area scenario

Fig 4.8 shows the projected water demand of scenario two for the year (2021-2051). In this scenario the populated growth rate and the consumption rate were constant. From the result, it was projected that in the year 2051, the total water demand was increased to 173.2 Mm^3. From the total water demand, the agricultural water demand was projected that in the year of 2051, was increase to 98.3 Mm^3 with (56.8%) of the total water demand, this was because of expansion of irrigated area from year to year. The water conception rate for domestic remain constant 74.89 Mm^3, it is the same as of reference scenario. Figure 4.9 show the unmet water demand of the scenario which was 25.9 Mm^3 with (11%). This shortage occurred in dray period, particularly in January and February in the future scenario and the water coverage was illustrated in appendix C (figure 17).

4.5.4 Scenario 3: Increase Domestic Water Demand Scenario

In this study area there were expansion of irrigation which is highly related with population growth to reduce poverty, it leads to economic growth and development of urbanization, due to this the water conception will increase in the next. So, what will happen if the per-capital water demand will increase by 50% from the current pe-capital water demand in the watershed in order to satisfy the water demand in the future.

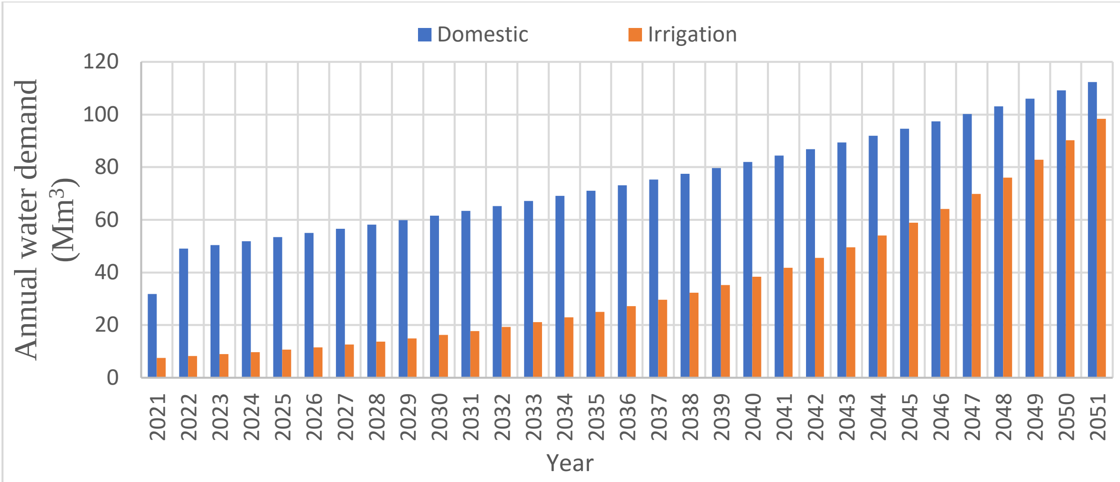


Figure 4.9 Water demand for increase domestic water demand scenario

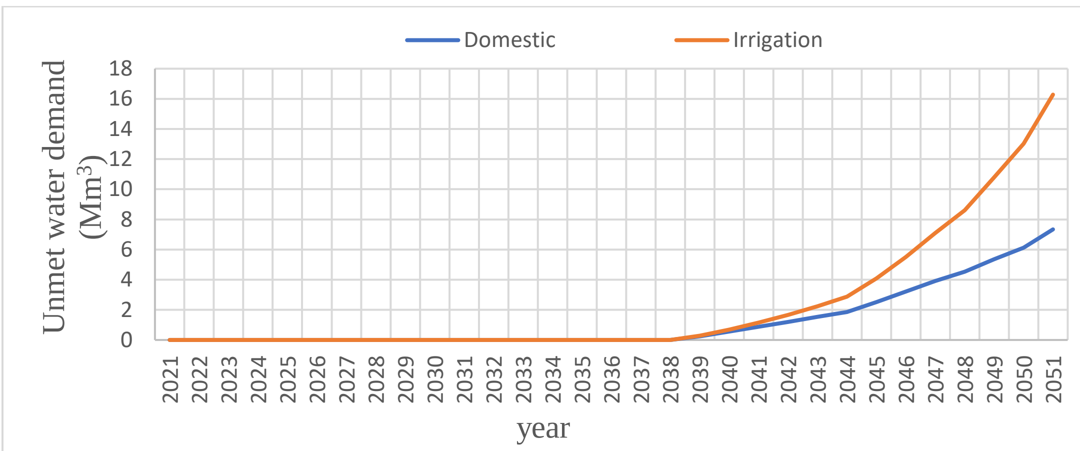
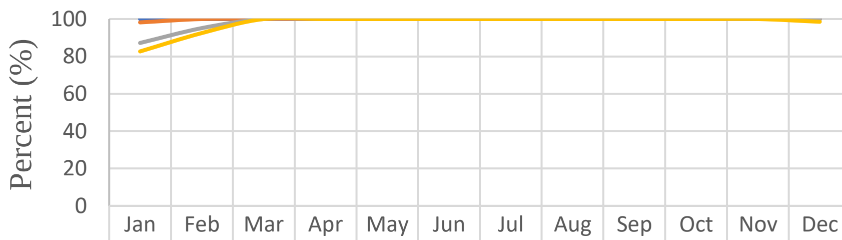


Figure 4.10 Unmet water demand under increase domestic water demand scenario

Figure 4.10 describe the future net water demand of scenario three. The result of this scenario explains that the total water demand at the end of 2051 was 210.7 Mm^3. From the net total, the domestic water demand was increase relative to reference scenario that was 112.3 Mm^3 (53.3%) in the year of 2051 this is because of the increment of consumption rate, but in this scenario the irrigation water demand was constant and it was the same as scenario two, which is 98.4 Mm^3. Figure 4.11 show, when unmet water demand increase, water supply coverage decreases, this indicate that insufficient to satisfy the demands. Therefore, the scarcity of water will be occurred during dray period of the future about 35 Mm^3 (16.6%) (i.e. December to February). So, the current water resource not covered 100% due to irrigation expansion and increment of consumption rate in this scenario as shown in appendix C (figure 18).

Generally, the total water requirement for each demand site was combined within the WEAP model and present the projected water demand for the year 2021-2051 appendix (table 16). From this result, it was projected that in the year 2051, the estimated that total annual consumptive water demand may be expected for reference scenario, high population scenario, increase irrigation scenario, and increase domestic water demand scenario around 82.44 Mm^3, 161.4 Mm^3, 173.2 Mm^3, and 210.6 Mm^3 respectively Appendix (figure 19). The water coverage for each scenario under (reference scenario, high population scenario, increase irrigation scenario and increase water demand scenario) was presented in (figure 4.12)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Reference	100	100	100	100	100	100	100	100	100	100	100	100
High population scenario	98	100	100	100	100	100	100	100	100	100	100	100
Increase irrigation scenario	87	95	100	100	100	100	100	100	100	100	100	99.6
Increase water demand scenario	83	92	100	100	100	100	100	100	100	100	100	98.5

Figure 4.11 Water coverage of each scenario in the watershed

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The origin of all water is rainfall. It reaches the ground, as surface water when it flows over the ground; or as ground water when it percolates in to the ground but this study considers only surface water. In this study area rainfall was not uniformly distributed at all-time throughout the year. This leads to the water resource available was not well managed as there was an excess flow of water in the rainy season and a low flow or no flow in the dry season of the Meki river. Additionally, rapid population growth, urbanization, and expansion of irrigation are putting more pressure on fresh water availability. These clearly show that there was a need to analyze the water balance of the river basin and formulate water allocation strategies and principles for present and the future. So, (SWAT) model to estimate surface water potential and (WEAP) model to allocate available water resource between different demand site.

Therefore, this study was conducted to assess surface water and the impact of different scenario on water demand in the Meki river watershed. The Meki river watershed receives an estimated mean annual precipitation of 696.3 mm, while the estimated mean annual surface runoff leaving the whole basin is 350.76 MCM which corresponds to 144.11mm mean annual runoff depth. It more sensitive with CN2 and SOL-Z

In the base year 109.47 MCM of water was required by both consumptive use and non-consumptive (EFR) water users. The result show that the total available water resource is greater than the requirement for the base year for the selected demand sites and this show that no unmet demand was encountered in the base year (2021). The scenarios were developed evaluate future demands based on different sets of "what if" up to the year 2051. Therefore, the estimated total annual consumptive water demand may be expected to be 82.44 Mm^3, 161.4 Mm^3, 173.2 Mm^3, and 210.6 Mm^3 and the unmet water demand 0, 2%, 11%, and 16.6% for the reference scenarios, high population growth scenarios, increase irrigation activity scenarios and increase water demand scenarios and 70.15 MCM for environmental flow requirement. Hence, this study uses the environmental flow requirement of 20% of the mean annual flow volume to maintain the ecological functioning and water balance in lake Ziway.

5.2 Recommendation

In this study the surface water resource management was solved by modeling the surface water potential in the year 2021 and water demands in the watershed were calculated to determine the status of the available surface water potential and also different water demand and supply were developed.

During high rainy season (June to September) Meki river has huge amount of water, and there was low flow of water in dry season (December to February). This makes difficult to determine and allocate water between different demand site in the watershed. Therefore, it is recommended to harvest water during rainy season by using engineering works such as construction of reservoirs, construction of canals, and increase irrigation efficiency without affecting the downstream environment. Additionally, it is recommended that simultaneous use of surface water and ground water is of importance for integrated water resource management.
According to sensitive analysis report the highly sensitive parameter are CN2 and SOL-Z. SOL-Z show that soil physical property therefore it is recommended to conduct further study on soil types and reclassification may be necessary to improve model performance.

The SWAT output show that the watershed has high potential available surface water resource, but the maximum amount of water enters in to the ziway lake. At this time the Level of Ziway lake increase. Because of this not only losses the water due to evaporation but also, losses the irrigable area (land) due to flooding. From this it is recommended that construction of soil and water conservation system, wise management of the land and construction of water harvesting structure at the upstream of the watershed that increase the water potential and to use the water during the dry period.

In order to eliminate the complexity of this study, different factors that are affect the water potential and demand scenario including climate change, land use land cover, and other are not considered. It is recommended that; further researcher should take great attention to assess the impact of climate change on the surface water potential and different scenario water allocation.

6 REFERENCE

Abdi, D.A. (2021) ‘Evaluation of the WEAP model in simulating subbasin hydrology in the Central Rift Valley basin , Ethiopia’, 5.

Abebe Guadie Shumet and Kassa Tadele Mengistu (2016) ‘of Waste Resources Assessing the Impact of Existing and Future Water Demand on Economic and Environmental Aspects (Case Study from Rift Valley Lake Basin : Meki-Ziway Sub Basin), Ethiopia’, (August). doi:10.4172/2252-5211.1000223.

Adey Nigatu Mersha, Ilyas Masih, Charlotte de Fraiture, J.W. and Alamirew, T. (2018) ‘Evaluating the impacts of IWRM policy actions on demand satisfaction and downstream water availability in the Upper Awash Basin, Ethiopia’, *Water (Switzerland)*, 10(7). doi:10.3390/w10070892.

Alamgir Khalil, A.R.Y.P. (2018) ‘The projected changes in water status of the Mae Klong Basin , Thailand , using WEAP model’, *Paddy and Water Environment* [Preprint], (0123456789). doi:10.1007/s10333-018-0638-y.

Areesha Asghar, Javed Iqbal, A.A. and L.R. (2019) ‘Integrated hydrological modeling for assessment of water demand and supply under socio-economic and IPCC climate change scenarios using WEAP in Central Indus Basin Areesha Asghar , Javed Iqbal , Ali Amin and Lars Ribbe’, pp. 136–148. doi:10.2166/aqua.2019.106.

Ashenafi Kifle (2016) ‘GIS-Based Surface Irrigation Potential Assessment of River Catchments for Irrigation Development in Segen Basin.’

Behailu Hussen Ayalkebet Mekonnen Santosh Murlidhar Pingale (2018) ‘Integrated water resources management under climate change scenarios in the sub-basin of Abaya-Chamo , Ethiopia’, *Modeling Earth Systems and Environment*, 4(1), pp. 221–240. doi:10.1007/s40808-018-0438-9.

Belete Berhanu, Y.S. and A.M.M. (2014) ‘Surface Water and Groundwater Resources of Ethiopia : Potentials and Challenges of Water Resources Development Chapter 6 Surface Water and Groundwater Resources of Ethiopia : Potentials and Challenges of Water Resources Development’, (February). doi:10.1007/978-3-319-02720-3.

Berhe, B.A. (2020) ‘Evaluation of groundwater and surface water quality suitability for drinking and agricultural purposes in Kombolcha town area , eastern Amhara region , Ethiopia’, *Applied Water Science* [Preprint]. doi:10.1007/s13201-020-01210-6.

Bullock, A., Chirwa, A., Matondo, J. and Mazvimavi, D. (1990) 'Analysis of flow regimes in Malawi, Tanzania, and Zimbabwe: A feasibility study for Africa Friend. Overseas Development Report, Institute of Hydrology, Wallingford, UK.', p. 1990.

Bunta, A. and Abate, B. (2021) 'Runoff and Sediment Yield Modeling of Meki River Watershed Using SWAT Model in Rift Valley Lakes Basin , Ethiopia', 9(5), pp. 155–166. doi:10.11648/j.ajce.20210905.12.

CSA (2015) 'Central Statistical Agency of Ethiopia. 2015. Population Projection of Ethiopia for All Regions at Woreda Level from 2014-2017. August 2013, Addis Ababa.', (August 2013).

D. Legesse, T. A. Abiye, and C.V.-C. (2010) 'Modeling impacts of climate and land use changes on catchment hydrology : Meki River , Ethiopia', pp. 4535–4565. doi:10.5194/hessd-7-4535-2010.

D. Legesse, T. A. Abiye, C.V.-C. and H.A. (2020) 'Streamflow sensitivity to climate and land cover changes : Meki River , Ethiopia To cite this version : HAL Id : hal-00799608 Streamflow sensitivity to climate and land cover changes : Meki River , Ethiopia'. doi:10.5194/hess-14-2277-2010.

Daniel, E.B., J.V. Camp, E.J. LeBoeuf, J.R. Penrod, J.P. Dobbins, and M.D.A. 2011. (2011) 'Daniel, E.B., J.V. Camp, E.J. LeBoeuf, J.R. Penrod, J.P. Dobbins, and M.D. Abkowitz. 2011. Watershed modeling and its applications: A state-of-the-art review. The Open Hydrology Journal 5(1).', 5(1), p. 2011.

Daniel Mengistu, Woldeamlak Bewket, A.D. dand H.-J.P. (2020) 'Climate change impacts on water resources in the Upper Blue Nile (Abay) River Basin, Ethiopia'.

Dawit Lenjiso Edo, F.C.T. and D.B.P. (2021) 'Prediction of Stream Flow and Sediment Yield of Kesem Watershed Using SWAT Model', 5(4), p. 504007.

Dejene Abera, Kibebew Kibret, S.B. and F.K. (2018) 'Spatial and Temporal Dynamics of Irrigation Water Quality in Zeway , Ketar , and Bulbula sub-Watersheds , Central Rift Valley of Ethiopia Planning safe water use and management requires beforehand knowledge on', 28(3), pp. 55–77.

Desta, H. and Lemma, B. (2017) 'Journal of Hydrology : Regional Studies SWAT based hydrological assessment and characterization of Lake', *Journal of Hydrology: Regional Studies*, 13(August), pp. 122–137. doi:10.1016/j.ejrh.2017.08.002.

Do, X.K., Nguyen, T.H. and Tran, K.C. (2018) 'Assessment of Water Shortage in Sesan River Basin By Integrating the Swat and Weap Models', *International Symposium on Lowland Technology (ISLT 2018) Sept. 26 – 28, 2018, Hanoi, Vietnam* [Preprint], (January).

Dugda Woreda Finance and Economic Coopretion Office (2021) 'Physical and Socio Economic Profile of Dugda Woreda.', (April).

FAO (1985) 'Guidelines Land Evaluation for Irrigated Agriculture. FAO Soils Bull 55, Rome, 290.'

FAO (1998a) 'FAO (Food and Agriculture Organization). 1998. Crop evapotranspiration: Guidelines for computing crop water requirements. By: Richard Allen, Luis Pereira, Dirk Raes and Martin Smith. FAO Irrigation and Drainage Paper 56. Rome, Italy.

GWP (2009) 'A handbook for integrated water resources management in basins'.

HR Wallingfored (2003) 'Handbook for the Assessment of Catchment Water Demand and Use'.

Jebelli, J. (2018) 'Water Allocation to Small Scale Irrigation Schemes using the Results of Analysis from WEAP Model : An Application to Mekabo Scheme in Tigray , Ethiopia', 3(7), pp. 88–95.

Jeffrey G. Arnold, Daniel N. Moriasi, Philip W. Gassman, Karim C. Abbaspour, Michael J. White, Raghavan Srinivasan, Chinnasamy Santhi, Daren Harmel, Ann van Griensven, Michael W. Van Liew, Narayanan Kannan, and M.K.J. (2012) 'SWAT : Model use , calibration , and validation'.

Jha, M.K. (2011) 'Evaluating Hydrologic Response of an Agricultural Watershed for Watershed Analysis', pp. 604–617. doi:10.3390/w3020604.

Kishiwa, P. *et al.* (2018) 'Assessment of impacts of climate change on surface water availability using coupled SWAT and WEAP models : case of upper Pangani River Basin , Tanzania', pp. 23–27.

Kumar, R. and , Pratibha Kumari , Ajai Singh, P.K.P. and V.K.T. (2020) 'Modelling future water supply and demand in Jharkhand region of Subarnarekha River basin by using weap model with RCP 4 . 5', 26(4).

Legesse, D. and Abiye, T.A. (2010) 'Modeling impacts of climate and land use changes on catchment hydrology : Meki River , Ethiopia', pp. 4535–4565. doi:10.5194/hessd-7-

4535-2010.

Van Liew MW, Arnold JG, G.J. (2003) ‘Hydrologic simulation on agricultural watersheds choosing between two models’, 46(6), p. 2003.

M J Makin T J Kingham A E Waddams C J Birchall and B W Eavis (1976) ‘Land Resources Division, Ministry of Overseas Development’.

Meki Irrigation and Rural Development Project, 2000 (no date) ‘The Study for Meki Irrigation and Rural Development Project in Oromia Region , Ethiopia.’

Mesele, Y. and Mechal, A. (2020) ‘Hydrochemical characterization and quality assessment of groundwater in Meki River Basin , Ethiopian Rift’, *Sustainable Water Resources Management* [Preprint]. doi:10.1007/s40899-020-00471-y.

Mills, J.A. and Prasad, K. (1992) ‘A comparison of model selection criteria’, *Econometric Reviews*, 11(2), pp. 201–234. doi:10.1080/07474939208800232.

Mohammed Gedefaw, Hao Wang, Denghua Yan, Tianling Qin, K.W. and Abel Girma, D.B. and A.A. (2019) ‘Water Resources Allocation Systems under Irrigation Expansion and Climate Change Scenario in Awash River Basin of Ethiopia’, pp. 1–15.

Mounir ZM, Ma CM, and A. (2011) ‘Application of water evaluation and planning (WEAP): a model to assess future water demands in the Niger River (In Niger Republic). Modern Application of Science 5(1):38–49’, 5, p. 2011.

MoWIE (2015) ‘Federal Democratic Republic of Ethiopia Ministry of Water , Irrigation and Electricity Second Growth and Transformation National Plan for the Water Supply and Sanitation Sub-’.

MoWR (2010) ‘Ministry of Water Resources (MoWR). 2010. Ethiopian Water Resources Management Policy’.

Mulatu Tsegaye Kebede, A.S.N. And M.D. (2014) ‘The Impact Of Urban And Rural Land Use Types On Water Quality Of Meki River In Sodo Wereda ’, 2, Pp. 376–389.

Mulugeta Musie, Sumit Sen, and I.C. (2020) ‘Hydrologic Responses to Climate Variability and Human Activities in Lake Ziway Basin, Ethiopia’, pp. 1–26.

Nash, J.E. and Sutcliffe, J.V. (1970) ‘River flow forecasting through conceptual models: part I. A discussion of principles. Journal of Hydrology, 10 (3), 282–290’, 10(3), p. 1970.

Negash Tessema, A.K.& D.Y. (2020) ‘Modelling the effects of climate change on streamflow using climate and hydrological models : the case of the Kesem sub-basin of the Awash River basin , Ethiopia', *Intl. J. River Basin Management*, 0(0), pp. 1–12. doi:10.1080/15715124.2020.1755301.

Neitsch SL, Arnold JG, Kiniry JR, W.J. 2005 (2005) 'Soil and Water Assessment Tool (SWAT),Theoretical Documentation. BlacklandResearch Center, Grassland, Soil and Water Resear Laboratory,Agricultural Research Service: Temple, TX.', p. 2005.

Niksokhan, M.H., Kerachian, R. and Karamouz, M. (2009) 'A game theoretic approach for trading discharge permits in rivers', *Water Science and Technology*, 60(3), pp. 793–804. doi:10.2166/wst.2009.394.

Owwdse, 2010 (2010) 'Oromia Water Works Design And Design Guideline For Water Supply Projects Gg Water Works Consultant'.

Parveen Sihag, Balraj Singh, A.S.V.& V.M. (2018) 'Modeling the infiltration process with soft computing techniques Parveen', *ISH Journal of Hydraulic Engineering*, 5010(May), pp. 1–15. doi:10.1080/09715010.2018.1464408.

Phue and Chuenchooklin, 2020 (2020) 'Existing Water Balance in the Bago River Basin , Myanmar Existing Water Balance in the Bago River Basin , Myanmar'. doi:10.1088/1755-1315/552/1/012003.

Psomas, A. *et al.* (2016) 'Designing Water Efficiency Measures in a Catchment in Greece Using WEAP and SWAT Models', *Procedia Engineering*, 162, pp. 269–276. doi:10.1016/j.proeng.2016.11.058.

Roa-garcía, M.C. (2014) 'Equity , Efficiency and Sustainability in Water Allocation in the Andes : Trade-offs in a Full World', 7(2), pp. 298–319.

S.L. Neitsch, J.G. Arnold, J.R. Kiniry, J.R.W. (2009) 'Soil & Water Assessment Tool Theoretical Documentation Version 2009'.

Sahoo, S. *et al.* (2020) 'Future Water Use Planning by Water Evaluation and Planning System Model'.

SEI (2015) 'Water evaluation and planning system – user guide. Stockholm Environment Institute.

SEI (2016) 'Water Evaluation And Planning System', (August).

Sheng Meng, Lauren F. Greenlee, Y. R. Shen, and E. G. Wang. (2015) 'Basic science of water : Challenges and current status towards a molecular picture'. doi:10.1007/s12274-015-0822-y.

Sieber, J. (2006) 'WEAP Water Evaluation and Planning System'.

Singh, A. *et al.* (2014) 'Assessing the performance and uncertainty analysis of the SWAT and RBNN models for simulation of sediment yield in the Nagwa watershed , India Assessing the performance and uncertainty analysis of the SWAT and', *Hydrological Sciences Journal*, 59(2), pp. 351–364. doi:10.1080/02626667.2013.872787.

Speed Robert, Yuanyuan Li, Zhiwei Zhou, Quesne Tom Le, P.G.| M. 2013 (2013) 'Basin Water Allocation Planning : Principles , Procedures and Approaches for Basin Allocation Planning', (May).

Stefano Casconea, Julià Comab, Antonio Gaglianoc, G.P. (2019) 'The evapotranspiration process in green roofs : a review', (c).

Tena Bekele Adgolign, G.V.R.S.R.& Y.A. (2016) 'Weap Modeling Of Surface water resources allocation in Didessa', *Sustainable Water Resources Management*, 2(1), pp. 55–70. doi:10.1007/s40899-015-0041-4.

Tennant, D.L. (1976) 'Instreamflow regimens for fish, wildlife, recreation and related environmental resources. Fisheries 1 (4), 6–10.

Tesfaye Negasa Jaleta, M.B.Y. and D.B.H.C. (2019) 'Modeling Surface Water Resources for Effective Water Allocation Using Water Evaluation and Planning (WEAP) Model , A Case Study on Finchaa Sub basin , Ethiopia', 4, pp. 402–419.

Tewodros Assefa, Manoj Jha , Manuel Reyes, R.S. and A.W.W. (2018) 'and Water-Lifting Technologies', pp. 1–21. doi:10.3390/w10040495.

Touseef, M., Chen, L. and Yang, W. (2021) 'Assessment of surfacewater availability under climate change using coupled SWAT-WEAP in hongshui river basin, China', *ISPRS International Journal of Geo-Information*, 10(5). doi:10.3390/ijgi10050298.

USDA (1972) 'USDA Soil Conservation Service (SCS).1972. National Engineering Handbook Section4 hydrology.United States Department of Agriculture (USDA).Washington, DC. 10 (1):10-24.

Zachary M. Easton, A. (2015) 'Hydrology Basics and the Hydrologic Cycle'.

Zhang, X. (2015) 'Conjunctive surface water and groundwater management under climate change', 3(September), pp. 1–10. doi:10.3389/fenvs.2015.00059.

7 APPENDIXS

Appendix A: Metrological station

Appendix table 1: Buie Meteorological station corrected monthly rainfall (mm)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
116.900	0.000	191.100	34.900	**101.000**	206.700	249.300	265.600	90.300	11.700	4.700	17.400
59.300	**4.700**	53.800	101.800	11.200	103.400	177.500	149.400	31.300	78.900	19.300	0.000
46.000	57.400	117.000	53.200	85.400	134.300	260.200	152.300	65.600	**21.200**	0.000	0.000
1.200	**33.400**	54.300	**10.200**	48.200	**198.500**	341.600	**154.400**	43.400	131.800	0.000	0.000
0.000	0.000	20.000	62.100	57.200	54.100	161.400	180.500	270.100	96.200	81.200	15.600
26.000	62.000	201.100	49.500	162.300	210.900	**253.800**	194.800	44.600	10.400	0.000	**0.000**
52.800	39.900	44.900	49.800	101.000	117.700	161.000	198.600	111.800	0.000	0.000	23.800
4.000	**0.000**	122.200	**49.000**	17.300	150.700	250.600	166.100	132.000	0.000	**14.000**	**0.000**
59.300	4.700	23.100	158.100	2.600	**114.300**	211.000	**193.900**	117.900	26.800	9.500	0.000
0.000	17.400	143.900	103.300	158.900	122.800	146.800	353.900	90.000	34.800	36.700	0.000
14.500	33.700	**206.200**	161.800	95.900	76.000	298.600	**190.000**	74.600	33.200	0.000	12.500
17.700	33.400	31.500	70.200	97.300	**174.200**	286.600	154.400	98.200	21.200	3.500	0.000
0.000	0.000	0.000	0.000	**86.200**	186.200	332.400	187.100	116.400	17.800	147.800	0.000
19.200	**0.000**	68.700	74.900	0.000	22.200	244.400	140.700	116.800	140.700	0.000	11.000
0.000	**152.300**	141.100	**262.400**	114.400	209.100	205.500	269.400	154.400	0.000	9.200	0.000
0.000	0.000	50.600	49.000	44.700	149.400	218.200	179.900	85.500	0.000	**14.000**	0.000
0.000	0.000	20.100	111.400	66.900	110.600	221.100	95.000	99.700	0.000	0.000	2.500
0.000	0.000	136.200	88.500	54.100	156.900	210.800	190.000	57.400	47.500	0.600	0.000
0.000	29.000	169.700	**34.400**	59.700	48.700	180.800	**249.100**	58.700	74.000	**15.400**	0.000
0.000	**0.000**	11.500	0.000	105.900	**98.300**	92.900	156.100	96.700	0.000	0.000	0.000
40.800	1.300	31.800	175.800	119.400	100.900	177.800	99.000	74.900	7.500	13.400	0.000
0.000	37.800	83.800	2.300	312.900	62.900	215.400	**156.100**	174.300	1.500	0.000	0.000
0.000	26.000	107.500	251.800	64.400	168.600	136.100	182.800	68.700	0.000	16.700	0.000
0.000	0.000	25.900	120.600	61.500	185.600	287.600	153.300	425.500	33.800	24.600	6.000
0.000	**0.000**	127.400	121.500	**54.100**	**156.900**	299.600	251.000	**57.400**	9.300	0.000	**0.000**
0.000	2.500	0.000	161.200	104.800	68.700	225.600	140.400	120.100	**0.000**	**0.000**	**2.500**

Appendix table2: Butajera station Meteorological station corrected monthly rainfall (mm)

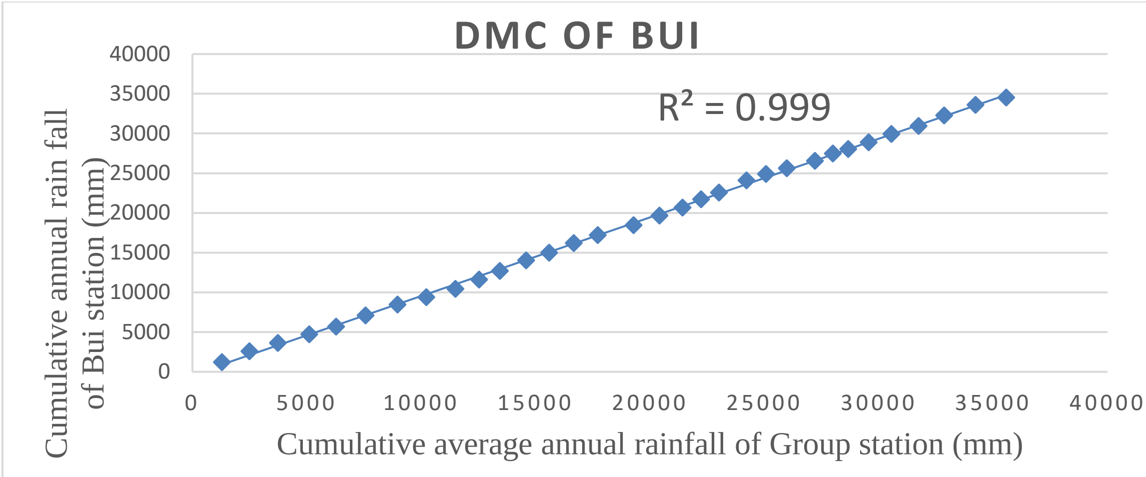
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996	149.000	0.000	314.300	103.900	212.200	277.300	133.000	199.400	72.500	9.000	13.200	0.000
1997	111.800	0.000	126.400	190.800	35.200	199.100	101.100	207.600	108.100	109.800	50.400	0.000
1998	115.700	107.700	217.800	111.900	200.700	94.700	194.000	223.400	120.700	73.300	0.000	0.000
1999	3.000	15.200	91.000	35.300	69.400	92.500	205.900	214.600	111.700	215.800	0.000	0.000
2000	0.000	0.000	6.100	122.200	75.400	57.800	150.000	133.300	55.500	57.000	90.000	118.300
2001	0.000	59.000	262.600	59.200	**80.100**	234.300	136.600	189.300	120.500	24.000	9.400	1.800
2002	49.200	38.800	143.500	82.400	105.000	182.000	93.600	249.300	167.800	0.000	0.000	48.300
2003	10.400	58.300	129.000	155.100	43.400	230.100	272.000	114.900	122.600	0.300	7.700	44.000
2004	75.400	6.100	58.500	190.400	6.900	109.100	145.300	116.100	136.100	67.200	2.100	0.200
2005	**3.000**	7.000	94.000	220.700	266.900	166.100	394.800	169.000	274.600	133.700	29.800	0.000
2006	3.000	53.400	176.100	324.800	98.900	229.200	218.800	175.400	229.100	53.300	0.400	9.900
2007	5.600	185.100	67.000	91.300	116.000	**182.000**	**93.600**	**249.300**	215.200	**0.000**	**0.000**	**48.300**
2008	**111.800**	1.700	0.000	37.100	141.400	**199.100**	145.100	197.700	88.500	65.000	76.700	0.000
2009	**75.400**	4.500	23.800	31.000	**6.900**	26.300	187.000	68.100	34.000	52.200	0.000	**0.200**
2010	0.000	71.000	53.100	**190.400**	**6.900**	141.600	68.200	140.400	71.200	23.200	8.800	4.500
2011	**115.700**	**107.700**	**217.800**	23.000	183.700	121.100	**194.000**	**223.400**	121.100	**73.300**	**0.000**	**0.000**
2012	**0.000**	**0.000**	**118.000**	**87.900**	**80.100**	**246.600**	269.600	143.900	88.000	15.800	**14.100**	3.500
2013	**149.000**	**0.000**	**314.300**	**103.900**	**212.200**	274.200	**133.000**	164.700	48.100	50.100	0.000	0.000
2014	0.000	129.400	170.000	72.700	106.000	76.800	**93.600**	440.600	161.000	13.000	5.600	0.000
2015	**75.400**	**6.100**	22.300	0.000	52.100	78.000	79.800	56.400	70.600	6.600	0.000	**0.200**
2016	7.200	5.000	9.000	57.200	61.600	52.200	63.800	34.000	21.600	6.800	4.400	**0.200**
2017	0.000	7.800	13.200	**190.400**	15.400	23.200	54.400	24.000	10.600	0.000	0.000	0.000
2018	0.000	2.600	9.800	28.700	43.000	36.800	**150.000**	**133.300**	**55.500**	**57.000**	**90.000**	**118.300**
2019	0.000	0.000	44.800	**87.900**	131.000	178.900	**269.100**	**100.900**	**108.800**	52.000	29.400	**2.700**
2020	**0.000**	8.000	138.000	176.000	138.400	165.000	357.200	276.800	136.200	42.400	6.000	0.000
2021	0.000	0.000	0.000	**122.200**	**75.400**	**57.800**	**150.000**	**133.300**	**55.500**	**57.000**	**90.000**	**118.300**

Appendix table3: fato station Meteorological station corrected monthly rainfall (mm)

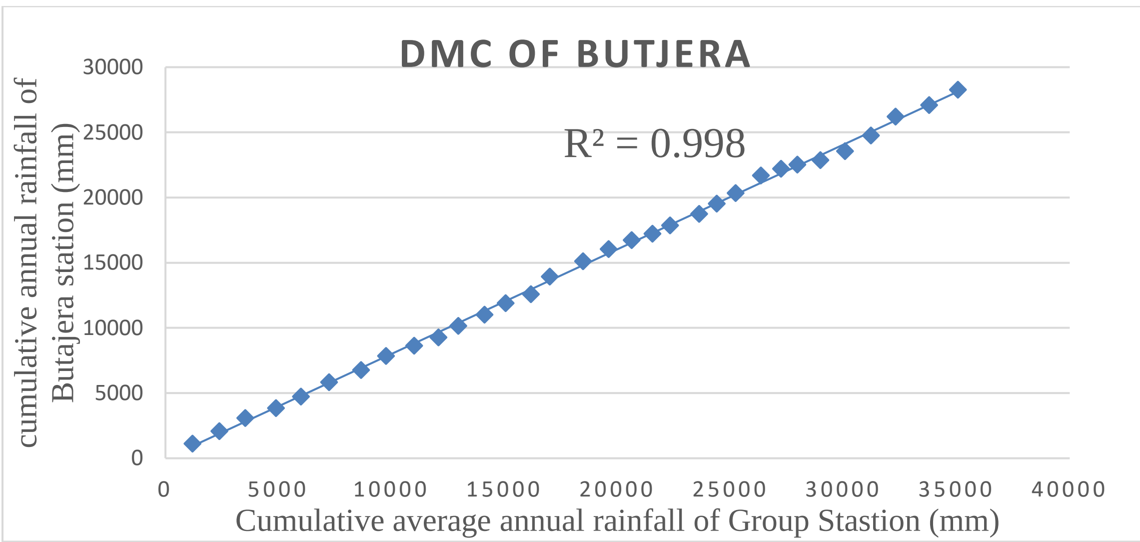
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996	**20.100**	0.000	91.800	64.300	212.400	286.600	173.100	312.100	169.600	0.000	18.100	0.000
1997	73.900	0.000	39.500	116.200	6.400	111.500	**111.300**	149.500	47.300	62.500	0.000	0.000
1998	58.200	7.000	101.800	34.100	111.000	80.800	288.700	260.700	66.500	80.800	0.000	0.000
1999	0.000	0.000	50.000	19.000	24.700	89.500	274.900	160.500	70.200	119.100	0.000	0.000
2000	0.000	0.000	12.100	65.100	58.400	72.700	**174.500**	137.100	134.100	51.300	63.400	0.000
2001	0.000	45.100	**228.500**	9.100	**79.600**	217.200	336.700	171.000	28.900	0.000	0.000	0.000
2002	15.700	0.000	32.300	49.900	36.400	12.500	**269.100**	65.000	**32.800**	0.000	0.000	21.100
2003	6.200	45.100	71.600	141.500	28.000	84.000	269.100	145.400	76.000	0.000	2.000	26.000
2004	73.300	0.000	64.500	229.700	2.400	**70.800**	111.300	151.200	92.100	20.400	0.000	0.900
2005	**20.100**	46.200	103.800	111.500	118.300	145.000	148.100	211.900	87.100	3.600	8.100	0.000
2006	8.700	104.600	**137.900**	57.700	82.100	107.600	246.900	127.500	50.400	23.700	0.000	6.200
2007	**6.100**	18.500	64.900	37.300	72.000	136.700	123.000	146.900	74.300	10.000	4.700	0.000
2008	0.000	0.000	1.800	23.200	83.500	97.100	171.800	235.900	123.000	4.500	**160.400**	0.000
2009	46.600	0.000	40.300	32.600	14.000	**50.100**	203.800	144.100	64.300	105.700	0.000	15.200
2010	0.000	69.200	**68.600**	120.400	101.800	98.300	191.000	240.400	113.900	0.000	0.000	0.000
2011	**0.000**	0.000	80.000	28.200	86.500	107.500	129.500	169.000	149.400	0.000	27.200	0.000
2012	0.000	0.000	54.200	111.800	35.300	**111.900**	301.200	**169.000**	104.000	0.000	0.000	0.000
2013	0.000	0.000	93.200	106.600	35.100	348.300	230.700	118.900	111.400	34.300	0.000	**0.000**
2014	0.000	**51.000**	**15.600**	6.500	**39.000**	0.000	163.800	311.400	106.900	60.800	0.000	0.000
2015	0.000	0.000	17.500	0.000	171.900	65.100	161.200	109.100	77.100	**0.000**	0.000	0.000
2016	12.100	0.000	10.500	269.300	103.800	104.300	312.000	**126.800**	131.800	0.000	0.000	**0.000**
2017	**0.000**	18.500	**64.000**	1.200	**118.300**	3.500	264.700	128.200	114.600	0.000	0.000	0.000
2018	0.000	0.000	88.800	112.000	60.400	92.200	124.300	**169.000**	**149.400**	0.000	10.700	0.000
2019	0.000	0.000	21.100	0.000	35.600	**143.900**	**296.000**	**190.300**	**218.600**	**0.000**	**4.200**	**7.600**
2020	0.000	0.000	**54.200**	179.400	146.900	96.200	355.200	262.100	60.300	0.000	**0.000**	**0.000**
2021	0.000	0.000	0.000	103.000	**58.400**	**72.700**	**174.500**	**137.100**	**134.100**	**51.300**	**63.400**	**0.000**

Appendix table4: Ranked Meki Meteorological station corrected monthly rain fall (mm)

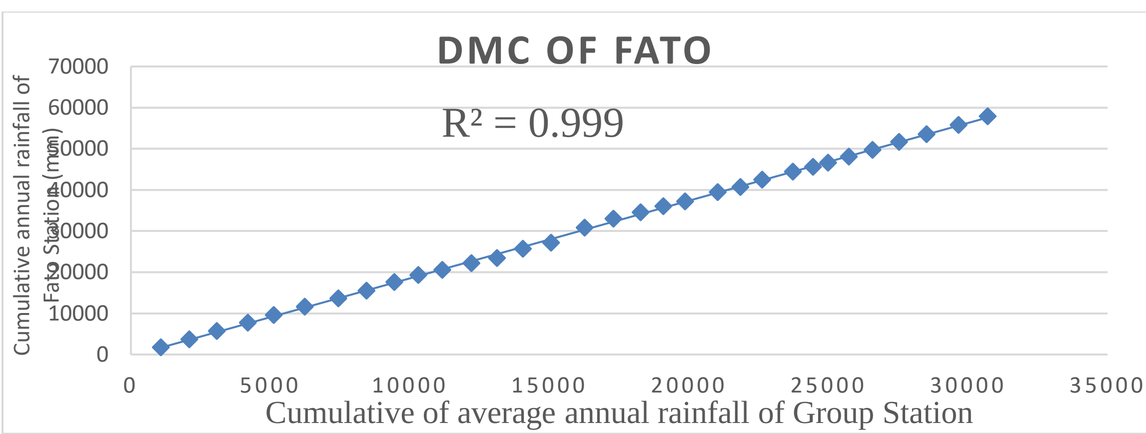
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	121.4	86.3	173.7	149.9	292.3	205.4	286.7	200.3	175.8	153.1	140.7	50.5
2	115.7	81.5	155.7	**139.7**	172.2	149.8	239.6	189.1	144.1	127.5	50.5	50.5
3	**88.8**	68.3	141.4	125.4	172.2	141.6	234.2	**171.4**	141.4	127.5	13.9	50.5
4	53.3	63.5	**105.8**	114.3	170.9	120.9	231	168.4	136.2	127.5	8	40.2
5	53.3	**63.5**	104.9	107.3	146.4	**109.6**	218.9	168.4	136.2	105.4	6.4	11.6
6	53.3	61.3	92.5	104.8	139.7	109.6	183.9	163.3	136.2	84.9	5.6	7.6
7	47.9	36	88.3	104.8	124.9	109.6	183.1	**151.7**	135.5	**76.6**	2.7	4.4
8	47.4	34.9	70.8	95.1	110.9	**108.3**	182.4	135.9	**131.6**	62.9	0	1.2
9	47.4	22.8	**65.6**	88.4	102.7	108.3	174.2	131.6	110.9	62.9	0	1.2
10	34.6	11.7	61.8	64.3	72.2	100.2	171.2	**127.2**	93.7	49.1	0	0
11	32.3	7.2	**61.6**	44.1	72.2	88.5	**171.2**	**127.2**	88.6	46.5	0	0
12	12.5	1.3	61.6	44.1	**70.6**	80	166.2	126.5	87.8	40.7	0	0
13	9.3	1.3	60.8	40.6	58	79.3	158.4	110.2	82.5	40	0	0
14	8.7	1.2	60.8	40.6	50	78.3	158.4	**110.2**	77.5	25.7	0	0
15	7.4	1.2	58.2	**40.6**	50	**76.4**	149.4	**110.2**	77.5	15.9	0	0
16	3.5	0	58.2	34.5	38.2	66.5	**124.5**	107.2	77.2	12.3	0	0
17	**3.3**	0	52	34.3	35.1	61.5	123.6	107.2	70.8	**12.3**	0	0
18	0	0	52	31.2	18.6	56	122.7	105.4	69.7	12.3	0	0
19	0	0	26	31.2	18.3	55.8	**119.6**	104.8	69	9.4	0	0
20	0	0	25.8	31.2	13.9	55.8	112.7	95.9	66.6	0.5	0	0
21	0	0	**23.5**	**20.3**	10.7	46.4	108.5	84	55.8	0	0	0
22	0	0	22.1	7.9	10.7	30.7	106.8	77.5	50.2	0	**0**	0
23	0	0	7.9	4.5	10.7	25.3	90.6	**49.9**	39.1	0	0	0
24	0	0	2.1	3.5	0.2	19.8	88.5	48.9	38.2	0	0	0
25	0	0	0	0	0	11.3	84.1	42.5	22.7	0	0	0
26	0	0	0	0	0	6.3	40.5	39.6	16.9	0	0	0



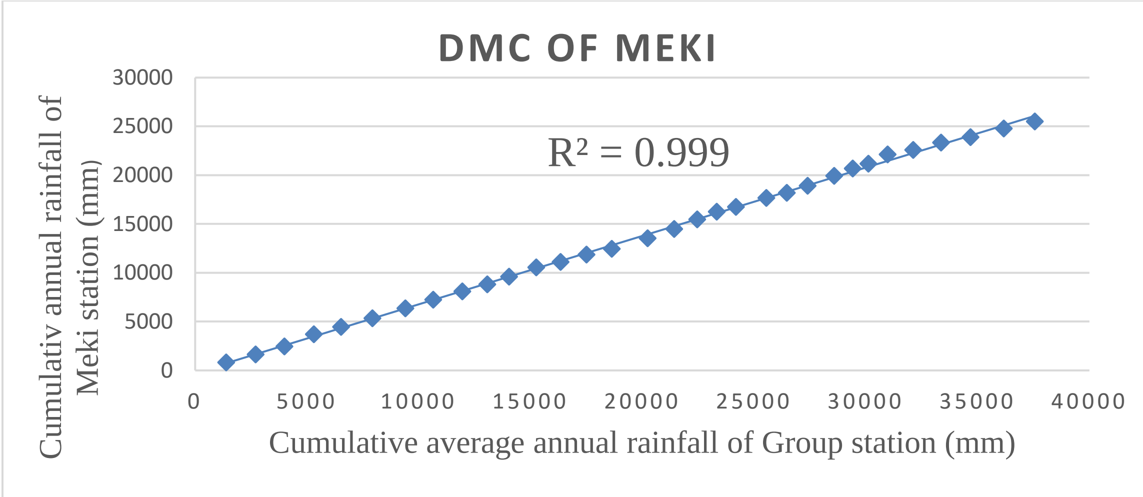
Appendix figure1: Double mass curve for Bui rain gage station



Appendix figure2: - double mass curve for Butajera rain gage station



Appendix figure3: - Double mass curve for Fato rain gage station.



Appendix figure 4: Double mass curve for Meki rain gage station

Appendix Table5: Homogeneity test on Metrological station

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Bui Av menthly RF	17.6038462	20.5961538	83.9769231	90.6807692	84.1269231	130.3307692	224.8692308	184.7615385	110.6269231	30.7038462	15.7923077	3.51153846
Average Annual RF	997.580769	997.580769	997.580769	997.580769	997.580769	997.5807692	997.5807692	997.5807692	997.5807692	997.580769	997.580769	997.580769
pi	1.76465372	2.06461015	8.41805753	9.09006790	8.43309391	13.06468341	22.54145606	18.52096032	11.08952042	3.07783060	1.58306056	0.35200543
ButaJera Monthly RF	40.7923077	33.6307692	108.476923	111.4	98.6230769	143.5307692	167.4423077	168.4269231	107.8884615	48.3769231	20.3076923	19.95
Average Annual RF	1068.84615	1068.84615	1068.84615	1068.84615	1068.84615	1068.846154	1068.846154	1068.846154	1068.846154	1068.84615	1068.84615	1068.84615
Pi	3.81648075	3.14645556	10.14897445	10.42245412	9.22706009	13.42857143	15.66570709	15.75782656	10.09391868	4.52608852	1.89996402	1.86649874
Fato AVMonthly RF	13.1153846	15.5846154	61.8653846	78.0615385	73.9307692	107.9230769	215.6307692	175.0038462	99.54230769	24.1538462	13.9307692	2.96153846
Average Annual RF	881.703846	881.703846	881.703846	881.703846	881.703846	881.7038462	881.7038462	881.7038462	881.7038462	881.703846	881.703846	881.703846
Pi	1.48750453	1.76755670	7.01657193	8.85348735	8.38498885	12.24028651	24.45614479	19.84837051	11.28976675	2.73945115	1.57998281	0.33588812
Meki Av Monthly RF	28.4653846	20.8461538	62.8115385	57.7923077	75.4461538	80.81538462	155.0346154	117.4807692	89.68076923	45.8846154	8.76153846	8.37307692
Average Annual RF	777.11875	777.11875	777.11875	777.11875	777.11875	777.11875	777.11875	777.11875	777.11875	777.11875	777.11875	777.11875
Pi	3.66293885	2.68249271	8.08261781	7.43674087	9.70844595	10.39936105	19.94992598	15.11747969	11.54016284	5.90445352	1.12743882	1.07745141

Appendix table 6 population projection of the watershed

	Population number 2016		Population number 2020		Population number 2021	
	urban growth rate 4.25	Rural growth rate 2.08	Urban growth rate 4.25	Rural growth rate 2.08	Urban growth rate 4	Rural growth rate 1.82
District	Urban	Rural	Urban	Rural	Urban	Rural
Dugda	55617.2	133940.3	68714.2	147880.9	71517	150424.4
Sodo	30117.8	182860.0	37085.5	202685.1	38576	206374.0
Meskan	29057.5	221773.9	35779.9	245818.0	37218	250291.9
Mareko	15060.0	85559.7	18544.0	94835.9	19289	96561.9

Total	129852.5	624133.8	160123.7	691219.9	166601	703652.2
Net total	753986.3		851343.6		870254.1	

Appendix B: SWAT output sample

Appendix table7: HRU land use/soil/slop repot

SWAT model simulation Date: 10/30/2022 12:00:00 AM Time: 00:00:00

MULTIPLE HRUs Land Use/Soil/Slope OPTION THRESHOLDS: 10 / 10 / 10 [%]

Number of HRUs: 281

Number of Subbasins: 33

	Area [ha]	Area[acres]
Watershed	179799.7102	444294.0739

	Area [ha]	Area[acres]	%Wat. Area
LANDUSE:			
Forest-Evergreen --> FRSE	25990.7405	64224.4194	14.46
Barren --> BARR	1119.9515	2767.4563	0.62
Range-Brush --> RNGB	1185.0014	2928.1977	0.66
Agricultural Land-Generic --> AGRL	127618.0524	315350.5885	70.98
Residential-High Density --> URHD	19168.9153	47367.3482	10.66
Wetlands-Mixed --> WETL	3609.4326	8919.0885	2.01
Pasture --> PAST	1107.6163	2736.9753	0.62
SOILS:			
Chromic Luvisols	28124.0905	69496.0338	15.64
Eutric Vertisols	37357.6636	92312.6547	20.78
Lithic Leptosols	18033.6259	44561.9913	10.03
Eutric Cambisols	69011.9986	170532.0991	38.38
Vertic Cambisols	3303.1023	8162.1308	1.84
Luvic Phaeozems	13198.2855	32613.6233	7.34
Vitric Andosols	3181.2606	7861.0540	1.77
Fibric Histosols	7589.6832	18754.4868	4.22
SLOPE:			
16-32	46871.8677	115822.7288	26.07
8-16	61557.6678	152112.0749	34.24
32-9999	20533.9815	50740.4951	11.42
0-8	50836.1932	125618.7751	28.27

	Area [ha]	Area[acres]	%Wat. Area	%Sub. Area

SUBBASIN # 1 7160.0211 17692.7701 3.98

LANDUSE:

Forest-Evergreen --> FRSE 6040.1375 14925.4818 3.36 84.36

Barren --> BARR 1119.9515 2767.4563 0.62 15.64

SOILS:

Chromic Luvisols 1772.8811 4380.8780 0.99 24.76

Eutric Vertisols 1468.6508 3629.1096 0.82 20.51

Lithic Leptosols 3918.5571 9682.9505 2.18 54.73

SLOPE:

16-32 2685.1364 6635.1062 1.49 37.50

8-16 1383.6536 3419.0773 0.77 19.32

32-9999 2452.6701 6060.6704 1.36 34.26

0-8 638.6290 1578.0842 0.36 8.92

HRUs

1 Forest-Evergreen --> FRSE/Chromic Luvisols/16-32 292.7608 723.4267 0.16 4.09 1

2 Forest-Evergreen --> FRSE/Chromic Luvisols/8-16 110.0197 271.8643 0.06 1.54 2

3 Forest-Evergreen --> FRSE/Chromic Luvisols/32-9999 250.1490 618.1308 0.14 3.49 3

4 Forest-Evergreen --> FRSE/Eutric Vertisols/16-32 445.2772 1100.3023 0.25 6.22 4

5 Forest-Evergreen --> FRSE/Eutric Vertisols/0-8 232.5315 574.5969 0.13 3.25 5

6 Forest-Evergreen --> FRSE/Eutric Vertisols/32-9999 449.2931 1110.2258 0.25 6.28 6

7 Forest-Evergreen --> FRSE/Eutric Vertisols/8-16 341.5490 843.9846 0.19 4.77 7

8 Forest-Evergreen --> FRSE/Lithic Leptosols/32-9999 1055.3051 2607.7116 0.59 14.74 8

9 Forest-Evergreen --> FRSE/Lithic Leptosols/8-16 932.0849 2303.2284 0.52 13.02 9

10 Forest-Evergreen --> FRSE/Lithic Leptosols/16-32 1525.0696 3768.5232 0.85 21.30 10

11 Forest-Evergreen --> FRSE/Lithic Leptosols/0-8 406.0975 1003.4873 0.23 5.67 11

12 Barren --> BARR/Chromic Luvisols/32-9999 697.9228 1724.6022 0.39 9.75 12

13 Barren --> BARR/Chromic Luvisols/16-32 422.0287 1042.8540 0.23 5.89 13

	Area [ha]	Area[acres]	%Wat. Area	%Sub. Area

SUBBASIN # 2 8384.0763 20717.4717 4.66

LANDUSE:

Forest-Evergreen --> FRSE 8384.1559 20717.6684 4.66 100.00

SOILS:

Eutric Vertisols 5755.5183 14222.1735 3.20 68.65

Lithic Leptosols 2628.6376 6495.4949 1.46 31.35

SLOPE:

16-32	2862.8088	7074.1438	1.59	34.15
0-8	1502.4813	3712.7065	0.84	17.92
32-9999	1464.1240	3617.9235	0.81	17.46
8-16	2554.7418	6312.8947	1.42	30.47

HRUs

14	Forest-Evergreen --> FRSE/Eutric Vertisols/16-32	1756.8883	4341.3589	0.98	20.96	1
15	Forest-Evergreen --> FRSE/Eutric Vertisols/0-8	1199.1460	2963.1498	0.67	14.30	2
16	Forest-Evergreen --> FRSE/Eutric Vertisols/32-9999	929.6377	2297.1812	0.52	11.09	3
17	Forest-Evergreen --> FRSE/Eutric Vertisols/8-16	1869.8463	4620.4836	1.04	22.30	4
18	Forest-Evergreen --> FRSE/Lithic Leptosols/32-9999	534.4863	1320.7423	0.30	6.38	5
19	Forest-Evergreen --> FRSE/Lithic Leptosols/0-8	303.3353	749.5567	0.17	3.62	6
20	Forest-Evergreen --> FRSE/Lithic Leptosols/16-32	1105.9205	2732.7848	0.62	13.19	7
21	Forest-Evergreen --> FRSE/Lithic Leptosols/8-16	684.8955	1692.4110	0.38	8.17	8

		Area [ha]	Area[acres]	%Wat. Area	%Sub. Area
SUBBASIN #	3	8852.9623	21876.1124	4.92	

LANDUSE:

Range-Brush --> RNGB	1185.0014	2928.1977	0.66	13.39
Forest-Evergreen --> FRSE	1647.1801	4070.2645	0.92	18.61
Agricultural Land-Generic --> AGRL	1418.5212	3505.2369	0.79	16.02
Residential-High Density --> URHD	4602.3436	11372.6211	2.56	51.99

SOILS:

Chromic Luvisols	5039.2981	12452.3577	2.80	56.92
Lithic Leptosols	1711.6302	4229.5238	0.95	19.33
Eutric Cambisols	725.8019	1793.4928	0.40	8.20
Eutric Vertisols	1376.3161	3400.9459	0.77	15.55

SLOPE:

0-8	653.5736	1615.0131	0.36	7.38
8-16	1839.6181	4545.7883	1.02	20.78
32-9999	3270.0145	8080.3695	1.82	36.94
16-32	3089.8401	7635.1494	1.72	34.90

HRUs

22	Range-Brush --> RNGB/Chromic Luvisols/0-8	81.1778	200.5944	0.05	0.92	1
23	Range-Brush --> RNGB/Chromic Luvisols/8-16	197.8405	488.8738	0.11	2.23	2
24	Range-Brush --> RNGB/Chromic Luvisols/32-9999	184.6187	456.2021	0.10	2.09	3
25	Range-Brush --> RNGB/Chromic Luvisols/16-32	320.7252	792.5280	0.18	3.62	4

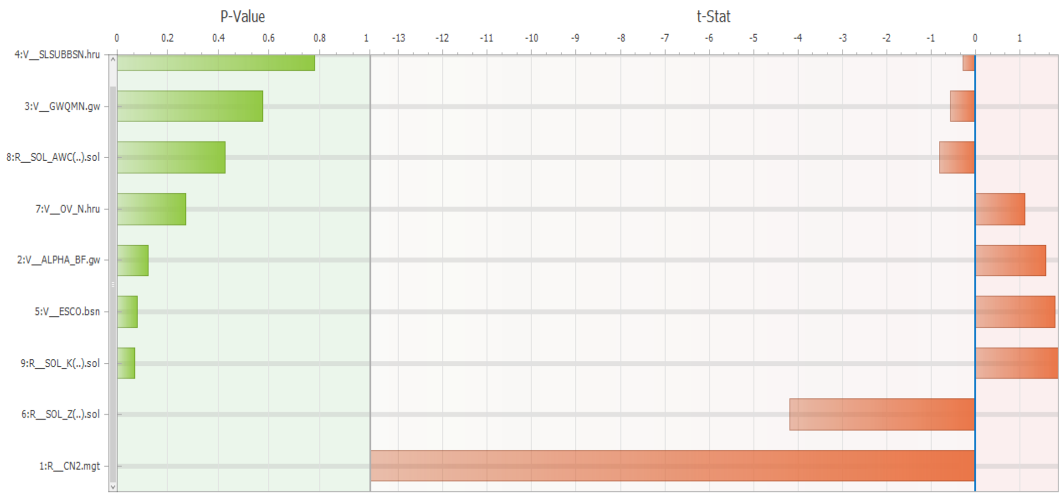
26	Range-Brush --> RNGB/Lithic Leptosols/32-9999	55.9009	138.1339	0.03	0.63	5
27	Range-Brush --> RNGB/Lithic Leptosols/8-16	124.6347	307.9785	0.07	1.41	6
28	Range-Brush --> RNGB/Lithic Leptosols/16-32	160.5084	396.6244	0.09	1.81	7
29	Range-Brush --> RNGB/Lithic Leptosols/0-8	59.5952	147.2627	0.03	0.67	8
30	Forest-Evergreen --> FRSE/Chromic Luvisols/8-16	55.3025	136.6552	0.03	0.62	9
31	Forest-Evergreen --> FRSE/Chromic Luvisols/32-9999	168.1987	415.6274	0.09	1.90	10
32	Forest-Evergreen --> FRSE/Chromic Luvisols/16-32	112.6879	278.4575	0.06	1.27	11
33	Forest-Evergreen --> FRSE/Lithic Leptosols/32-9999	359.7077	888.8557	0.20	4.06	12
34	Forest-Evergreen --> FRSE/Lithic Leptosols/8-16	320.8678	792.8805	0.18	3.62	13
35	Forest-Evergreen --> FRSE/Lithic Leptosols/16-32	483.6439	1195.1082	0.27	5.46	14
36	Forest-Evergreen --> FRSE/Lithic Leptosols/0-8	146.7717	362.6801	0.08	1.66	15
37	Agricultural Land-Generic --> AGRL/Eutric Cambisols/0-8	212.9160	526.1262	0.12	2.41	16
38	Agricultural Land-Generic --> AGRL/Eutric Cambisols/32-9999	75.8142	187.3407	0.04	0.86	17
39	Agricultural Land-Generic --> AGRL/Eutric Cambisols/16-32	185.1352	457.4782	0.10	2.09	18
40	Agricultural Land-Generic --> AGRL/Eutric Cambisols/8-16	251.9365	622.5477	0.14	2.85	19
41	Agricultural Land-Generic --> AGRL/Eutric Vertisols/8-16	232.4263	574.3369	0.13	2.63	20
42	Agricultural Land-Generic --> AGRL/Eutric Vertisols/0-8	153.1129	378.3497	0.09	1.73	21
43	Agricultural Land-Generic --> AGRL/Eutric Vertisols/16-32	199.1316	492.0642	0.11	2.25	22
44	Agricultural Land-Generic --> AGRL/Eutric Vertisols/32-9999	108.0485	266.9933	0.06	1.22	23
45	Residential-High Density --> URHD/Chromic Luvisols/8-16	521.5705	1288.8268	0.29	5.89	24
46	Residential-High Density --> URHD/Chromic Luvisols/16-32	1349.4228	3334.4913	0.75	15.24	25
47	Residential-High Density --> URHD/Chromic Luvisols/32-9999	2047.7535	5060.1012	1.14	23.13	26
48	Residential-High Density --> URHD/Eutric Vertisols/8-16	135.0393	333.6890	0.08	1.53	27
49	Residential-High Density --> URHD/Eutric Vertisols/32-9999	269.9723	667.1152	0.15	3.05	28
50	Residential-High Density --> URHD/Eutric Vertisols/16-32	278.5851	688.3977	0.15	3.15	29

		Area [ha]	Area[acres]	%Wat. Area	%Sub. Area
SUBBASIN #	4	4818.9111	11907.7703	2.68	
LANDUSE:					
	Forest-Evergreen --> FRSE	1850.6138	4572.9591	1.03	38.40
	Agricultural Land-Generic --> AGRL	1431.9040	3538.3063	0.80	29.71
	Residential-High Density --> URHD	1536.4391	3796.6179	0.85	31.88
SOILS:					
	Eutric Vertisols	4621.7440	11420.5605	2.57	95.91
	Lithic Leptosols	197.2129	487.3229	0.11	4.09
SLOPE:					
	32-9999	867.2438	2143.0028	0.48	18.00
	8-16	1451.6257	3587.0397	0.81	30.12
	0-8	897.9438	2218.8639	0.50	18.63
	16-32	1602.1436	3958.9770	0.89	33.25

HRUs

51Forest-Evergreen --> FRSE/Eutric Vertisols/32-9999	230.3655	569.2448	0.13	4.78	1
52 Forest-Evergreen --> FRSE/Eutric Vertisols/8-16	605.5654	1496.3824	0.34	12.57	2
53 Forest-Evergreen --> FRSE/Eutric Vertisols/0-8	388.5773	960.1939	0.22	8.06	3
54 Forest-Evergreen --> FRSE/Eutric Vertisols/16-32	626.1055	1547.1381	0.35	12.99	4
55 Agricultural Land-Generic --> AGRL/Eutric Vertisols/16-32	392.9485	970.9954	0.22	8.15	5
56 Agricultural Land-Generic --> AGRL/Eutric Vertisols/8-16	570.8273	1410.5427	0.32	11.85	6
57 Agricultural Land-Generic --> AGRL/Eutric Vertisols/0-8	468.1282	1156.7682	0.26	9.71	7
58 Residential-High Density --> URHD/Eutric Vertisols/8-16	198.8117	491.2737	0.11	4.13	8
59 Residential-High Density --> URHD/Eutric Vertisols/16-32	503.5363	1244.2633	0.28	10.45	9
60 Residential-High Density --> URHD/Eutric Vertisols/32-9999	636.8783	1573.7580	0.35	13.22	10
61 Residential-High Density --> URHD/Lithic Leptosols/8-16	76.4213	188.8408	0.04	1.59	11
62 Residential-High Density --> URHD/Lithic Leptosols/16-32	79.5533	196.5802	0.04	1.65	12
63 Residential-High Density --> URHD/Lithic Leptosols/0-8	41.2383	101.9018	0.02	0.86	13

Appendix C: SWAT-CUP out



Appendix figure5: Graphical view of sensitive parameters generated from SWAT-CUP

Appendix D: CROPWAT8 out put

Appendix table 8: ETo and climate data Meki metrological data for CROPWAT8

Monthly ETo Penman-Monteith - C:\ProgramData\CROPWAT\data\climate\MEKI CWR.PEM

Country ETHIOPIA Station Meki

Altitude 1662 m. Latitude 8.15 °N Longitude 38.81 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	7.9	26.0	55	37	8.0	19.6	3.29
February	8.9	27.3	53	40	8.3	21.2	3.71
March	10.5	27.9	53	42	7.9	21.5	3.97
April	11.2	27.7	56	43	7.9	21.7	4.06
May	10.9	27.8	55	41	7.9	21.1	3.96
June	10.3	26.6	62	42	7.4	19.9	3.72
July	10.0	24.0	68	40	6.9	19.3	3.46
August	10.2	24.2	74	37	5.0	16.9	3.12
September	9.8	25.2	78	33	4.7	16.5	3.09
October	8.4	25.7	70	32	5.5	17.1	3.14
November	7.4	25.7	60	33	6.6	17.7	3.10
December	6.8	25.5	57	34	7.9	18.9	3.13
Average	**9.4**	**26.1**	**62**	**38**	**7.0**	**19.3**	**3.48**

Appendix table 9: Rain fall and effective rain fall

Monthly rain - untitled

Station Meki Station Eff. rain method Fixed percentage

	Rain	Eff rain
	mm	mm
January	0.0	0.0
February	0.0	0.0
March	52.0	41.6
April	31.2	25.0
May	18.6	14.9
June	56.0	44.8
July	122.7	98.2
August	105.4	84.3
September	69.7	55.8
October	12.3	9.8
November	0.0	0.0
December	0.0	0.0
Total	**467.9**	**374.3**

Appendix table 10: CWR and IWR for tomato

Planting date: October 01/2021

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Oct	1	Init	0.6	1.88	11.3	8.1	4.5
Oct	2	Init	0.6	1.89	18.9	5	13.9
Oct	3	Init	0.6	1.88	20.7	4.7	15.9
Nov	1	Deve	0.64	1.99	19.9	5.4	14.5
Nov	2	Deve	0.77	2.39	23.9	4.2	19.7
Nov	3	Deve	0.91	2.82	28.2	3.2	25
Dec	1	Deve	1.04	3.26	32.6	1.6	30.9
Dec	2	Mid	1.14	3.58	35.8	0.3	35.4
Dec	3	Mid	1.15	3.65	40.1	1.9	38.3
Jan	1	Mid	1.15	3.71	37.1	3.5	33.6
Jan	2	Mid	1.15	3.77	37.7	4.6	33.1
Jan	3	Late	1.13	3.89	42.8	6.9	35.9
Feb	1	Late	1.03	3.69	36.9	8.9	28
Feb	2	Late	0.92	3.41	34.1	10.9	23.2
Feb	3	Late	0.82	3.13	18.8	11.1	11.4
					438.6	80.3	363.2

Appendix table11: CWR and IWR for cabbage

Planting date: October 01/2021

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Oct	1	Init	0.7	2.19	13.1	8.1	6.4
Oct	2	Init	0.7	2.2	22	5	17
Oct	3	Init	0.7	2.19	24.1	4.7	19.4
Nov	1	Init	0.7	2.18	21.8	5.4	16.4
Nov	2	Deve	0.72	2.22	22.2	4.2	18
Nov	3	Deve	0.77	2.4	24	3.2	20.8
Dec	1	Deve	0.83	2.59	25.9	1.6	24.3
Dec	2	Deve	0.89	2.78	27.8	0.3	27.5
Dec	3	Deve	0.95	3.02	33.2	1.9	31.3
Jan	1	Deve	1.01	3.26	32.6	3.5	29.1
Jan	2	Mid	1.04	3.44	34.4	4.6	29.8
Jan	3	Mid	1.05	3.59	39.4	6.9	32.5
Feb	1	Mid	1.05	3.73	37.3	8.9	28.4
Feb	2	Mid	1.05	3.88	38.8	10.9	27.9
Feb	3	Mid	1.05	3.97	31.8	14.7	17
Mar	1	Late	1.03	3.98	39.8	19.5	20.4
Mar	2	Late	0.97	3.83	30.7	18.8	7.2
					499	122.3	373.4

Appendix table 12: - CRW and IWR maze

Planting date: October 1/2021

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Oct	1	Init	0.3	0.94	5.6	8.1	0
Oct	2	Init	0.3	0.94	9.4	5	4.4
Oct	3	Deve	0.37	1.14	12.6	4.7	7.8
Nov	1	Deve	0.62	1.93	19.3	5.4	13.9
Nov	2	Deve	0.87	2.71	27.1	4.2	22.9
Nov	3	Mid	1.12	3.49	34.9	3.2	31.7
Dec	1	Mid	1.19	3.73	37.3	1.6	35.7
Dec	2	Mid	1.19	3.74	37.4	0.3	37.1
Dec	3	Mid	1.19	3.8	41.9	1.9	40
Jan	1	Late	1.18	3.81	38.1	3.5	34.6
Jan	2	Late	0.96	3.14	31.4	4.6	26.8
Jan	3	Late	0.66	2.26	24.9	6.9	18
Feb	1	Late	0.42	1.5	9	5.3	4.5
					329	54.8	277.5

Appendix table13: - CWR and IWR onion

Plant date October 04/2021

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Oct	1	Init	0.7	2.19	13.1	8.1	6.4
Oct	2	Deve	0.7	2.2	22	5	17.1
Oct	3	Deve	0.78	2.45	26.9	4.7	22.2
Nov	1	Deve	0.91	2.82	28.2	5.4	22.9
Nov	2	Mid	0.99	3.08	30.8	4.2	26.5
Nov	3	Mid	1	3.1	31	3.2	27.7
Dec	1	Mid	1	3.11	31.1	1.6	29.5
Dec	2	Mid	1	3.12	31.2	0.3	30.9
Dec	3	Mid	1	3.17	34.9	1.9	33
Jan	1	Mid	1	3.22	32.2	3.5	28.7
Jan	2	Mid	1	3.27	32.7	4.6	28.1
Jan	3	Late	1	3.41	37.6	6.9	30.6
Feb	1	Late	1	3.55	35.5	8.9	26.6
Feb	2	Late	0.99	3.69	36.9	10.9	26
Feb	3	Late	0.99	3.78	30.2	14.7	15.5
Mar	1	Late	0.99	3.86	11.6	5.8	1.9
					466	89.9	373.6

Appendix table14: CWR and IWR for potato

Plating date: October 01/2021

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Oct	1	Init	0.5	1.56	9.4	8.1	2.7
Oct	2	Init	0.5	1.57	15.7	5	10.7
Oct	3	Deve	0.51	1.58	17.4	4.7	12.7
Nov	1	Deve	0.66	2.06	20.6	5.4	15.2
Nov	2	Deve	0.88	2.72	27.2	4.2	23
Nov	3	Mid	1.09	3.38	33.8	3.2	30.6
Dec	1	Mid	1.15	3.58	35.8	1.6	34.2
Dec	2	Mid	1.15	3.59	35.9	0.3	35.6
Dec	3	Mid	1.15	3.65	40.2	1.9	38.3
Jan	1	Mid	1.15	3.71	37.1	3.5	33.6
Jan	2	Late	1.1	3.61	36.1	4.6	31.5
Jan	3	Late	0.96	3.29	36.2	6.9	29.3
Feb	1	Late	0.82	2.92	29.2	8.9	20.3
Feb	2	Late	0.74	2.76	2.8	1.1	2.8
					377.3	59.5	320.3

Appendix table 14: CWR and IWR for pepper

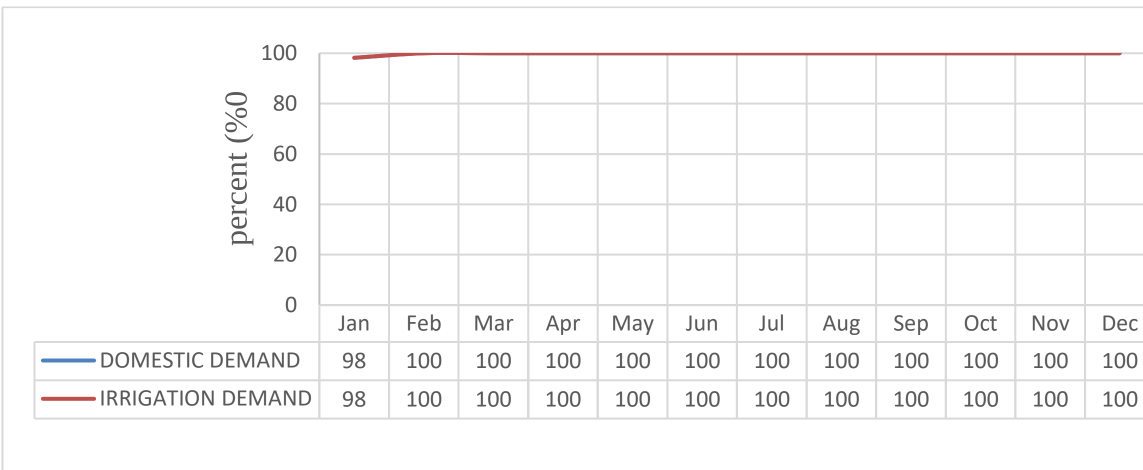
Plating date: October 01/2021

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Oct	1	Init	0.6	1.88	11.3	8.1	4.5
Oct	2	Init	0.6	1.89	18.9	5	13.9
Oct	3	Init	0.6	1.88	20.7	4.7	15.9
Nov	1	Deve	0.64	1.98	19.8	5.4	14.4
Nov	2	Deve	0.76	2.35	23.5	4.2	19.3
Nov	3	Deve	0.89	2.76	27.6	3.2	24.4
Dec	1	Mid	1.01	3.15	31.5	1.6	29.9
Dec	2	Mid	1.05	3.28	32.8	0.3	32.4
Dec	3	Mid	1.05	3.33	36.6	1.9	34.8
Jan	1	Mid	1.05	3.38	33.8	3.5	30.4
Jan	2	Late	1.04	3.42	34.2	4.6	29.6
Jan	3	Late	0.98	3.35	36.9	6.9	30
Feb	1	Late	0.91	3.26	19.6	5.3	15.1
					347.1	54.8	294.6

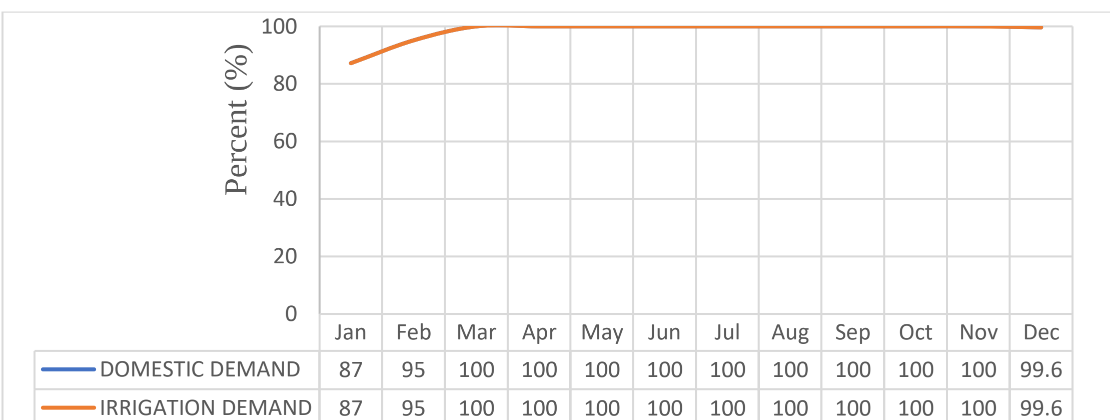
Appendix table16: Crop water requirement, irrigation schedules and annual water share for WEAP model input.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
ETo	3.29	3.71	3.97	4.06	3.96	3.72	3.46	3.12	3.09	3.14	3.1	3.13
Peff	0	0	40.5	42.6	49.2	91.4	168.8	124.9	68.4	7.4	0	0
1. Tomato	116	117.6	63.5	0	0	0	0	0	0	0	54	78.6
2. MAIZE (Grain)	87.1	4.1	0	0	0	0	0	0	0	25.1	87.5	116.6
3. CABBAGE Crucifers	93.6	107	87.7	39.2	0	0	0	0	0	0	63	72.2
4. Potato	106.5	22.6	0	0	0	0	0	0	0	40.5	86.7	111.9
5. Peppers	103.7	9.7	0	0	0	0	0	0	0	48.8	74.3	101.7
6. Onion	102.5	102.6	81.5	0	0	0	0	0	0	0	66.9	95.1
Net scheme irr.req.												
in mm/day	3.3	3.1	1.8	0.2	0	0	0	0	0	0.3	2.1	2.8
in mm/month	103.5	86.4	55.6	6.3	0	0	0	0	0	8.9	64.1	87.1
in l/s/h	0.39	0.36	0.21	0.02	0	0	0	0	0	0.03	0.25	0.33
Irrigated area	98	98	75	16	0	0	0	0	0	23	98	98
(% of total area)												
Irr.req. for actual area	0.39	0.36	0.28	0.15	0	0	0	0	0	0.14	0.25	0.33
(l/s/h)												
Total area (ha) 615	602.7	602.7	461.25	98.4	0	0	0	0	0	141.45	602.7	602.7
Annual shear %	20.53	18.95	14.74	7.89	0.00	0.00	0.00	0.00	0.00	7.37	13.16	17.37
m3/y/ha	12299.04	11352.96	8830.08	4730.40	0.00	0.00	0.00	0.00	0.00	4415.04	7884.00	10406.88
MCM	7.56	6.84	4.07	0.47	0.00	0.00	0.00	0.00	0.00	0.62	4.75	6.27

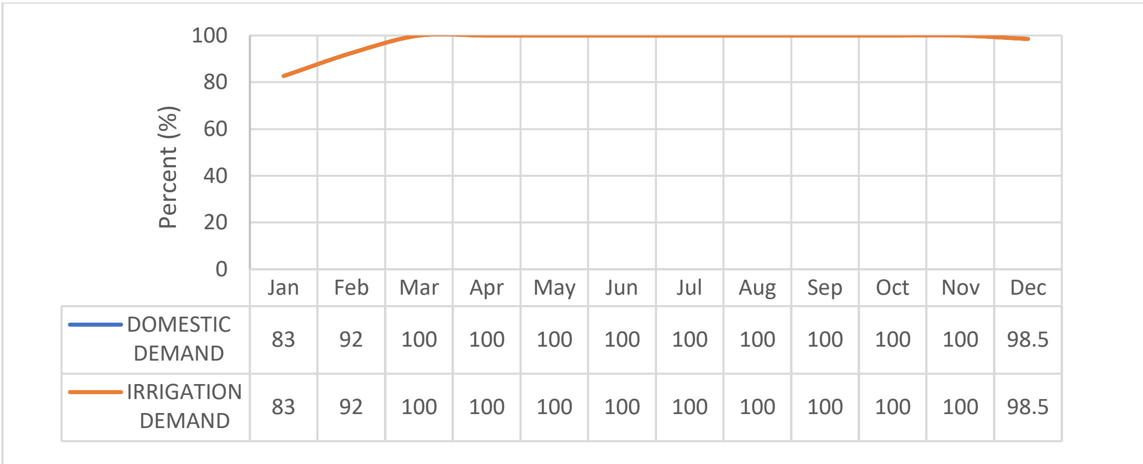
Appendix C: WEAP out pout figure



Appendix figure16 water coverage under high population growth scenario (2022-2051)



Appendix figure17 water coverage under increase irrigation command area scenario

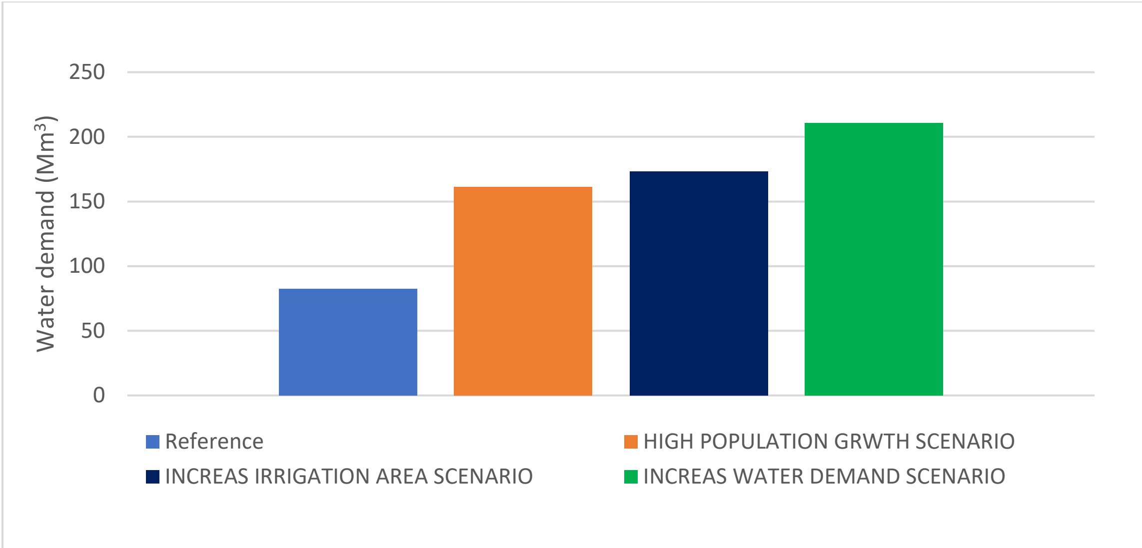


Appendix figure18: water coverage under increase domestic water demand scenario

Appendix table 17: Water demand of the demand site for each scenario (2021-2051)

	Reference scenario (Mm^3)			High population scenario (Mm^3)			Increase irrigation area scenario Mm^3)			Increase domestic water demand scenario (Mm^3)		
Year	Domestic Demand	Irrigation Demand	Sum	Domestic Demand	Irrigation Demand	Sum	Domestic Demand	Irrigation Demand	Sum	Domestic Demand	Irrigation Demand	Sum
2021	31.764	7.556	39.321	31.764	7.556	39.321	31.764	7.556	39.321	31.764	7.556	39.321
2022	32.685	7.556	40.242	33.480	7.556	41.036	32.685	8.231	40.916	49.019	8.231	57.250
2023	33.633	7.556	41.190	35.287	7.556	42.844	33.633	8.966	42.599	50.441	8.966	59.407
2024	34.609	7.556	42.165	37.193	7.556	44.749	34.609	9.767	44.375	51.904	9.767	61.670
2025	35.612	7.556	43.169	39.201	7.556	46.758	35.612	10.639	46.251	53.409	10.639	64.047
2026	36.645	7.556	44.201	41.318	7.556	48.875	36.645	11.589	48.234	54.958	11.589	66.546
2027	37.708	7.556	45.264	43.549	7.556	51.106	37.708	12.623	50.331	56.551	12.623	69.175
2028	38.801	7.556	46.358	45.901	7.556	53.457	38.801	13.750	52.552	58.191	13.750	71.942
2029	39.927	7.556	47.483	48.380	7.556	55.936	39.927	14.978	54.905	59.879	14.978	74.857
2030	41.084	7.556	48.641	50.992	7.556	58.549	41.084	16.316	57.400	61.615	16.316	77.931

2031	42.276	7.556	49.832	53.746	7.556	61.302	42.276	17.772	60.048	63.402	17.772	81.175
2032	43.502	7.556	51.058	56.648	7.556	64.204	43.502	19.359	62.861	65.241	19.359	84.600
2033	44.763	7.556	52.320	59.707	7.556	67.263	44.763	21.088	65.851	67.133	21.088	88.221
2034	46.062	7.556	53.618	62.931	7.556	70.488	46.062	22.971	69.032	69.080	22.971	92.051
2035	47.397	7.556	54.954	66.330	7.556	73.886	47.397	25.022	72.419	71.083	25.022	96.105
2036	48.772	7.556	56.328	69.911	7.556	77.468	48.772	27.256	76.028	73.144	27.256	100.401
2037	50.186	7.556	57.743	73.687	7.556	81.243	50.186	29.690	79.876	75.266	29.690	104.955
2038	51.642	7.556	59.198	77.666	7.556	85.222	51.642	32.341	83.982	77.448	32.341	109.789
2039	53.139	7.556	60.696	81.860	7.556	89.416	53.139	35.228	88.368	79.694	35.228	114.923
2040	54.680	7.556	62.237	86.280	7.556	93.836	54.680	38.374	93.054	82.005	38.374	120.380
2041	56.266	7.556	63.822	90.939	7.556	98.496	56.266	41.800	98.066	84.384	41.800	126.184
2042	57.898	7.556	65.454	95.850	7.556	103.406	57.898	45.533	103.431	86.831	45.533	132.364
2043	59.577	7.556	67.133	101.026	7.556	108.582	59.577	49.598	109.175	89.349	49.598	138.947
2044	61.305	7.556	68.861	106.481	7.556	114.038	61.305	54.027	115.332	91.940	54.027	145.967
2045	63.082	7.556	70.639	112.231	7.556	119.788	63.082	58.851	121.933	94.606	58.851	153.457
2046	64.912	7.556	72.468	118.292	7.556	125.848	64.912	64.106	129.018	97.350	64.106	161.456
2047	66.794	7.556	74.351	124.679	7.556	132.236	66.794	69.830	136.624	100.173	69.830	170.003
2048	68.731	7.556	76.288	131.412	7.556	138.968	68.731	76.065	144.796	103.078	76.065	179.143
2049	70.724	7.556	78.281	138.508	7.556	146.065	70.724	82.857	153.581	106.067	82.857	188.924
2050	72.775	7.556	80.332	145.988	7.556	153.544	72.775	90.255	163.031	109.143	90.255	199.398
2051	74.886	7.556	82.442	153.871	7.556	161.427	74.886	98.314	173.200	112.308	98.314	210.622
Total	1796.085			2649.356			2676.592			3441.21		

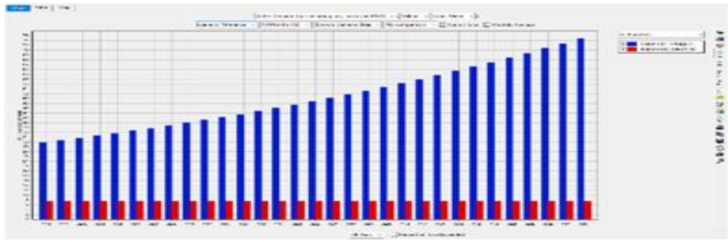


Appendix figure19 Comparison of total water demand in 2051 scenario

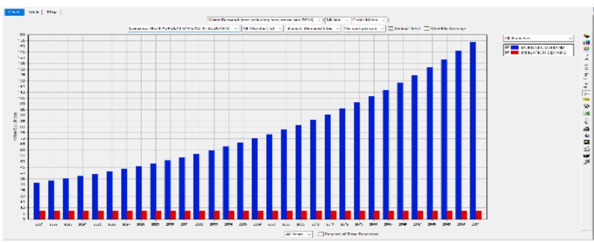
Appendix table18: Unmet water demand of the demand site for each scenario (2021-2051)

	Reference scenario			High population scenario			Increase irrigation area scenario			Increase domestic water demand s		
year	DOMESTIC I	IRRIGATION	Sum	DOMESTIC I	IRRIGATION	Sum	DOMESTIC	IRRIGATION	Sum	DOMESTIC	IRRIGATION	Sum
2021	0	0	0	0	0	0	0	0	0	0	0	0
2022	0	0	0	0	0	0	0	0	0	0	0	0
2023	0	0	0	0	0	0	0	0	0	0	0	0
2024	0	0	0	0	0	0	0	0	0	0	0	0
2025	0	0	0	0	0	0	0	0	0	0	0	0
2026	0	0	0	0	0	0	0	0	0	0	0	0
2027	0	0	0	0	0	0	0	0	0	0	0	0
2028	0	0	0	0	0	0	0	0	0	0	0	0
2029	0	0	0	0	0	0	0	0	0	0	0	0
2030	0	0	0	0	0	0	0	0	0	0	0	0
2031	0	0	0	0	0	0	0	0	0	0	0	0
2032	0	0	0	0	0	0	0	0	0	0	0	0
2033	0	0	0	0	0	0	0	0	0	0	0	0
2034	0	0	0	0	0	0	0	0	0	0	0	0
2035	0	0	0	0	0	0	0	0	0	0	0	0
2036	0	0	0	0	0	0	0	0	0	0.0024251	0.00218895	0.004614
2037	0	0	0	0	0	0	0	0	0	0.359047	0.342138	0.701186
2038	0	0	0	0	0	0	0	0	0	0.712188	0.718411	1.430599
2039	0	0	0	0	0	0	0	0	0	1.070664	1.143298	2.213962
2040	0	0	0	0	0	0	0.267027	0.454013	0.72104	1.423357	1.61338	3.036737
2041	0	0	0	0	0	0	0.562272	1.009254	1.571526	1.803168	2.157738	3.960906
2042	0	0	0	0	0	0	0.85376	1.62225	2.476009	2.19252	2.777781	4.970301
2043	0	0	0	0	0	0	1.144054	2.308845	3.452899	2.977038	4.00383	6.980868
2044	0	0	0	0	0	0	1.431561	3.062631	4.494192	3.642573	5.170178	8.81275
2045	0	0	0	0	0	0	1.953444	4.428185	6.381629	4.57157	6.908496	11.48007
2046	0	0	0	0	0	0	2.571625	6.178184	8.749809	5.381188	8.614912	13.9961
2047	0	0	0	0.311323	0.0435847	0.35491	3.190987	8.120629	11.31162	6.198837	10.511213	16.71005
2048	0	0	0	0.788042	0.108188	0.89623	3.728424	9.968531	13.69696	7.188083	12.722995	19.91108
2049	0	0	0	1.352828	0.176592	1.52942	4.431069	12.653608	17.08468	8.642422	16.199575	24.842
2050	0	0	0	1.925559	0.239102	2.16466	5.193115	15.6416	20.83471	10.030266	19.776761	29.80703
2051	0	0	0	2.535291	0.298915	2.83421	6.242736	19.694404	25.93714	11.427935	23.741715	35.16965

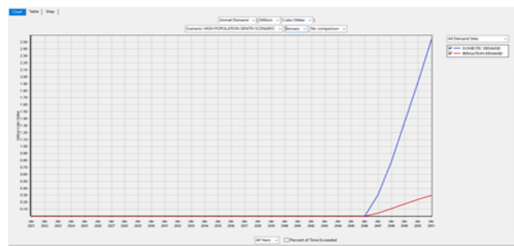
The out pout of WEAP model chart font size is not clear for reading; that is why show the result of WEAP using excel in the main topic. However, some sample result of WEAP model as followed.



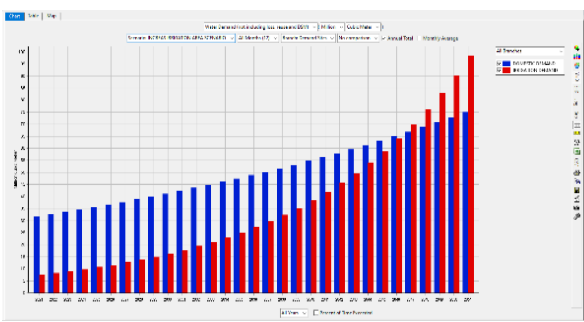
Reference scenario



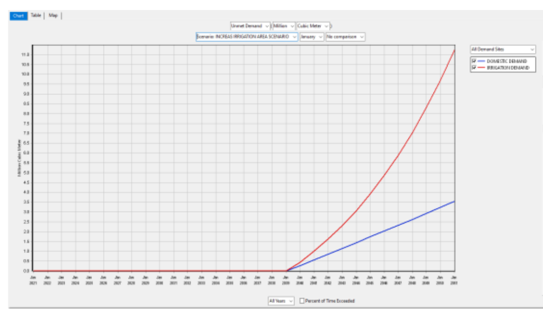
High population scenario



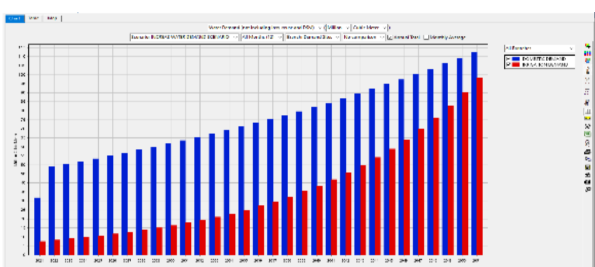
unmet demand under high population scenario



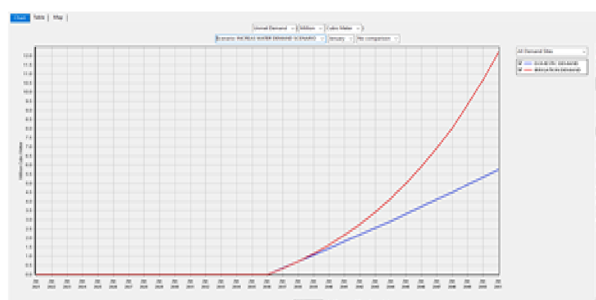
Increase irrigation area scenario



unmet water demand under increase irrigation area scenario



increase domestic water demand scenario



unmet water demand under increase Domestic water demand scenario