



**SURFACE WATER AVAILABILITY AND SCENARIO BASED DEMAND
ASSESSMENT OF THE KELETA RIVER WATERSHED, AWASH RIVER BASIN,
ETHIOPIA**

MSC THESIS

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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ETHIOPIA**

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EXAMINERS APPROVAL SHEET-1

(Submission sheet-2)

We, the undersigned, members of the board of the final open defense by **Mehiret Hone Fisha** have read and evaluated his/her thesis entitled “**Surface Water Availability and Scenario Based Demand Assessment of the Keleta River Watershed, Awash River Basin, Ethiopia**” and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree.

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DEDICATION

I dedicate this thesis to my father **Mr. Hone Fisha** and my mother, who is not alive **Mrs. Haregie Tegegne** for nurturing me with friendliness, love, and for their partnership in the success of my life.

LIST OF ABBREVIATIONS AND ACRONYMS

BCM	Billion Cubic Meters
Br	Bottom Branch
CSA	Central Statistical Agency
DEM	Digital Elevation Model
DMC	Double Mass Curve
DS	Demand Side
ET _o	Reference Crop Evapotranspiration
FAO	Food Agricultural Organization
GIS	Geographic Information System
GPS	Global Positional System
GTP	Growth And Transformation
GUI	Geographic User Interface
HEC-HMS	Hydrologic Engineering Center's Hydrologic Modeling System
HSPF	Hydrological Simulation Program – Fortran
IWRM	Integrated Water Resources Management
IWR-MAIN	Institute For Water Resource Municipal And Industrial Need
IWR-MAIN	Institute For Water Resources - Municipal And Industrial Needs
JWU	Jerusalem Water Under Taking

KARC	Klumsa Agricultural Research Center
KC	Crop Coefficient
LULC	Land Use Landover
MARC	Melkasa Agricultural Research Center
Max	Maximum
MCM	Million Cubic Meters
MCP	Marginal Cost Pricing
MCP	Marginal Cost Price
MOWIE	Ministry Of Water Irrigation And Electricity
MS-DOS	Microsoft Disc Operation System
MULINO–DSS	Multi-Sectorial Integrated And Operational Decision Support System
NMA	National Metrology Agency
NMSA	National Meteorological Service Agency
PBIAS	Percent Bias
PRMS	Precipitation Runoff Modeling System
RIBASIM	River Basin Simulation Model
SEI	Stockholm Environmental Institute
SWAT	Soil And Water Assessment Tool
SWAT-CUP	SWAT Calibration And Uncertainty Programs
UN	United Nation
UNFPA	United Nations Population Fund

USGS	United States Geological Survey
WBalMo	Water Balance Model
WEAP	Water Evaluation And Planning
WHO	The World Health Organization
WMO	World Meteorological Organization
WRM	Water Resource Management

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ABSTRACT

The ever-increasing world population, changes in the living standard and consumption pattern, and the rapid expansion of irrigation agriculture exert a lot of pressure on water resources. Irrigation, the major water user, relies mostly on surface water from the Awash River and its tributaries and it is very important to assess surface water potential at this basin. This study was conducted at Keleta River Watershed, which is found in the Upper Awash River Basin of Ethiopia. The main objective of this study was to assess the surface water availability and scenario-based water demand assessment in the Watershed using the Soil and Water Assessment Tool (SWAT) and Water Evaluation and Planning System (WEAP) models. The SWAT and WEAP models were used to estimate the surface water availability and scenario base users' water demands in Keleta River Watershed, respectively. The SWAT model was calibrated and validated using observed streamflow data to get reliably predicted streamflow values. The model performance was evaluated employing two error indices called Nash-Sutcliffe efficiency (NSE) and coefficient of determination (R^2). The results showed that the mean annual precipitation, actual evapotranspiration, and potential evapotranspiration were 831.1, 451.4, and 1180.4 mm, respectively in Keleta Watershed. The estimated surface runoff available from the entire catchment was 124.50 million cubic meters (MCM), which was equivalent to 165 mm depth of mean annual runoff. The assessment of water demand was done based on the current and projected future scenarios. The identified sectors of water users in the watershed were irrigation, livestock, domestic (rural and urban), public and industrial demands. The scenarios evaluated what would be the water demand if the population growth rate is 4% and the Irrigable area increases by 5% annually in the coming 25 years until 2045. The results showed that irrigation was found the highest water consumer among the demand sites whereas the lowest was observed in the public demand site, which consumed 42.22 and 0.63%, respectively from the total demand. The predicted water demand increases by 83.55% in 2045 while the unmet demand increases from the current volume of 0.25 MCM to 7.65 MCM due to the expansion of the irrigable area as compared to the reference scenario. Generally, the result indicated that the water demand as well as the unmet demand increases in the Kelata watershed. The study shows that the water demands in January, February, March, and April were found to be high as the supply was found to be low during the same months. This indicates the temporal variation of supply and demand in the Watershed. Water harvesting structure and groundwater development should be conducted to supplement this water deficit.

Key Words: SWAT; WEAP; surface water; water demand; Keleta River

1 INTRODUCTION

1.1 Background

Global population is expected to 65% increase in the next 50 years (Saur *et al.*, 2010), while the per capita income is expected to rise. This leads to an increase in water demand and food in the world (Islam & Karim, 2019). The ever increasing world population and changing of the living standard and consumption pattern, and rapid expansion of irrigated agriculture exerts a lot of pressure on water resources to produce more food to meet the increasing demands (Andarzian *et al.*, 2011, Mersha *et al.*, 2018). On the other hand, there is an obvious reduction in water availability in time and space due to both natural and anthropogenic causes (Adeba *et al.*, 2015). Water scarcity problems are becoming increasingly common due to higher water demand, urbanization, economic development, and climatic variability (Wang *et al.*, 2018, Mersha, *et al.*, 2018). Allocation of limited water resources, environmental quality, and policies for sustainable water use are issues of increasing concern (Uitto, 2004; Conway *et al.*, 2009, Mounir *et al.*, 2011). Several parts of Africa are exposed to high climate variations leading to frequent drought and famine. So proper management of the limited water resources and watershed is important for sustainable domestic and agricultural water supply and minimizes the impact of human activities on water resources (Jayakrishnan *et al.*, 2005).

Ethiopia is currently experiencing significant natural and socioeconomic change, which is modifying the availability and demand for water resources (Mosello *et al.*, 2015). Because of its geography and climate, Ethiopia has been characterized by its high hydrological variability, while currently experiencing significant natural and socioeconomic changes which are modified the availability and demand of water resources

(Awulachew *et al.*, 2006). Hydrologic year-to-year variability has long challenged on the ability of Ethiopia's poverty eradication even several successful growing seasons may quickly be nullified by one devastating year (Block, 2008). Poverty reduction needs to relate to water management at national and local levels, which is the key approach to integrated water resources management, and part of a wider process of poverty reduction and sustainable development (Soussan *et al.*, 2006). Irrigation in Ethiopia is considered as the main strategy to decrease poverty and useful to transform the rainfed agricultural system into a combined rainfed and irrigated agricultural system (Thang, 2017).

Under the combined impacts of climate change and human activities, a series of water issues, such as water shortages have arisen all over the world (Wang *et al.*, 2016). As water demand gets closer and closer to the available water in many regions, so each drop of water must be managed more efficiently and intensively (Wada *et al.*, 2016). This is especially true for developing countries, particularly in Ethiopia, where the need to enhance agricultural productivity faces diminishing water supplies for agriculture owing to rapid industrialization and ever-increasing municipal needs (Shumet and Mengistu, 2016). The continued pressure on water resources leads to undesirable consequences such as imbalances between demand and availability, water quality degradation, competition between sectors, and more often water is regarded as one of the major resources that create conflicts (Mersha *et al.*, 2016).

To avoid such challenges, modern basin allocation planning now focuses more on optimizing the use of existing supplies through significant economic, social, and environmental analyses and the assessment of trade-offs between competing users (Speed, 2013). Over the last decade, an integrated approach to water development has begun which places water supply projects in the context of demand-side issues, as well as issues

of water quality and ecosystem preservation. The Water Evaluation and Planning System (WEAP) aims to incorporate water supply and demand values into a practical tool for water resource planning (Sieber and Purkey, 2015).

Water scarcity is set to become more pronounced as a result of the rapidly growing population, assuming people start using more water through better services and perhaps access to small-scale irrigation, and unless efforts are made to improve water management (Mosello, 2015). This is likely to lead to increased incidences of conflict between local communities and pastoralists, as already observed in the Rift Valley Basin of Ethiopia (Shumet and Mengistu, 2016). According to research done in Kenya, water systems have complex component interactions necessitating the development and evaluation of management amidst uncertainties of climate and constrained natural resources (Sieber and Purkey, 2015). Conceptual models such as WEAP, when used, are effective planning and management tools as they forecast future effects of resource use efficiency at the sub-catchment level using existent hydrological and climate data thereby acting as a corrective measure to poor resources management (Mosello, 2015).

Water resources in the Awash River Basin are under enormous pressure due to climate change and variability, population pressure and land degradation, and pollution, and its major tributaries have been subjected to major environmental stress and climate change (Bekele, 2017). Keleta River is one of the tributaries of the Awash River Basin in which there is no information about the available water resource and water demand at the watershed level. So assessing the water resource availability and demand at Keleta River watershed is important for effective water resource management.

1.2 Statement of the Problem

The social and economic transformation associated with rapid urbanization and the widespread adoption of irrigation to overcome the climate change constraints profoundly altered the pattern of water use (Sanjaq, 2009). Water has always played a central role in Ethiopian society. It is an input, to a greater or lesser extent, to almost all products. In Ethiopia, as in all societies, there has always been a struggle to reduce the destructive impacts of water and increase its productive impacts. This struggle has intensified over the past century or so as the population has grown dramatically. In Ethiopia the total amount of rainfall varies greatly from year to year, resulting in severe droughts in some years and floods in others (Desalegn et al, 2006).

This is true in Awash which is subject to high climate variability, experiencing frequent floods and droughts (Taye et al., 2018). The basin is already subject to water stress, with higher water demand than supply (Taye *et al.*, 2018). The Awash River Basin is the most utilized basin of Ethiopia, with nearly all of its surface water resources abstracted for multiple uses at some points over the river course (Mersha et al 2018). Surface runoff is an important component in the circle of water balance and different environmental issues, such as excessive runoff causes for soil erosion and water pollution, degradation of the land, floods, and habitat distraction (Zeberie, 2019).

Irrigation, the major water user, relies mostly on surface water from the Awash River and its tributaries (Mersha *et al.*, 2016). Therefore, proper assessment of available water resources, existing and future water demand by using scenario analysis approach is very essential for the present and future socioeconomic and environmental sustainability (Shumet and Mengistu, 2016). Keleta River is one of the tributaries of the Awash River

Basin, in which water users relies on the surface water, the water demand surface water availability assessment is crucial for future project development. This study would assess the surface water availability and water demand in the Keleta River watershed.

1.3 Objectives

1.3.1 General objective

The general objective of this study was to determine the available surface water resource and scenario based water demand of Keleta River watershed, Awash River Basin Ethiopia.

1.3.2 Specific objectives

The specific objectives of this study were:

- ❖ to assess the available surface water resource at the watershed
- ❖ to identify water users in the watershed and estimate the users' water demand
- ❖ to evaluate water demand with scenarios development at the watershed

1.4 Research questions

- ❖ How much is the total amount of surface water at watershed?
- ❖ Who are the water users and how much amount of water is need for each user?
- ❖ What will be the future water demands if the population number and irrigation area increase?

1.5 Significance of the study

Assessing the overall surface water resources potentials and the existing and planned demand centers in the catchment would help in limiting developments only to the carrying

capacity of the resource while considering the sustainability issues which need to address the right of the future generation to make their lives from the resource. It is used as a benchmark for other researchers, designers, investors, resource allocators, policymakers, development of irrigation, and water management authorities.

1.6 Scope of the study

The study is focused on the Keleta River Watershed located in the Awash River Basin of Ethiopia, where the overall available surface water resource and demand assessment were the main objective. Only for Keleta River Watershed water availability and user's water demand would be assessed. The study did not take into account the effect of climate change on future water availability and also does not involve groundwater resources. Future irrigation expansion is considered with the present situation and high population growth rate scenario is also considered.

2 LITERATURE REVIEW

2.1 Water resource in Ethiopia

Ethiopia has a generous endowment of water resources that could easily satisfy domestic requirements for irrigation and hydropower, but this water is distributed unevenly in space and time (World Bank, 2006, Ludi *et al.*, 2013). Unmitigated hydrological variability, compounded by climate change, has been estimated to cost the country roughly one-third of its growth potential (World Bank, 2006). It has adequate average annual rainfall, several major rivers and lakes, and significant groundwater resources. Surface water is water on the earth's surface, such as in streams, rivers, lakes, or reservoirs. Surface water is a valuable resource that can be used for public, industrial, and agricultural supply purposes. Surface watercourses also provide important natural habitats and environmental and leisure resources. Therefore, understanding surface water resources is a key aspect of water resource assessment and evaluation (Tadesse, 2006). The country has several major rivers and lakes, and significant groundwater resources, and annual rainfall. However, rainfall across much of the country is both highly seasonal with most of the rain falling in a single, short season and exceptionally variable and unpredictable, both in time and space (World Bank, 2006).

The total renewable surface water resources are estimated at 122 billion cubic meters per year from 12 major river basins and 22 lakes (World Bank, 2006, FOA, 2016). The groundwater resources potential is estimated by different scholars are different, as compared to the surface water potential Ethiopia has lower groundwater potential. According to the finding of (Awulachew *et al.*, 2007) the potential of groundwater was estimated to be about 2.6 BMC. But a recent study (Walker *et al.*, 2019) show that the

best estimate of groundwater potential of the country is about 40 BCM. The country possesses twelve major river basins that form four major drainage systems: the Nile basin. The next table shows all twelve river basins (FOA AQUASTAT report, 2016).

Table 2.1 Area and annual runoff by River Basin (FOA AQUASTAT report, 2016)

Major system	Drainage River Basin	Area	%of total Area	Annual Runoff	%total runoff
		(ha)	(%)	(KM(m ³ /yr)	(%)
Nile Basin		36881200	32.44	84.55	69.01
	Abbay(Blue Nile)	19981200	17.57	52.6	42.93
	Baro-Akobo	7410000	6.52	23.6	19.26
	Setit-Tekeze	8900000	7.83	7.63	6.23
	Mereb	590000	0.52	0.72	0.59
Rift Valley		31764000	27.94	29.02	23.69
	Awash	11270000	9.91	4.6	3.75
	Denakil	7400000	6.51	0.89	0.73
	Omo-Gibe	7820000	6.88	17.96	14.66
	Central Lake	5274000	4.64	5.6	4.57
Shebelli-Juba		37126400	32.65	8.95	7.30
	Wabi-Shebelle	20021400	17.61	3.15	2.57
	Genale-Dawa	17105000	15.04	5.8	4.73
North East Coast		7930000	6.97	0	0.00
	Ogaden	7710000	6.78	0	0.00
	Gulf of Aden	220000	0.19	0	0.00
Total		113701600	100.00	122.52	100.00

2.2 Irrigation in Ethiopia

Irrigation in Ethiopia is considered the main target to avoid poverty and address food security at this moment. In most parts of Ethiopia, production from rain-fed agriculture has been highly fluctuating, corresponding to the amount and distribution of rainfall in space

and time (Mengisitie and Kidane, 2016). Therefore it is useful to transform the rain-fed agriculture system into a combined rain-fed irrigation agricultural system. Irrigation in Ethiopia dates back several centuries, while modern irrigation was started by the commercial irrigated sugar estate established in the early 1950s by the Imperial government of Ethiopia and Dutch Company (FOA, 2005).

The irrigation potential area and irrigated lands were varying in different scholars at different times. When we see some of the scholars the total irrigation potential and the actual irrigated area was 3.7 Million ha and 197,000 ha according to (Awulachew *et al.*, 2007); 3.5 Million ha and 626,116 ha as reported by (Hagos et al., 2009); and 3.7 Million ha and 640,000 ha across the country (Awulachew, 2010) respectively. According to the report of (FOA, 2016), the maximum irrigation potential is 5.7 Million ha, but at present, the irrigation potential of Ethiopia is estimated to about 2.7 million ha considering the availability of water and land resource, technology, and finance. Even though the actual irrigation area is not precisely quantified, estimate in the year 2015, the area prepared for full-control irrigation estimated (sprinkler and drip) at 658,340 ha, the area prepared for community spate irrigation is estimated at around 200,000ha giving a total area of 858340 ha. In addition to this around 1,000,000 ha was estimated to be cultivated by small farmers using a temporary structure with non-equipped cultivated wetlands, inland valley bottoms, and flood recession cropping area (FOA, 2016).

The economical irrigation potential (considering the availability of water and land resources, technology, and finance) Awash river basin covers are 7.7% of Ethiopian irrigation potential which is equivalent to 205400 ha of irrigable land (FOA, 2016). It is the most utilized river basin in Ethiopia with several small, medium, and large scale irrigation schemes available which the irrigated lands reach about 200,000 ha (ARBA,

2017). Due to the intensive irrigation development in the basin particularly along the Awash River, there is high water stress during the peak of the irrigation season April to June (ARBA, 2017). With the high utilization of water resource, water availability demand requirement in current and future information is important for water resource allocation and development.

2.3 Integrated water resource management

To deal with the complexity of water management issues, discussion over water resources is typically separated into distinct topics such as economics, water quality, and the environment. In reality, however, each of these issues is interconnected; subsidized water prices, for example, can lead to rising water demand which may reduce the quantity of water in the environment thereby leading to an increase in the concentration of pollutants and a decline in water quality. Due to the interrelated nature of water issues, the use of particular economic or policy instruments can create trade-offs. Purchasing water access rights to secure environmental flows, for example, maybe a cost-effective method of increasing the amount of water in the environment, but reduced water extractions may also negatively impact small towns and communities dependent on irrigated agriculture (White, 2013).

For water security to be managed effectively, the use of economic and policy instruments cannot be considered in isolation, but rather should be considered in terms of their wider impact on society and the environment. Effective water security management, therefore, requires planners to take into account the ‘triple bottom line’ and evaluate policies in terms of their economic, environmental, and social impacts. To deal with this complexity and coordinate policy effectively, it is often argued that economic and policy instruments

should be used as part of a wider integrated water resource management (IWRM) framework (White, 2013). Integrated Water Resources Management (IWRM) promotes the coordinated management of water, land, and related resources, to maximize the resultant economic and social welfare equitably without compromising the sustainability of vital ecosystems (GWP, 2000).

IWRM is a framework designed to improve the management of water resources based on four key principles adopted at the 1992 Dublin Conference on Water and the Rio de Janeiro Summit on Sustainable Development. These principles hold that: (1) freshwater is a finite and vulnerable resource essential to sustain life, development, and the environment; (2) water development and management should be based on a participatory approach, involving users, planners, and policymakers at all levels; (3) women play a central part in the provision, management, and safeguarding of water; and (4) water has an economic value in all its competing uses and should be recognized as an economic good.

2.4 Hydrological and water management models

Water management involves development, control, protection, regulation, and beneficial use of surface (rivers and reservoirs) and groundwater resources. From the perspective of the scientist and researcher, the role of mathematical models is to contribute to a better understanding of real-world processes. From the perspective of the water manager, the role of mathematical models is to provide quantitative information to support decision-making activities. Models help both individual water managers and the water management community to make better decisions. Models do not relieve people of the burden of making difficult decisions. They simply provide some additional information to consider.

Models strengthen the knowledge base which supports decision-making processes (Wurbs, 1994).

Water resources planning and management are highly dependent on projections of future water needs. Such as preparation of drought contingency plans, evaluation of the effectiveness of alternative demand management (water conservation) plans, implementation of demand management measures during drought conditions, prediction of utility revenues to be expected from the sale of water, and development of local, regional, and national water resources assessments and formulation of water management policies and plans. Having on these water use forecasting and balancing water demand and supply is a very important aspect. Simulation of the basin hydrology indicates resource capacity. For water resource assessment, it is necessary to have an understanding of flow conditions unaffected by human-induced land cover and water use changes, ‘naturalized flow’ (Yaghobi *et al.*, 2014).

Having on these reasons, nowadays several hydrological models were available in worldwide. Rainfall-runoff modeling is very significant in catchment management simulation of hydrology as an indicator of resource capacity. For water resource assessment, it is necessary to have understood the catchment flow condition (Mekonnen, 2017). There is a choice among three methods to simulate catchment processes such as evapotranspiration, runoff, infiltration, and irrigation demands (SEI, 2005).

Generally, models can be grouped into three types: empirical/statistical, physically based, and conceptual (Zhang *et al.*, 2016). Empirical/statistical models are simple, less data-demanding, and particularly useful for understanding hydrological responses on a spatially lumped and/or temporally coarse resolution (He and Croley, 2007). Physically-based

models exhaustively describe all important hydrological components and processes (He and Croley, 2007). Conceptual models can reflect the hypothesis about the processes governing system behavior and require fewer variables and less computational time without trying to be exact representations of reality (Beven, 1989; He and Croley 2007). Distributed models are more suitable for the complex watershed because of its physical Heterogeneity (Tegegne et al., 2017).

Some of the models that used for rainfall run of modeling are HEC-1/HEC-HMS (Hydrologic Engineering Center's Hydrologic Modeling System), HSPF (Hydrological Simulation Program – FORTRAN), MIKE SHE (originally named SHE – Système Hydrologique Européen), PRMS (Precipitation Runoff Modeling System), SWAT (Soil and Water Assessment Tool), and WEAP (Water Evaluation and Planning) model (Daniel et al., 2011). Selection of a WRM model used to support water resource planning is a function of the scale and complexity of the issue to be addressed, an acceptable amount of uncertainty, data to support model development, computational capacity, duration of the study, and capacity and availability of the individuals developing, maintaining, and conducting simulations (Borden et al., 2016).

A distributed model explicitly accounts for spatial variability using spatial datasets describing soils, vegetation, and land use. A distributed model will subdivide a sub-basin area based on a particular grid size to capture spatial and temporal variability and then route flows through the sub-basin from cell to cell (Brirhet, 2016). When we see the two physical models HEC-HMS and SWAT; the HEC-HMS (Lumped Model) considers individual sub-basins as a single unit and averaging spatial characteristics related to rainfall-runoff response for the entire area of a sub-basin being analyzed (Brirhet, 2016). But the SWAT model (Arnold et al., 1998; Chekol et al., 2007) is a continuous-time,

physically-based hydrological model with the ability to characterize complex watershed representations to explicitly account for spatial variability of soils, rainfall distribution, and vegetation heterogeneity. The SWAT model was selected to assess the available water resource in this study.

2.4.1 SWAT (Soil and Water Assessment Tool) model

Geographic Information systems (GIS) and model GIS interfaces support the efficient creation of input data required by models. The soil and water assessment tool (SWAT) is one such model available for water resource professionals (jyakrishnan *et al.*, 2005). SWAT was created in the early 1990s, it undergoes with different continued reviewed and expansion. The most significant improvement the model between release includes; SWAT94.2, SWAT96.2, SWAT98.1, SWAT99.2, SWAT2000, and SWAT2005 (Arnold *et al.*, 2005). SWAT is a River basin or Watershed, scale model developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over a long period which is developed by Dr. Jeff Arnold for USDA Agricultural Research Service (ARS) (jyakrishnan *et al.*, 2005).

The ArcSWAT ArcGIS extension is a graphical user interface for the SWAT model. The interface requires the designation of land use, soil, weather, groundwater, water use, management, soil chemistry, pond, and stream water quality data as well as the simulation period, to ensure a successful simulation (Winchell *et al.*, 2013). SWAT can be used to simulate a single watershed or a system of multiple hydrological connected watersheds. Simulation of the hydrology of watershed can be separated into major two divisions; the first division is the land phase of the hydrologic cycle controls the amount of water,

sediment, nutrients, and pesticides loading the main channel and the second phase is the water or routing phase of the hydrologic cycle defined as the movement of water and sediment. The model simulates in daily time step based. Water balance is the driving force behind everything that happens in the watershed (Akpoti *et al.*, 2016). The SWAT simulation of the hydrological cycle is based on water balance equation (Arnold *et al.*, 2005 and Akpoti *et al.*, 2016)

$$SW_t = SW_o + \sum_{i=1}^t [R_{day} - Q_{surf} - E_a - W_{seep} - Q_{wg}] \text{-----Eq. 2.1}$$

Where; SW_t is the final water content (mm), SW_o is the initial water content on a day I (mm), t is the time (days), R_{day} is the amount of precipitation on a day i (mm), Q_{surf} is the amount of surface runoff on a day i (mm), E_a is the amount of evapotranspiration on a day i (mm), W_{seep} is the amount of water entering the void zone in the soil profile on a day i (mm) and Q_{wg} is the amount of water return flow to on day i (mm). Once SWAT determines the loading of water-sediment nutrient and pesticide to the main channel the loading is routed through the stream network of the watershed.

2.4.1.1 Surface runoff estimation

Surface runoff occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration rate. When the application of water is higher than the infiltration rate surface depressions begin to fill and surface runoff will appear. SWAT model determines surface runoff by SCS curve number procedure and the Green &Ampt infiltration method (jyakrishnan *et al.*, 2005, Akpoti *et al.*, 20016). The SCS curve number method is commonly used for estimating the amount of runoff from small to medium basins developed by USDA scientist; it involves the use of simple empirical formula, tables, and

curves (jyakrishnan *et al.*, 2005, Akpoti *et al.*, 2016, Ara andZakwan, 2018). The SCS curve number equation is

$$Q_{surf} = \frac{(R_{day}-I_a)^2}{(R_{day}-I_a+S)} \text{----- Eq. 2.2}$$

Where the actual runoff (mm), R_{day} is rainfall depth for the day (mm), I_a is an initial abstraction that includes surface storage, interception, and infiltration before runoff in (mm) and S is the retention parameter.

$$S = 25.4 \left(\frac{1000}{CN} - 10 \right) \text{----- Eq. 2.3}$$

Where, CN is the curve number for the day. The initial abstraction, I_a, commonly approximated as 0.2S and surface runoff equation become:

$$Q_{surf} = \frac{(R_{day}-0.2S)^2}{(R_{day}+0.8S)} \text{-----Eq. 2.4}$$

2.4.1.2 Estimation of water balance components at watershed

A catchment water balance is an assessment of outputs (demands) and inputs (supplies) to understand the functioning of surface water, its hydrological setting and the sustainability of groundwater (Dingman, 2002). The water balance equation of a catchment

$$O - I = \Delta S \text{-----Eq.2.5}$$

Where I represent the water input (rainfall and groundwater flow), O represents the output (river discharge, evapotranspiration, and abstraction) and ΔS indicates water storage change (Nyika et al., 2017). Estimation of water balance is necessary for the water resources development for checking the reliability and general pattern of the availability of water from month to month. As the planning, development, and operation of the water resources projects in a river basin are very much dependent upon the availability of water,

in required quantities, the water balance study is imperative and water balance is useful for determining or predicting the water deficit and surplus in the basin (Thakural et al, 2009). The available surface water of the catchments will be estimated using streamflow discharges and rainfall data. In this study, the watershed water balance component such as potential evapotranspiration, actual evapotranspiration, areal rainfall, and catchment runoff will be estimated.

2.4.1.3 SWAT model application

The SWAT model is a continuation of nearly proximately 30 years of modeling conducted which gains international acceptance as a robust interdisciplinary watershed modeling tool as evidenced by international conferences, more than hundreds of SWAT-related papers, and dozens of articles published in peer-reviewed journals (Jiyakrishnan *et al.*, 2005, Gassman *et al.*, 2007). Many of applications have been conducted on the need of various government agencies particularly in U.S. and European Union, on the assessment of anthropogenic, climate change and other influence on a wide range of water resources or exploratory assessments of model capabilities for potential future applications (Gassman *et al.*, 2007). It also becomes commonly applied in Africa on climate change, land, and water resources management. Some examples of SWAT model application in Africa and Ethiopia were:

The assessment of the impact of climate change on surface water availability for different water users in the upper Pangani river basin in Tanzania (Kishiwa *et al.*, 2018).

The application of soil and water assessment tool (SWAT) for calibration, validation and uncertainty analysis at the Olifant basin in South Africa (Gyamfi *et al.*, 2016).

Modeling of water quantity and quality using the SWAT model at Lipopo river basin, south Africa (Querner, 2013). Modeling of runoff and sediment yield Kesem dam watershed at Awash River Basin Ethiopia (Abebe and Gebremariam, 2019). This shows that SWAT is an appropriate model to assess water resource potential, water quality and climate change and so on.

2.5 Models used for water development and management policies

Several programs are designed to simulate water development and management policies in river basins. Each of these programs is based on a node-link network representation of the water resource system being simulated. All contain menu-driven graphics-based interfaces that facilitate user interaction (Akivanga, 2010). Some of these models include River Basin Simulation Model RIBASIM, MIKE Basin, Water Balance Model (WBalMo) MULti-sectoral, Integrated and Operational Decision Support System (MULINO–DSS), Institute for Water Resources - Municipal and Industrial Needs (IWR-MAIN) and Water Evaluation and Planning System (WEAP).

WEAP model which is used for the allocation of limited water resources, environmental quality, and policies for sustainable water use are issues of increasing concern (Sirber, 2005). Conventional supply-oriented simulation models are not always adequate. Over the last decade, an integrated approach to water development has emerged which places water supply projects in the context of demand-side issues, water quality and ecosystem preservation. WEAP aims to incorporate these values into a practical tool for water resource planning.

WEAP is distinguished by its integrated approach to simulating water systems and by its policy orientation (Sirber, 2005). WEAP is comprehensive, straightforward and easy-to-

use, and attempts to assist rather than a substitute for the skilled planner. As a database, WEAP provides a system for maintaining water demand and supply information. As a forecasting tool, WEAP simulates water demand, supply, flow, and storage, and pollution generation, treatment and discharge. As a policy analysis tool, WEAP evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems (Sirber, 2005). The model was preferred to others because of its robustness and ease of use depending on data availability. As described by Shumet and Mengistu (2016) the model can perform both lumped to distributed catchment hydrological simulation and can handle aggregated to disaggregated water management demands of various sectors. The system is therefore appropriate for studying catchments with minimum to moderate data availability. All tables can be exported directly into Excel (Sirber, 2005). Model calculations run in minutes. Considering the above-mentioned points WEAP model is selected to conduct this research.

2.5.1 WEAP model

Water Evaluation and Planning (WEAP) model has a long history of development and uses in the water planning arena (Mounir *et al.*, 2011). WEAP model first applied to a study on the Aral Sea, but that version of WEAP had several limitations, including an allocation scheme that treated rivers independently, gave priority to demands on upstream sites over downstream sites, and assured demand sites that preferred groundwater to surface water were last in line in getting surface water allocations (Raskin *et al.*, 1992). Given these deficiencies, WEAP21 introduces major advances including a modern Graphic User Interface (GUI), a robust solution algorithm to solve the water allocation problem, and the integration of hydrologic sub-modules that include a conceptual rainfall-

runoff, an alluvial groundwater model, and a stream water quality model (Singh *et al.*, 2014).

WEAP was developed by the Tellus Institute, which is a team of scientists, planners, and policy analysts organized into non-profit research and consulting organization. The Tellus Institute serves as the Boston Center of the Stockholm Environment Institute, an international organization based in Sweden (Wuber, 1994). WEAP runs on MS-DOS based microcomputers in an interactive menu-driven mode. WEAP is comprehensive, straightforward and easy-to-use, and attempts to assist rather than a substitute for the skilled planner. As a database, WEAP provides a system for maintaining water demand and supply information. As a forecasting tool, WEAP simulates water demand, supply, flow, and storage, and pollution generation, treatment and discharge. As a policy analysis tool, WEAP evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems (Sierber, 2005).

The model includes the following modules or programs: setup, demand, distribution, supply, and evaluation. The Setup Program characterizes the problem under study by defining the study period, physical elements comprising the water demand-supply network and their spatial relationships. It can be used to perform various types of analyses including sectoral water demand forecasts, supply source allocations, streamflow and reservoir storage simulations, hydropower forecasts, pollution loading estimates, and benefit-cost analyses.

The demand program uses a hierarchical branching structure to manage data. The levels are the sector, subsector, end-use, and device. The economy is divided into sectors, which are defined for the particular study. Sectors for a typical study might include agriculture, industry, and municipal and each sector is divided into subsectors. The design of WEAP

is guided by several methodological considerations: an integrated and comprehensive planning framework; use of scenario analyses in understanding the effects of different development choices; Demand-management capability; Environmental assessment capability; and Ease-of-use. Besides, WEAP allows users to develop their own set of variables and equations to further refine and/or adapt the analysis to local constraints and conditions.

WEAP applications generally involve the following steps:

- Problem definition including a time frame, spatial boundary, system components, and configuration
- Establishing the ‘current accounts’, which provides a snapshot of actual water demand, resources, and supplies for the system
- Building scenarios based on different sets of future trends based on policies, technological development, and other factors that affect demand, supply, and hydrology
- Evaluating the scenarios concerning criteria such as adequacy of water resources, costs, benefits, and environmental impacts. The scenarios can address a broad range of ‘what if’ questions, such as: What if population growth and economic development patterns change? What if ecosystem requirements are tightened? What if irrigation techniques and crop patterns are altered? What if various demand management strategies are implemented?

WEAP model has two primary functions (Yates *et al.*, 2005 and Mounir, 2011):

- Simulation of natural hydrological processes (e.g., evapotranspiration, runoff, and infiltration) to enable assessment of the availability of water within a catchment.

- Simulation of anthropogenic activities superimposed on the natural system to influence water resources and their allocation (i.e. consumptive and non-consumptive water demands) to enable evaluation of the impact of human water use.

To allow simulation of water allocation, the elements that comprise the water demand-supply system and their spatial relationship are characterized for the catchment under consideration. The system is represented in terms of its various water sources (e.g. surface water, groundwater, and desalinization and water reuse elements); withdrawal, transmission, reservoirs, and wastewater treatment facilities, and water demands (i.e. user-defined sectors but typically comprising industry, mines, irrigation, domestic supply, etc.).

2.5.1.1 Application WEAP model

WEAP model was used in different regions to allocate water resources for effective water resource management. Assessing the impact of existing and future water demand on economic and environmental aspects from Rift Valley Lake Basin, Meki-Ziway Sub Basin. The general objective of this study was to assess and identify the existing and future water demand of the user sectors and their related impacts in hydrology, environmental and economic development of the Central Rift Valley Lake Basin, Ethiopia and propose the management strategies for the present and possible future scenarios (Sumet and Mengistu, 20116).

Scenario analysis of water supply and demand using the WEAP model: a case of Yala Catchment, Kenya. This study was applied to evaluate past trends and simulate current demand scenarios for planning by authorities regarding future use (Okungu *et al.*, 2017). Simulation of rainfall-runoff using the WEAP model at Qaraso Basin in the year 2014.

The main purpose of this paper is to provide a method that applies precipitation-runoff mathematical models (soil moisture model) (Yaghobi *et al.*, 2014). Modeling of surface water resource allocation in Didessa Sub-Basin, West Ethiopia. The main objective of this study is to assess the impact of additional water demand and surface water resources development in the Didessa Sub-basin on downstream and in-stream water availability, using the water evaluation and planning (WEAP) system (Adgolgn *et al.*, 2015).

The use of water evaluation and planning "WEAP" program as a planning tool for Jerusalem water undertaking to develop an integrated water resources management for the service area of Jerusalem Water Undertaking (JWU) by using the WEAP model (Sanjaq, 2009). WEAP model was used to study water allocation for existing and future demands under changing climate condition: the case of Upper Awash Sub River Basin to study the existing and future water availability which contributes significant flow to Koka dam and also on water allocation of the existing and planned water resource projects (irrigation, hydropower, industries, livestock, etc.) (Kerim *et al.*, 2016).

2.5.1.2 WEAP model algorithm

WEAP operates on the basic principle of water balance for every node and links the system on a monthly time step subject to demand priorities, supply preferences, mass balance, and other constraints (Sanjaq, 2009).

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

$$\text{Annual Demands (DS)} = \sum_{Br} (\text{Total activity level}_{Br} \times \text{Water userate in } Br) \text{ -----}$$

Eq.2.6

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

2.5.2 CROPWAT model

CROPWAT is a decision support system developed by the Land and Water Development Division of FAO for planning and management of irrigation used for calculations for reference evapotranspiration, crop water requirements and crop irrigation requirements (Marica, 2013). It calculates crop water requirements and irrigation requirements based on soil, climate and crop data. In addition, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns.

For the estimation crop water requirements (CWR) the model requires (Clarke et al., 2001 and Marcia, 2013)

- Reference Crop Evapotranspiration (Eto) values measured or calculated using the FAO Penman-Montieth equation based on decade/monthly climatic data: minimum and maximum air temperature, relative humidity, sunshine duration and windspeed;
- Rainfall data (daily/decade/monthly data); monthly rainfall is divided into a number of rain storm each month;
- A Cropping Pattern consisting of the planting date, crop coefficient data files (including Kc values, stage days, root depth, depletion fraction) and the area planted (0-100% of the total area); a set of typical crop coefficient data files are

provided in the program. In addition, for Irrigation Scheduling the model requires information on:

- Soil type: total available soil moisture, maximum rooting depth, initial soil moisture depletion (% of total available moisture);

2.5.2.1 Reference evapotranspiration (ET_o)

Reference crop evapotranspiration or reference evapotranspiration denoted as ET_o or ET_{ref} is the estimation of the evapotranspiration from the "reference surface." The reference surface is a hypothetical grass reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s/m and an albedo of 0.23 (Sieber and Purkey, 2015). The fixed surface resistance of the 70s/m FAO-56 Penman-Monteith Equation is used to estimate ET_o (Zotarelli *et al.*, 2010) described by Equation 2.6 below.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1+0.34U_2)} \text{-----Eq. 2.7}$$

Where, ET_o = reference evapotranspiration, mm day⁻¹; R_n = net radiation at the crop surface, MJ m⁻² d⁻¹; G = soil heat flux density, MJ m⁻² d⁻¹; T = mean daily air temperature at 2 m height, °C; u₂ = wind speed at 2 m height, m s⁻¹; e_s = saturation vapor pressure, kPa; e_a = actual vapor pressure, kPa; e_s-e_a = saturation vapor pressure deficit, kPa; Δ = slope of the vapor pressure curve, kPa °C⁻¹; γ = psychrometric constant, kPa °C⁻¹.

2.6 Water resource allocation

Water allocation is the process of sharing a limited natural resource between different regions and competing users. It is a process made necessary when the natural distribution and availability of water fails to meet the needs of all water users' in terms of quantity,

quality, the timing of availability, or reliability. In simple terms, it is the mechanism for determining who can take water, how much they can take, from which locations, when, and for what purpose (Speed, 2013). Due to geographically and temporally unevenly distributed precipitation, rapidly increasing water demands driven by the world population and other stresses, and degradation of the water environment there are increasing scarcities of water resources in many countries. To achieve sustainable water management and secure society, institutions and approaches for water allocation should be reformed, especially for regions having water resource shortages (Deng, 2015).

2.6.1 Mechanism of water resource allocation

Water resources have been usually allocated to ensure sufficient quantity for human consumption and food production, addressing mainly equity issues. Considerations of efficiency have not always been incorporated. Water scarcity and quality have become a major problem in many countries that are beginning to appreciate water as an economic good (Moigne *et al.*, 1997). Low water efficiency and a serious waste of water are universal phenomena today, which intensify conflict between supply and demand for water resources and even impede the sustainable development of the economy. Public agencies responsible for water allocation and control are calling for analytical tools of planning. Hence, a systematical distribution mechanism specially designed to solve this problem is relevant for governments (Xia and Cui, 2009).

Appropriate means of resource allocation are necessary to achieve optimal allocation of resources. There are several criteria's used to compare forms of water allocation (Howe *et al.*, 1986, Moigne *et al.*, 1997)

- ✚ Flexibility in the allocation of supplies;

- ✚ Security of tenure for established users;
- ✚ The real opportunity cost of providing the resource is paid by the users;
- ✚ Predictability of the outcome of the allocation process;
- ✚ Equity of the allocation process;
- ✚ Political and public acceptability;

According to (Moigne *et al.*, 1997) there are three water allocations which are marginal cost pricing, public allocation, and water market allocation. Marginal cost pricing (MCP): a marginal cost pricing (MCP) mechanism, in principle, targets a price for water to equal the marginal cost of supplying the last unit of that water. A price is defined as an observed price (marginal value) of water on a demand curve, which corresponds to an observed quantity (i.e. Reference quantity). An allocation that equates the water's unit price (the marginal value of water) with the marginal cost is considered an economically efficient, or socially optimal, allocation of water resources. The limitation of MCP relates to difficulties to estimate the correct volume of water

Public Water Allocation: Public allocation promotes the equitable water use, can protect the poor, and can sustain environmental needs. But often leads to inefficient use of water and failure to create incentives for water users to conserve water, improve use efficiency and allow tradable water transfers to achieve maximum benefits in a whole river basin and also public allocation mechanisms often lead to waste and miss-allocation of water, as well as fragmented investment and management of the existing resource (Deng, 2015).

Water Markets: water markets allocate water using tradable water use rights and promote efficient water usage by allowing users to sell and buy their water rights freely. Furthermore, it argues that water markets are rare in reality and are not truly free markets. Due to the transaction costs, technological constraints, political constraints, and many

other reasons the real-world water markets do not attain first-best allocations (Deng, 2015).

2.7 Water demand

In theory, the term water demand coincides with water consumption. In practice, however, the demand is often monitored at supply points where the measurements include leakage, as well as the quantities used to refill the balancing tanks that may exist in the system (https://ocw.un.ihe.org/pluginfile.php/4307/mode_resource/content_to_urban_water_distribution). A booming population and the demands on water arising from the agricultural, industrial, and energy sectors are set to increase pressure on Ethiopia's water resources. The cumulative impact of demand growth from both demographic and sectoral changes bears significant costs. Without appropriate institutional mechanisms such as markets or allocation permits to ration water use and pollutants, there is the risk of over-exploitation and decreased water quality as absorptive capacities are exceeded. In the medium term, this limits water availability and leads to a negative cycle of resource degradation, which could be entrenched and amplified by climate change (Mosello, 2015).

2.7.1 Agricultural water demand

Water consumption in agriculture is mainly determined by irrigation and livestock needs. In peri-urban or developed rural areas, this demand may also be supplied from the local distribution system. Water required for livestock depends on the sort and age of the animal, as well as climatic conditions. The size of the stock and type of production also play a role. The quantity of water used in agriculture is a function of crop area, type of crop, and climatic conditions. Forecasting agricultural water use involves predicting future cropping patterns and management practices and estimating evapotranspiration and water

needs for particular crops. The agriculture demand is estimated based on land use and water requirement for rain-fed crops by using Area, Crop coefficients (K_c), and the Reference Crop Evapotranspiration (E_{To}). CROPWAT, which was developed by FAO, is used to estimate water requirements for the major crops.

2.7.2 Domestic water demand

Domestic water consumption is intended for toilet flushing, bathing and showering, laundry, dishwashing, and other less water-intensive or less frequent purposes: cooking, drinking, gardening, car washing, etc.

2.7.3 Industrial water demand

Industrial Water Demand: Industrial water demand includes the water required for factories and industries. Water in the industry can be used for various purposes: as a part of the final product, for the maintenance of manufacturing processes like cleaning, flushing, sterilization, conveying, etc.

2.7.4 Environmental water demand

Water in the environment can be explained differently. Environmental is the amount of water in the watercourse to sustain a healthy ecosystem (Lacroix and Xiu, 2013). A Minimum Flow Requirement defines the minimum monthly flow required along a river to meet water quality, fish & wildlife, navigation, recreation, downstream or other requirements. Depending on its demand priority, a flow requirement will be satisfied before, after, or at the same time as other demands on the river (Sieber and Purkey, 2015). It is also defined as an environmental or instream flow requirement for how much of the original flow regime of the river flow should continue to flow down to maintain the

riverine ecosystem. Sometimes its definition goes beyond the hydrology of the system because it also involves determining how much water is required to achieve a certain level of river health as agreed by water using community (Lacroix and Xiu, 2013). Understanding how we determine environmental water demand takes three forms (Lacroix and Xiu2013). Those are the science of identifying environmental flow needs and flow responses; the process for prioritizing water for the environment; and policy and management tools for considering environmental demand based on a community's priorities. Globally rational level of environmental freshwater requirement to maintain the ecosystem ranges from 20 to 50 percent of the mean annual river flow in the basin (Smakhtin, 2004). But for this study considering the prioritization and expectation of the society this study considers 10 % mean annual flow.

2.8 Prioritize for water allocation

In 2001, the Ethiopian water strategy was adopted with the stated aim of translating the 1999 Policy into action. At that time, the priority in terms of IWRM was water allocation for drinking and sanitation purposes, followed by water requirements for livestock. The strategy aimed to foster an enabling environment to strengthen the institutional framework and secure coordination of water resources development and management. The demand priority represents the level of priority for the allocation of constrained resources among multiple demand sites. WEAP will attempt to supply all demand sites with the highest demand priority, then moving to lower priority sites until all of the demand is met or all of the resources are used, whichever happens first (SEI, 2016).

WEAP will attempt to supply all of the demand with sources having the highest preference level, only using lower-level sources if the high- level sources do not have sufficient

supply. A demand priority can be any whole number between 1 and 99 (1 is the default) and allows the user to specify the order in which the water requirements of demand sites are satisfied in a WEAP model. WEAP will attempt to satisfy the water requirement of a demand site with a demand priority of 1 before a demand site with a demand priority of 2 or greater.

3 MATERIAL AND METHODS

3.1 Description of the study area

Awash River basin is one of the major twelve basins in Ethiopia. The basin has a total catchment area of 115,560km² and a total length of 1200km (Fufa, 2016). Keleta River Watershed is found in Arsi Zone, the central part of Ethiopia, in the Upper Awash Sub-basin. It is located between 7^o 53' 49"and 8^o17' 11" North latitude and 39^o 14' 34" and 39^o 32' 40" East longitude. The Watershed has an area of 754.87 km². Keleta River is the Sub-tributary of the Awash River. The mean annual rainfall of the area is around 890 mm and the mean annual minimum and maximum temperature are 8.6°C and 23.8°C, respectively. Figure 3.1 shows the location of Keleta River Watershed.

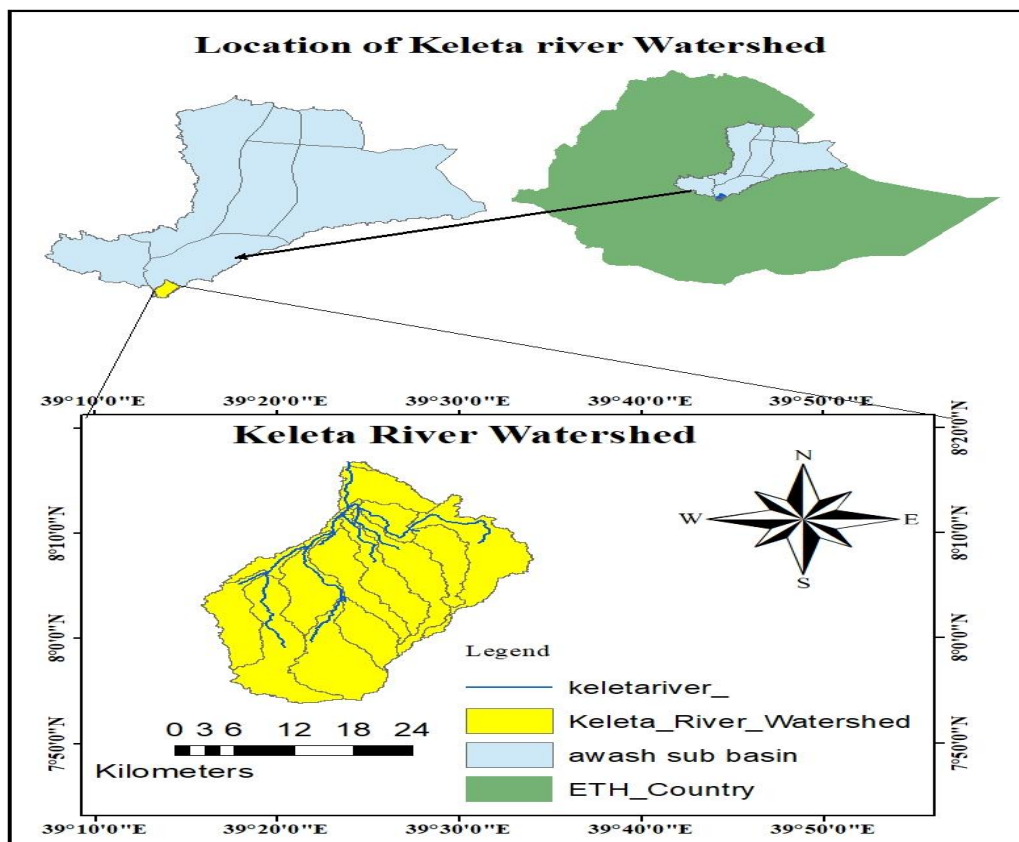


Figure 3.1 The location map of Keleta River Watershed

3.2 Data collection and analyses

3.2.1 Surface water assessment by SWAT model

The SWAT model required different spatial and hydro-meteorological input data estimate the surface water availability in this study area. The data required for this study were collected from different organization such as the Ethiopian Ministry of Water Irrigation and Electricity (MoWIE), National Meteorological Service Agency (NMA), website, and internet input and field-level investigation. The data collected which used as inputs were land use/land cover map, soil map, DEM, stream flow, and meteorological data. GPS was used to collect geographic coordinates at the Watershed to conduct a supervised classification of my study area and to take the coordinate of gauging station for the select outlet of the watershed. The softwares that were used to prepare and analyze data were ArcGIS10.1, ArcSWAT, CROPWAT8.0, PcpSTAT, and SWAT- CUP. The study area was delineated automatically by using ArcSWAT software and hydraulic response unit (HRU) was defined. Digital cameras used to collect field photographs which used as a signature of land cover class during supervised classification. After all the necessary data were processed with compatible format, it introduced to ArcSWAT model and running the model was conducted. Finally sensitivity analysis, model calibration, validation and simulation of the surface water resources were accomplished successfully.

3.2.1.1 SWAT model input data

3.2.1.1.1 Streamflow data

The Keleta is the main tributary of Awash River that has a gauging station, which is; located 08°16'36"N and 39°23'50"E. The discharge of Keleta River was obtained from the Ministry of Water, Irrigation, and Electricity. This streamflow data was used for SWAT

model calibration and validation to assess the available water potential at the Watershed.

Figure 3.2 shows monthly observed flow of Keleta River from the year 1999 - 2015.

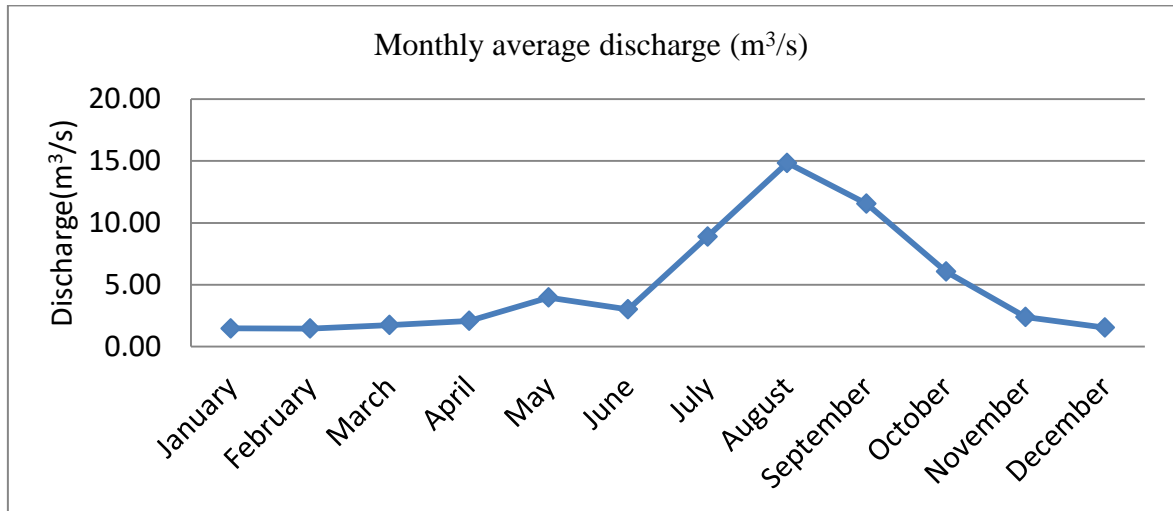


Figure 3.2 Monthly observed average discharge of Keleta River

3.2.1.1.2 Climatic data

The meteorological data required for this study collected from the National Meteorological Agency were precipitation, minimum and maximum temperature, relative humidity, wind speed, and solar radiation daily format. The data which were not available from the meteorological agency were generated by ArcSWAT software. Daily Precipitation, minimum and maximum temperature collected from Abomsa, Nazret, Eteya, Huruta, Melikasa, Kulumsa, and Sire stations were prepared into the format compatible with ArcSWAT. Relative humidity and wind speed were available at station Melkasa, Abomsa, and Nazret but Solar radiation was not found in all the above stations except Kulumsa and Melkasa station. Those unavailable data were generated by ArcSWAT weather generator software. Weather stations coordinate near and within Keleta Watershed are

illustrated in Table 3.1. Total monthly rainfall, average monthly maximum, and minimum temperature are illustrated below Figure 3.3, 3.4, and 3.5 from the year 1987 – 2017.

Table 3.1 Weather station coordinates near and in Keleta watershed

Station	Latitude	Longitude	Elevation
Abomsa	8.467	39.83	1630
Etheya	8.133	39.33	2129
Huruta	8.142	39.34	2044
Melkasa	8.4	39.32	1540
Naret	8.55	39.28	1622
Sire	8.271	39.49	2037
Kulumsa	8.0097	39.1553	2211

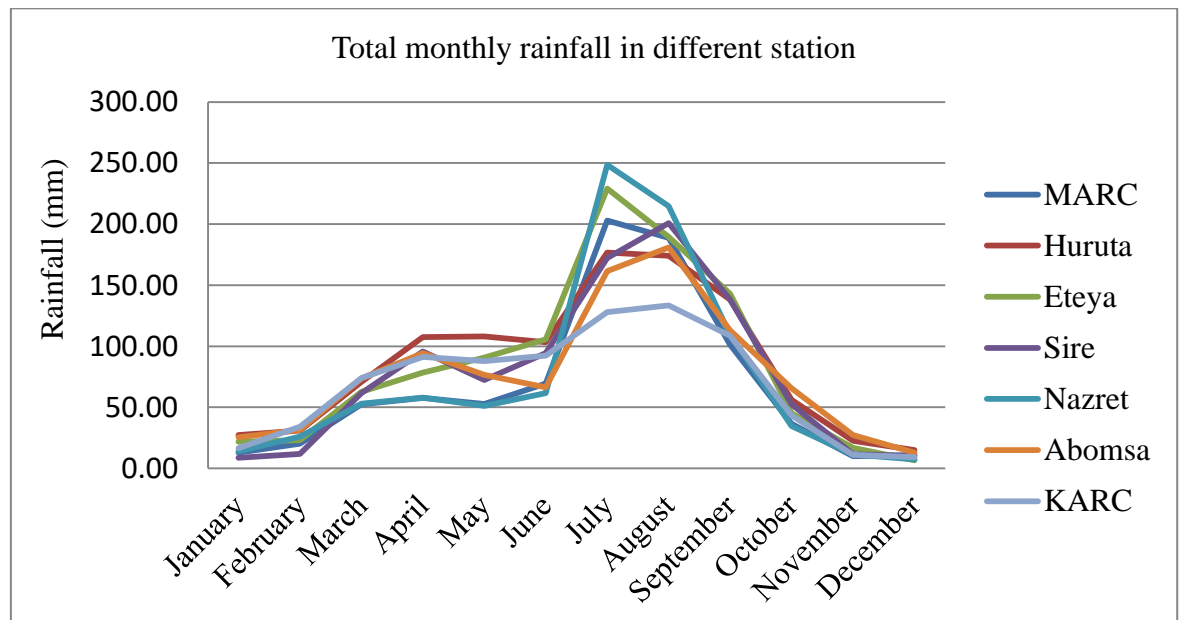


Figure 3.3 Total monthly rainfall in the different station within and near the study area

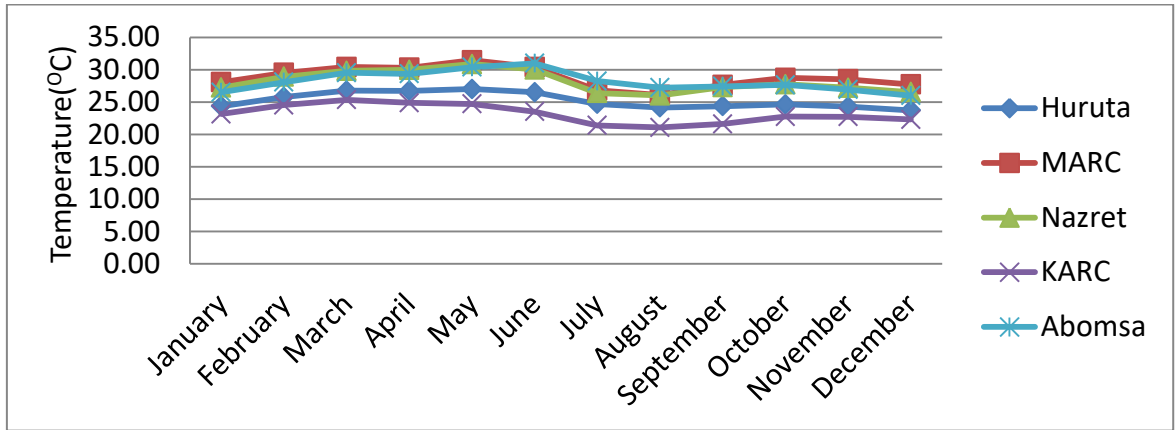


Figure 3.4 Monthly maximum temperature in the different station within and near the study area.

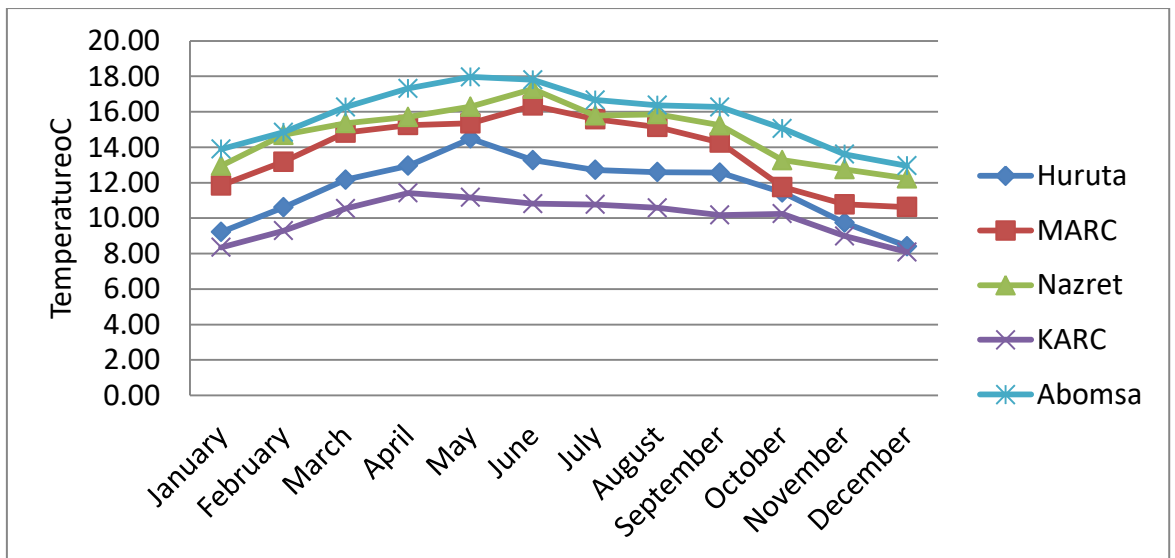


Figure 3.5 Monthly minimum temperature in the different stations within and near the study area.

3.2.1.1.3 Soil data

The soil map required for SWAT model input was obtained from the Ministry of Water Irrigation and Electricity of Ethiopia. The soil map introduces to the SWAT database linked to the user soil database information by loading the soil look-up table and

reclassification was done. The dominant soils in the basin were Eutric Nitosol, Haplic Xerosol, and Dystric Nitosol. The major soils at Keleta Watershed are illustrated in Table 3.2 and Figure 3.6.

Table 2.2 The areal coverage of soil map at Keleta Watershed (MoWIE, 2016)

No	Soil class	Area (ha)	Area coverage (%)	Hydrologic soil group	Soil texture
1	Eutric Nitosol	51952.28	68.82	B	Silt-loam
2	Dystric Regosol	8637.91	11.44	A	Sandy-loam
3	Haplic Xerosol	14896.87	19.73	B	Silt-loam

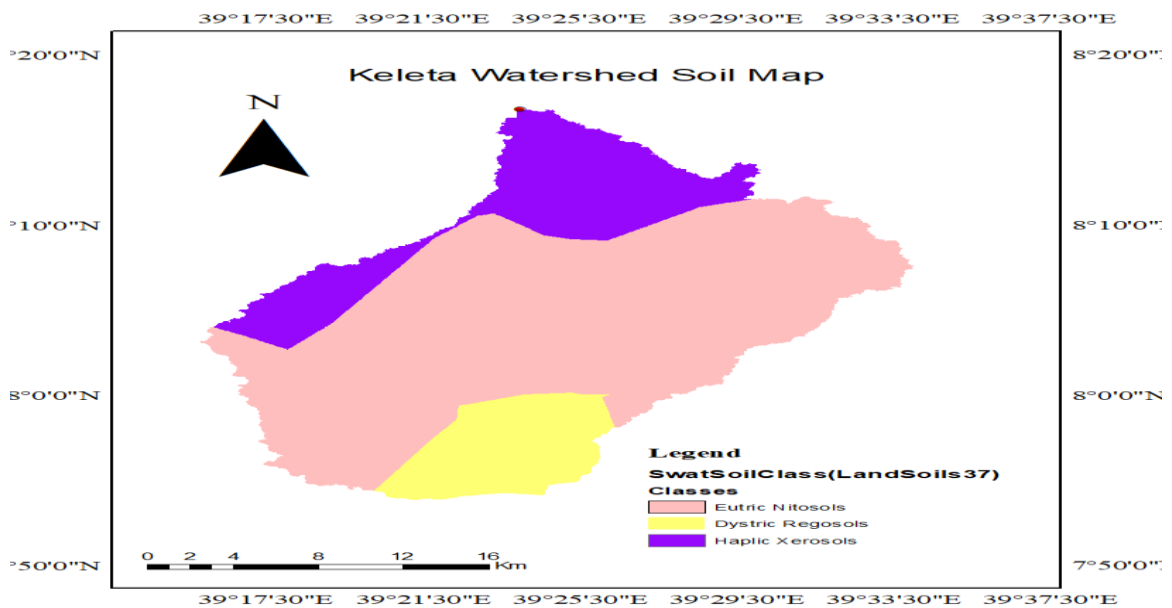


Figure 3.6 Soil map of Keleta River Watershed (MoWIE, 2016)

3.2.1.1.4 Land use land cover Data

Land use land cover was used as an input to the SWAT model to estimate surface runoff at the watershed. Land use data used for this study were Landsat satellite images covering

the Landsat 8 OLI/TIS acquired on 1 December 2015. The Landsat images were downloaded from United States Geological Survey (USGS) Earth explorer (<https://earthexplorer.usgs.gov/>). The image was pre-processing using ArcGIS 10.1 software and projected to Universal Transverse Mercator (UTM) projected system with the datum of world geodetic system 1984 (WGS 1984) and Northeast Zone 37. The land data were reclassified by ArcGIS software using a supervised classification method. The reclassification was based on visual and digital satellite image interpretation and a previous study (Bekele, 2017). During reclassification, training sites in this study, fifty training sites were been identified were selected by using a reference of Google earth and field visit collected data. The supervised classification was applied after defined area of interest (AOI) which is called training classes. The classification was done using interactive classification and the study area was clipped by using the boundary of the Watershed. The final merged classified LULC were agricultural and settlement land, degraded land, forest land, shrubs, and grassland and wetland. From the total land cover area, the highest (65%) area was covered by agriculture and settlement. Figure 3.7 shows the land use cover of Keleta River Watershed.

3.2.1.1.1 Land use Classification Accuracy Assessment

One of the most important final steps at classification process is accuracy assessment to quantify how the classification effectively much with the correct land cover classes (Rwanga an Ndambuki, 2017). An error matrix was produced for accuracy assessments which used to comparing the predicted result by ArcGIS analysis to a reference or ground truth data for selected sample points (Congalton 1991; Foody 2002).

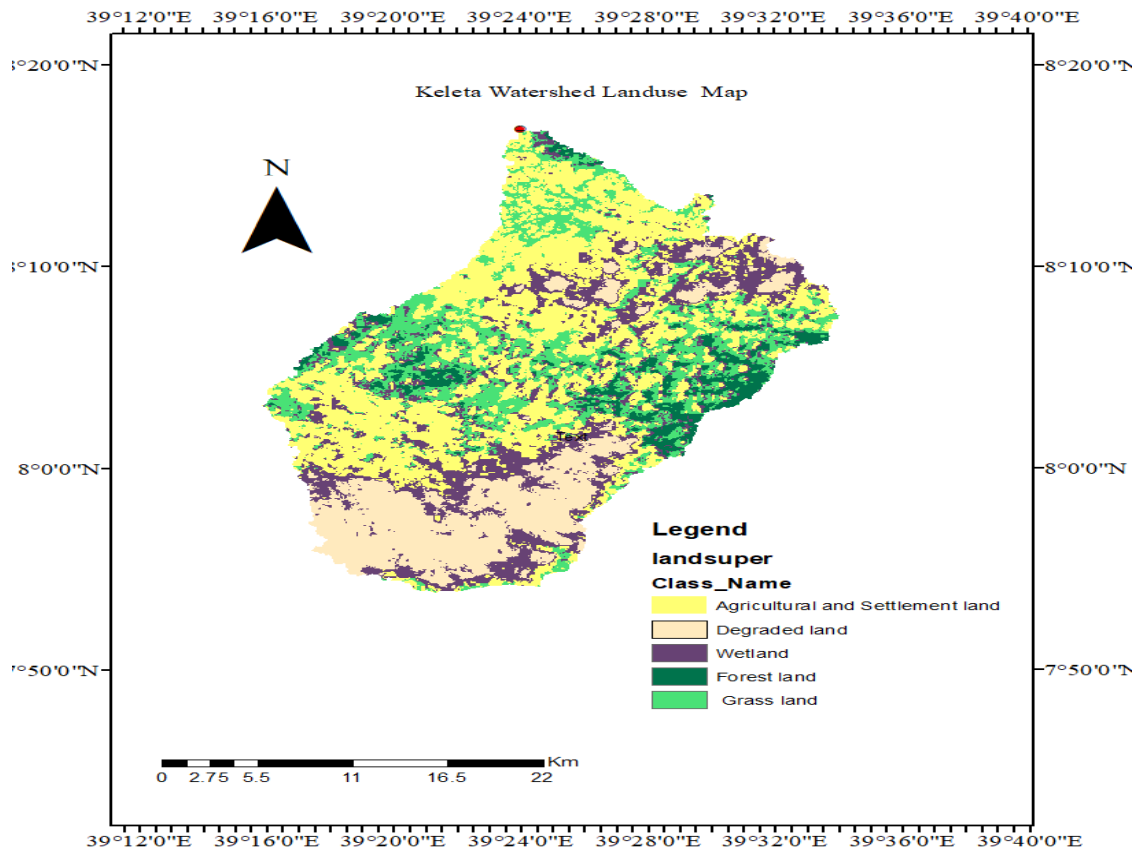


Figure 3.7 Keleta River Watershed land use map

An error matrix usually provides detailed assessment of the agreement between the classified results and reference data, with the information of how the misclassification happened. For accuracy evaluation, overall classification accuracy and Kappa coefficient were calculated from the error matrix. The Kappa statistic had used to measure the agreement between two sets of categorizations of a dataset (Tewabe and Fentahun, 2020). Full accuracy assessment needs to include the report on Overall accuracy, User Accuracy, and Producer Accuracy had investigated using the Kappa coefficient (Tewabe and Fentahun, 2020). In this study 116 random ground control points had used to validate the classified images at 2015 using Global Positioning System (GPS) point from Google

earth. The results from accuracy assessment indicates that 78.2% of overall accuracy and 73.28% of Kappa coefficient value. KAPPA is computed as (Congalton, 1991):

$$K = \frac{N \sum_{i=1}^r X_{ii} - \sum_{i=1}^r (X_{i+} * X_{+i})}{N^2 - (\sum_{i=1}^r X_{ii} * X_{+i})}$$

Where; r = number of rows and columns in error matrix, N = total number of observations (pixels) X_{ii} = observation in row i and column i, X_{i+} = marginal total of row i, and X_{+i} = marginal total of column i. Table 3.3.1 indicates the error matrix of land use classification.

Table 3.3. 1 Error matrix of land use classification

		Reference					Row Total	User's Accuracy
		Agricultural & settlement	Degraded	Wetland	Forest	Grass		
Classification Data	Agricultural & settlement	35	9	1	2	3	50	70.00
	Degraded	1	22	1	0	1	25	88.00
	Wetland	0	2	23	0	1	26	88.46
	Forest	1	0	0	7	0	8	87.50
	Grass	5	0	2	0	17	24	70.83
Column Total		42	33	27	9	22	133	
Procedural's Accuracy		83.33	66.67	85.19	77.78	77.27		78.20

According to (Landis and Koch, 1977) a Kappa coefficient equal to 1 means perfect the classification is agreement with the truth value. In addition to this Kappa coefficient 0.61 – 0.80, 0.41 -0.60 and 0.21 -0.40 is substantial, moderate and fair respectively.

3.2.1.1.2 Digital Elevation Model (DEM)

The DEM (Digital Elevation Model) was obtained from the Ministry of Water Irrigation and Electricity of Ethiopia, which was available in the form of a raster that was used as basic input for the SWAT model. The study area was delineated and the River networks were generated from DEM with a resolution of 30mx30m.

3.2.1.2 Data preprocessing and checking

Collected data contained errors may be of failure of measuring device or data recorder. Before using the data for a specific purpose, the data were checked inhomogeneity and the missing data was filled. The analysis was extended to hydrological and meteorological data that used as input data for water resources potential and demand estimation used by ArcSWAT and WEAP model. If recorded data at rain gauge stations have undergone significant change during the period of record, inconsistency would appear in the rainfall data of the station. Checking the rainfall data inconsistency is done by the double-mass curve technique (Belay and Melese, 2019). To use rainfall data for further application their consistency and homogeneity concerning possible should be checked. It is difficult to conduct direct analysis to detect possible errors of climate data (Tilahun, 2015). But it is possible to check the consistency and homogeneity of the individual stations with some reference of other stations by the double mass curve.

3.2.1.2.1 Checking homogeneity and consistency of Rainfall data

The rainfall data and their consistency were checked by double mass curve analysis. If a significant change in the regime of the curve observed it should be corrected by the following equation 3.1(Engdaw, 2015). In addition to this, the rainfall data was checked by cross-correlating between the stations monthly. The result of the correlation coefficient (r^2) implied that all stations were positively and strongly correlated and there were consistent records among the stations (Teso, 2014).

$$P_{cx} = P_x \frac{M_c}{M_a} \text{-----Equation 3.1}$$

Where; P_{cx} is corrected precipitation at any time, P_x is the originally recorded precipitation at period, M_c is corrected slope of the double mass-curve, and M_a original

slope of the double mass curve. But in this study all rainfall data were consistent (that is R^2 were greater than 0.9 for all). The following Figure 3.8 – 3.12 Illustrated the double mass curve graph of the different stations.

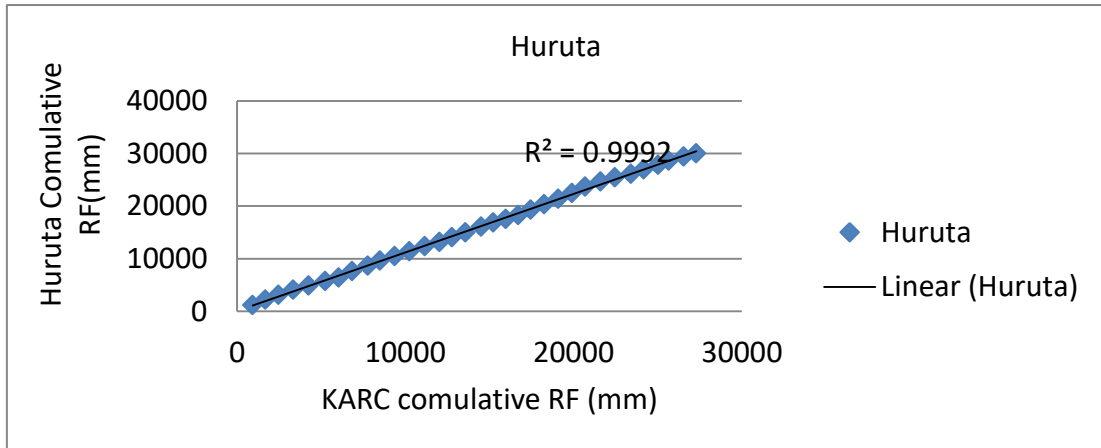


Figure 3.8 Precipitation data consistency check (DMC) for Huruta station

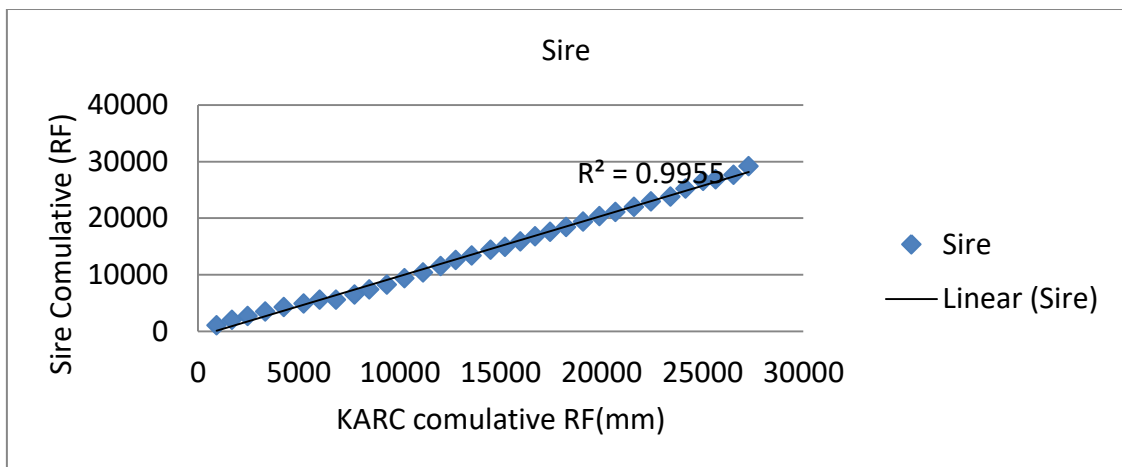


Figure 3.9 Precipitation data consistency check (DMC) for Sire station

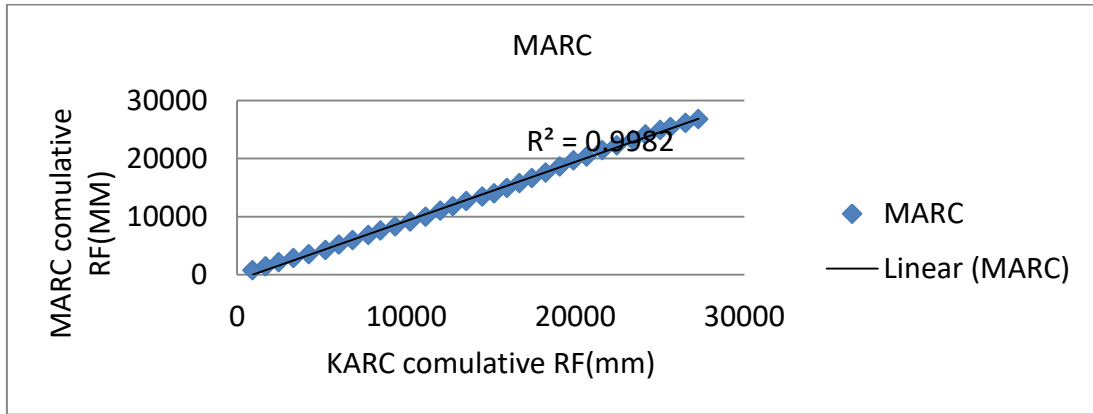


Figure 3.10 Precipitation data consistency check (DMC) for MARC station

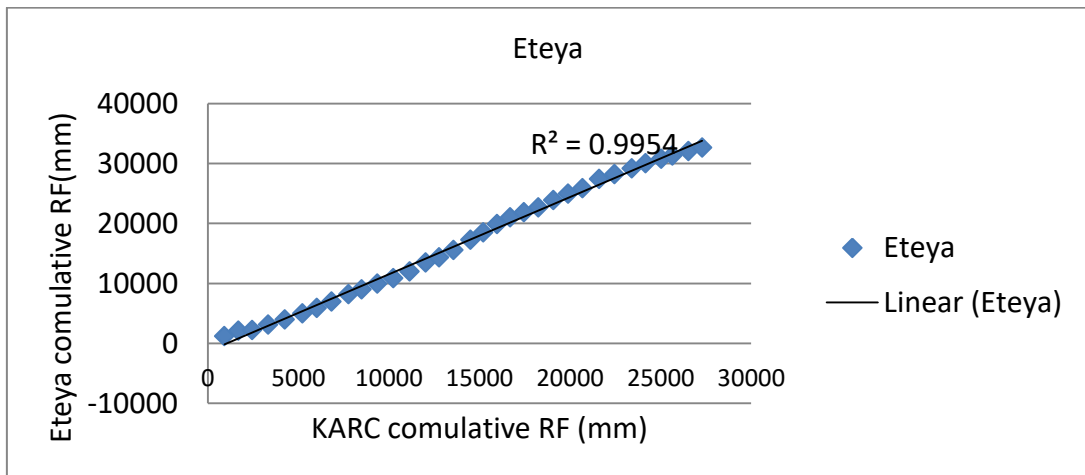


Figure 3.11 Precipitation data consistency check (DMC) for Eteya station

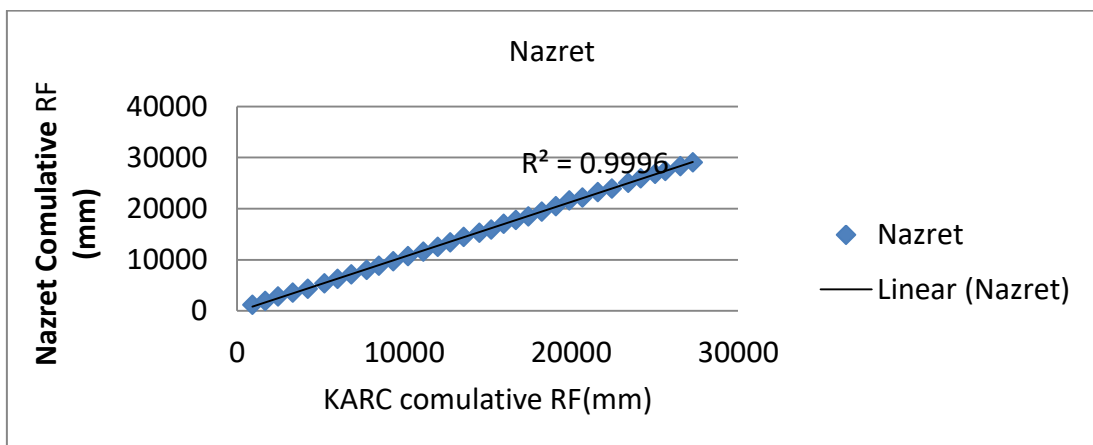


Figure 3.12 Precipitation data consistency check (DMC) for Nazret station

3.2.1.2.2 Missing rainfall data calculation

Some gauging stations may have missing rainfall data due to the absence of the observers or failure of an automatic recorder and it is often necessary filling this missing data for further applications (Sadovski, 2019). The station located within and near to the Watershed uses to fill the missing data by considering the hydro-meteorological similarity of the group station (Engdaw, 2015). Missing rainfall data were estimated by the normal ratio method which the normal annual precipitation of the index station greater than positive or negative ten percent of annual precipitation of the interpolated stations otherwise arithmetic mean method is recommended (Dingman,2002).

Normal ratio method: The rainfall surrounding the index station is weighed by the ratio of normal annual rainfall as follows in equation 3.2. However, some missing weather elements were generated using an ArcSWAT weather generator (WGNMarker4). The weather generator stations (Kulumsa and Melkasa station) have been firstly prepared in the proper text formats in which the ArcSWAT can understand. Weather generator input parameters for all-weather generator stations are shown in (APPENDIX Tables 4 and 5).

$$P_x = \frac{1}{n} \left[\sum_{i=1}^n \frac{N_x}{N_i} * P_i \right] \text{-----} 3.2$$

Where, P_x is the missing precipitation for any storm at the interpolation station 'x', P_i is the precipitation for the same period for the same storm at the "ith" station of a group of index stations, N_x is the normal annual precipitation value for the 'x' station and N_i is the normal annual precipitation value for 'ith' station.

3.2.1.3 Watershed delineation and HRU definition

The watershed delineation was done by the Soil and Water Assessment Tool (SWAT) model which is an ArcGIS extension having its user interfaces such as SWAT project setup, watershed delineator, HRU analysis, write input table, edit SWAT input, and SWAT simulation. The delineation started from the SWAT project setup, an opening working directory where all outputs from the model are saved; then the automatic watershed delineator is active and the Awash River Basin DEM was loaded to the SWAT model from the disk. After that the DEM project set was done, the stream definition is based on DEM based and the stream network was created automatically. Watershed outlet definition and the selection was done manually to add the outlet at the location of stream gauging stations that is important for comparing measured and simulated discharge at the Watershed.

The hydraulic Response Unit (HRU) is defined by lumping similar land use, soil type and optionally slope characteristics within a given sub-basin based on user-defined thresholds for each category (Her et al., 2015). One to five slope classes can be appropriate and three or fewer slope classes are sufficient for most situations however, more than five classes are unreasonable (Arnold, 2010). In this study, multiple slope discretization operation was preferred over the single slope discretization, and two slope classes with the slope range of 0–2% and > 2% were used. SWAT, allows users to specify thresholds of land cover, soil, and slope in defining HRUs (Her et al., 2015).

Although, there is no discrete recommended HRU number per area, as a general rule a sub-basin should have 1-10 HRU and recommended a greater number of sub-basins in the watershed than many HRUs within a few sub-basins (Arnold et al., 2011). Thresholds from 5% to 15% are commonly used (Han et al., 2012 and Johnson et al., 2012). Similarly, the

multiple HRUs with 10% threshold value for both soil and land use, and 5% for slope were preferred. Finally, 19 sub-basins with 125 HRU calculated and the watershed delineation and HRU analysis were completed.

3.2.1.4 Sensitivity analysis

After the model setup and all SWAT input data were loaded, the next step was continued as a sensitivity analysis. The sensitivity analysis was conducted automatically with the help of SWAT CUP Software in SUFI-2 using global sensitivity analysis. Sensitivity analysis determines the effect of different input parameters on the model output for which parameter significantly affect our results. During the calibration of the model, the most difficult thing is which parameter effect high on the model output value that is near or equal to the actual measured hydrologic value. At this condition sensitivity analysis useful to identify and order parameters that affect the model result from high to low or no significant effect. Parameters that have no significant effect on the model output were not used for the calibration purpose. Only parameters which have a high and medium effect are used for calibration purpose.

3.2.1.5 Model Calibration

Model calibration is the regulation of the input parameter until the model result and observed data are near to similar or equal. Input parameters determined in the sensitivity analysis that have a significant effect are used to calibrate the model. In the calibration process, the model input parameters were varied until the simulated result approach to the recorded streamflow value. The model calibration was conducted by adjustment of the model parameter values to get accurate simulation results based on the recommended model performance value. This calibration was conducted manually and automatically

with the help of SWAT-CUP software. The SWAT model was calibrated by using monthly base time-series streamflow data from January 1, 1999, to December 1, 2006.

3.2.1.6 Model Validation

After the calibration process is completed and the optimum parameters are determined the model was validated by using recorded streamflow data. The data for the period from January 1, 2011, to December 1, 2015, was used for validation. The simulated flow and the observed flow were compared to evaluate the model performance.

3.2.1.7 Model Evaluation

During the model calibration and validation, the model parameters were adjusted until observed streamflow and simulated flow show an acceptable level of agreement. Those agreements are evaluated by different statistical measures that determine the quality and reliability of simulated value compared with the observed value. The most common model performance measures are the coefficient of determination (R^2), Nash-Sutcliffe simulation efficiency (NSE), root mean square of error (RMSE), and percent bias (Moriasi et al., 2007, Masih, 2011, Santhi *et al.*, 2011).

The coefficient of determination (R^2) is an indicator of the strength of the linear relationship between the observed and simulated value, while NSE indicates how well the plot of observed versus simulated value fits the line.

$$(R)^2 = \left\{ \frac{\sum_{i=1}^n (O_i - O_{avr})(P_i - P_{avr})}{\left[\sum_{i=1}^n (O_i - O_{avr})^2 \sum_{i=1}^n (P_i - P_{avr})^2 \right]} \right\}^2 \text{-----} 3.3$$

Where O_i is the observed value, P_i is the predicted value; O_{avr} and P_{avr} are arithmetic mean of observed and simulated flow respectively. N is the number of observations during the simulation period.

$$NSE = 1 - \frac{\sum_{i=1}^n (O_i - P_i)^2}{\sum_{i=1}^n (O_i - O_{avr})^2} \text{-----} 3.4$$

Where O_i is the observed value, P_i is the simulated value and O_{avr} is the arithmetic mean of the observed value.

The root mean square of error (RMSE) is the ratio of the root mean square of the error to the standard deviation of measured data.

$$RMSE = \sqrt{N^{-1} \sum_{i=1}^n (O_i - P_i)^2} \text{-----} 3.5$$

Where O_i and P_i are observed and simulated streamflow data, n is the number of observations.

Percent bias (PBIAS) measures the average tendency of simulated data to be larger or smaller than their counterparts. The optimal value of PBIAS with a low magnitude value indicates accurate model simulation. The positive value of PBIAS indicates model underestimation bias and the negative value indicates overestimation bias.

$$PBIAS = \frac{\sum_{i=1}^n (P_i - O_i)}{\sum_{i=1}^n O_i} * 100 \text{-----} 3.6$$

Where, P_i and O_i are the simulated and observed streamflow respectively.

3.2.2 Current water demand assessment by WEAP model

The water demand is the total amount of water required to meet domestic water, livestock, agricultural water, industrial and commercial, environmental, and hydropower water demand. Generally, water demand calculation is done by estimating all of the above water

demand. The average demand is the sum of all domestic, public water, industrial, livestock, and environmental demand. The current Account represents the basic definition of the water system as it currently exists. It is assumed to be the starting year for all scenarios (Sieber and Purkey, 2015). The current account is based on the data available in that year (Tilahunl, 2015). The current account for this study started in the year 2020. At this step demand sites, such as domestic, public, industrial, irrigation, and environmental water demand were identified at the Watershed. The annual level of activity, annual water use rate per unit of activity, demand site priority and monthly share of annual demand was feed to the WEAP Model. In most allocation system basic societal needs such as domestic, livestock and water for an ecological reserve: which is the water required to protect dependent aquatic ecosystems is naturally the first priority (speed *et al.*, 2013). This study assumes domestic, livestock and environmental prioritized first and irrigation demand site second. Then, the model gives the current monthly average and total annual water demand for all demand sites. SWAT simulated surface flow data at the catchment used as demand-supply input for the WEAP model.

3.2.2.1 Domestic water demand

The domestic water demands are the water requirement to accomplish households that can be sub-grouped into urban and rural domestic water demand. Estimating domestic water demand and consumption at the catchment level for rural areas in Ethiopia is difficult due to the lack of measured data available. Consumption is the actual volume of water consumed, whereas demand is how much water people would use if they have the opportunity. There are two main methods for assessing rural domestic water demand assessment (Wallingford, 2003).

Those are indirect methods where the quantity of water consumed is from the population level and estimated demand level in terms of per capita consumption. The direct methods were socioeconomic surveys and participatory techniques involving the relevant stakeholders. The indirect method of estimating is relatively straightforward to use and the most practical method on a sub-catchment and catchment basis. It requires population data per capita water demand and losses/leakage.

The second growth and transformation and plan of Ethiopia (GTP II) were used as a benchmark to estimate per capita demand in the watershed. The water demand standard based on the newly revised GTP II is 40- 100 lpcd for urban and rural respectively up to the year 2020 (Tilahun, 2015). But this study forecast the water demand up to the year 2045 which is above GTP II, therefore the water demand will increase, assuming a 20% increment From GTP II, it becomes 48 and 120 lpcd for rural and rural respectively.

The water demand was estimated by multiplying the annual water use rate by the total population number found at the watershed. The population data collected from the Central Statistical Agency on census 2007 was projected to the targeted year. According to reported by (STATISTA, 2020) population growth compared to previous year: 2019, 2.58%. 2018, 2.62%. 2017, 2.66%. 2016, 2.71%. 2015, 2.76%. 2014, 2.8%. This statistic shows the population change in Ethiopia from 2010 to 2020. In 2020, Ethiopia's population increased by approximately 2.54 percent compared to the previous year (<https://www.statista.com/statistics/455127/population-growth-in-ethiopia/>). Because of this population was projected to the target year (Appendix table 12 page 95) by geometric population projected method assuming that a population will change by the same percentage rate over a given increment of time in the future as during the base period(George et al., 2014).

$$P_t = (P_1) [(1 + r)^z] \text{----- Equation 3.7}$$

Where P_t is the population in the target year, P_1 is the population in the launch year, r is the average geometric rate of change, and z is the number of years in the projection horizon.

3.2.2.2 Agricultural water demand

The agricultural water demand is estimated based on agricultural land use, the crop is grown, and water requirement at the given area. To compute the water requirement, the crops were selected based on field assessment and data collected from Arsi Zone Water and Irrigation development office. The major crops that are grown in the area were used to estimate crop water requirements are Tomato and Onion by the FAO CROPWAT model at the watershed. The irrigation water need of a certain crop is the difference between the crop water need and that part of the rainfall which can be used by the crop (the effective rainfall).

Crop water requirement is determined, usually on a monthly basis; the crop water need is expressed in mm water layer per time unit, in this case mm/month. The effective precipitation is estimated on a monthly basis, using measured rainfall data (Appendix Table 1- 3). For all crops and for each month of the growing season, the irrigation water need is calculated by (Appendix Table 6 and 7) subtracting the effective rainfall from the crop water requirement. Crop Information, crop coefficient (K_c), rooting depth, critical depletion fraction (p) and length of individual growth stages used for irrigation water requirement illustrated at appendix table 11.

The average seasonal crop water requirement of those crops which estimated by CROPWAT software was feed to the WEAP model in volume per hectare ($5354 \text{ m}^3/\text{ha}$).

The total actual production area of all small scale and medium scale irrigation schemes (Arsi Zone Water resource, and irrigation development sector) were 637 ha and 1100 ha of land respectively. In addition to this, there is a dam under construction which its source of water is keleta River with the capacity of developing 1100 hectares of land. SWAT simulated streamflow at the catchment used as a source of water for the WEAP model. In this study, small scale and medium scale irrigation schemes were considered within the watershed. Existing irrigation schemes are illustrated in Table 3.3.

Table 3.3 Location of irrigation schemes at the catchment

No	Scheme location	Scheme name	potential irrigation area(ha)	Current status
1	Hitosa woreda	1	176	Functional
2	Lodehitosa woreda	2	1561.5	Functional
3	Dodota woreda	Dam	1100	Under construction

(Source, Arsi Zone Water resource, and irrigation development sector)

3.2.2.3 Institutional and commercial water demand

The water demand for shops, offices, restaurants, hotels railway stations, and airports are categorized under commercial water demand. Whereas the water demands for hospitals, schools, universities, and government offices are grouped into Institutional water demand. Usually, all these water demands are generalized as public water demand and it is considered as 5% percent of average domestic water demand (Engdaw, 2015). The commercial and institutional water demand (120×0.05) would be 6 lpcd for this Watershed.

3.2.2.4 Hydropower and Industrial water demand

Hydropower is a form of renewable energy that uses water stored in Adam as well as water flowing in a large river to produce electricity through hydropower plants. In this study area, there is no hydropower plant, so hydropower water demand is not considered

by the WEAP model. Industrial water demand is water consumed by industries to cool intermediate inputs, producing high-pressure steam, direct use for production, etc. Assuming the development of industries in the (Engdaw, 2015) Watershed and for planning purposes, 10% of domestic water demand is assumed for towns while a rural area is not accounted for. Therefore the industrial water demand would be 12 lpcd at Watershed.

3.2.2.5 Livestock water demand

The water demand for livestock is affected by several factors, for example, type of livestock, location, type of diet, temperature, weight, etc. The number of livestock found in the watershed was collected from Aris Zone Agricultural Offices. In this study, the estimation of livestock water requirement accounts for only the number and type of livestock and determines the average water demand per day as indicated by Table 3.4.

Table 3.4 Daily water demand under African condition

Animal	Weight(kg)	Minimum water Demand(Liter)	Maximum water Water demand(liter)	For planning purpose
Cattle	350	16.4	56.1	25
Sheep	35	1.9	5.2	5
Goat	30	2	5.4	5
Horse	-	-	-	25
Mule	-	-	-	25
Donkey	-	-	-	25

Source: (Kinde, 2015)

To determine the average water demand per livestock per day, taking the average of all livestock daily water demand. Therefore the average water demand for livestock becomes 16 liters per day per livestock. Table 3.5 indicates the daily, annual livestock water demand per head and total estimated total number of livestock with in the watershed.

Table 3.5 Annual Livestock water demand at the catchment

Animals	Daily average water demand (lt/head/day)	Annual water demand (Cu.mt/hd/yr)	Total livestock (Head)
Cattle	25	9.13	189081
Sheep	5	1.83	233076
goat	5	1.83	59641
Horse	25	9.13	11628
Mule	25	9.13	2075
Donkey	25	9.13	54057
Average	16	6	-

3.2.2.6 Environmental flow water demand

Considering Environmental flow is necessary for the prevention of invasive plant species, navigations, recreations, wildlife, and other downstream water abstractors. To maintain the ecosystem some portion of the river flow should be reserved. In this study, 10 % of the mean annual run of the watershed is accounted for the environmental flow requirement by the WEAP model.

3.2.3 Scenario based water demand assessment by WEAP model

According to the report (USIAD, 2016) drought is the single most destructive climate-related natural hazard in Ethiopia and climate change may reduce Ethiopia's GDP up to 10 percent by 2045, primarily through impacts on agricultural productivity. Therefore predicting what would be the water demand for the future 2045 is important. A scenario can be developed from the reference scenario with an alternative assumption of what would happen in future development. This scenario assesses the model with the following what-if questions, Such as: What will be the water demand at the catchment if the population growth increases; more efficient and modern irrigation technique used, and irrigated potential area increased. In WEAP the typical scenario modeling consists of three steps. The first current account

year is chosen to serve as the base year of the model. The second reference scenario is established from the current accounts to simulate the likely evolution of the system without intervention.

Finally, a what-if scenario can be created to alter the reference scenario and evaluate the change in policies and/or technologies (SEI, 2016).

3.2.3.1 The reference Scenario

The reference scenario is the current situation, used as a reference to other scenarios with different trends. Other developed scenarios compared to the reference scenario to show its future tendency on the WEAP model result. World Bank (2019) indicated that the Ethiopian population annual growth rate was 2.70% and 2.06% in the year 2017 and 2018. Besides the World Bank report, Worldometer (<https://www.worldometers.info/world-population/ethiopia-population/2020>) report showed that 2.70%, 2.65%, 2.65, and 2.57% annual growth rate in the year 2017, 2018, 2019, and 2020 respectively. This study considered a current 2.57% annual growth rate at the reference scenario extended to 2045 with the current population linear growth rate.

3.2.3.2 High population growth scenario

It is obvious when the Population growth rate changes it also affects social, economic, and environmental development. Population growth is the main factor that affects the water demand and supply balance. High population projection applies to less developed countries that are passing through the demographic transition stage (UNFPA, 2011). Therefore it is important to consider the water demand of the future by the assumption of population growth rates based on historical nature. According to the annual report of (World Bank, Worldometer, and UN (2019) the historically Ethiopian population growth

rate was 3.05, 1.24, 3.66%, and 2.60% in the year 1972, 1978, 1992, and 2017 respectively. This study considers the maximum growth rate (3.66% in 1992) as a benchmark, what would be the water demand if the population growth patterns increase from 2.57 % approaches to 4.5 % using geometric projection methods.

3.2.3.3 Irrigation expansion scenario

Cropping intensities will rise in all developing regions, from 93% to 99% (Bruinsma, 2002). This will arise through the way of a shortening of fallow periods, and an increase in multiple cropping made possible partly by growth in the irrigated area (Bruinsma, 2003). Therefore this scenario observes irrigation water demand variation with the irrigation area development techniques. What will be the irrigation demand if the irrigable area increases by 5% annual growth rate for the next 2045 year? Irrigated croplands have increased in area from 55 to 65 % in the last past 30 years (from 1986 to 2016) in the Lake Tana Basin of Ethiopia (Abera et.al., 2020). This indicates it increase with 2.20% annual growth rate. Now a day irrigation developments in Ethiopia are emphasis and priorities are given to irrigation in the growth and transformation plan of the country, indigenous knowledge and introduction of promising household water harvesting and micro- irrigation technologies, Government's strong political commitment and encouragement to private and public sectors involvement in irrigation development (Haile and Kassa, 2015). Due to this the current growth rate may be approached to five percent annually.

3.3 Conceptual work flow chart

The general framework used for the assessment of surface water potential and water demand in the study area is illustrated in the next Figure 3.13.

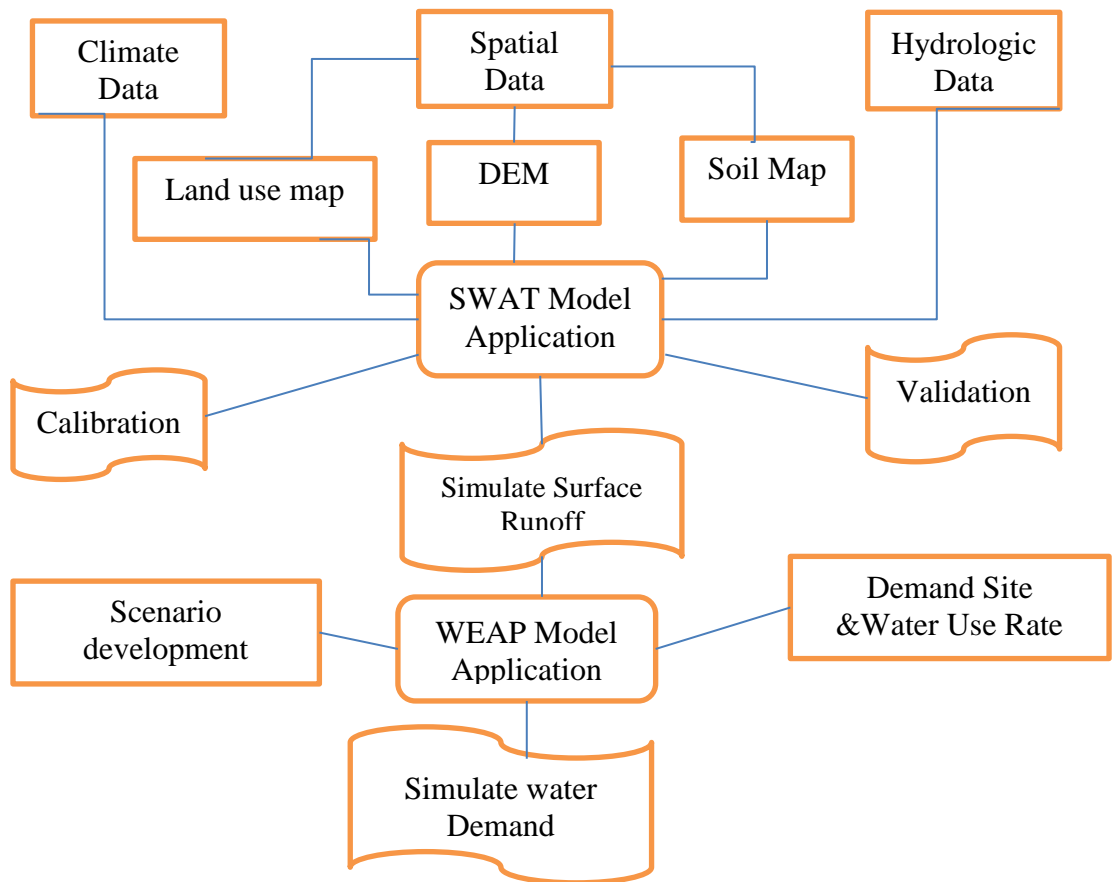


Figure 3.13. Conceptual work flow chart to assess surface water potential and demand

4 RESULTS AND DISCUSSIONS

4.1 Surface water assessment

The meteorological, hydrological, and spatial data, which are the requirements for the SWAT were collected, processed, and input according to the format demanded by the model. Then, the watershed boundary was delineated automatically using the ArcSWAT interface integrated into the model. The quality of rainfall data was checked by cross-correlating among stations on monthly basis. After all, the temporal and spatial data required for the SWAT model were properly loaded, calibration, validation, and sensitivity analysis was conducted, and the surface water balance estimated

4.1.1 Sensitivity analysis

The sensitivity analysis was done to determine which model parameter is more liable to change or has an important effect on the runoff estimation. Results revealed that eleven parameters were found sensitive with the p-value ranges from 0.003 to 0.964 (Table 4.1). the curve number (CN II), groundwater delay (GW-DELAY), effective hydraulic conductivity in the main channel (CH-K2), soil evaporation compensation factor (ESCO), Groundwater “revap” coefficient (GW_REVAP), maximum canopy storage (CANMX), and available water capacity of the soil (SOL_AWC) were the sensitive parameters which had a significant effect on the surface discharge potential. The results further showed that the most sensitive parameter that significantly affected the surface runoff at the watershed was the curve number with a p-value of 0.003 (Table 4.1). The curve number depends on several factors including soil types (textures and permeability) and land use that affects infiltration, surface runoff, and evapotranspiration (Bekele et al., 2019). The streamflow

parameters along with the relative sensitive values for the final calibration analysis have been shown in Table 4.1.

Table 4.1 Calibration parameters and its global sensitivity analysis

Parameters		Global sensitivity			
Code	Description	Relative sensitive value	Range		P-Value
CN2	SCS CN runoff curve number	-0.145	-0.209	0.057	0.003
GW_DELAY	Groundwater delay	0.691	0.000	1.000	0.098
CH_K2	Effective hydraulic conductivity in main channel	90.060	30.000	450.000	0.107
GWQMN	Threshold depth of water in the shallow aquifer required for return flow	1.706	0.000	2.000	0.201
RCHRG_DP	Deep aquifer percolation fraction	69.321	0.000	70.520	0.265
ALPHA_BF	Baseflow alpha factor	0.042	-0.038	0.121	0.393
ESCO	Soil evaporation compensation factor	0.444	0.019	2.056	0.400
GW_REVAP	Groundwater “revap” coefficient	0.188	-0.044	0.267	0.588
CANMX	Maximum canopy storage	78.788	25.176	95.075	0.717
SOL_AWC	Available water capacity of the soil	0.928	0.878	1.039	0.812
SOL_BD	Moisture bulk density	0.243	0.077	0.693	0.964

4.1.2 SWAT model calibration and validation

The error indices used to measure the goodness of fit of the model were Nash and Sutcliffe (NSE) and the coefficient of determination (R^2). The NSE value of 1.0 indicates a perfect match, a value of 0 indicates the model’s prediction is no better than using the mean of observed values, and a value of less than 0 indicates the model is unrealistic (Nash and Sutcliffe, 1970). The simulation result of a model is assumed to be acceptable when the value of $R^2 > 0.6$ and $NSE > 0.5$ (Chekol et al., 2007; Zhang et al., 2016). The model

calibration and validation were undertaken using SWAT Calibration and Uncertainty Programs (SWAT-CUP) using the measured data from 1999 to 2006.

The overall model calibration results showed good fitness compared to the measured streamflow data (Figure 4.1). The computed error indices were: (i) $R^2 = 0.72$ and (ii) $NSE = 0.70$, which showed a good agreement between simulated and observed streamflow data. Despite the overall goodness of fit of the model calibration, there were both under- and over-estimation of the observed data for a period few months (Figure 4.1).

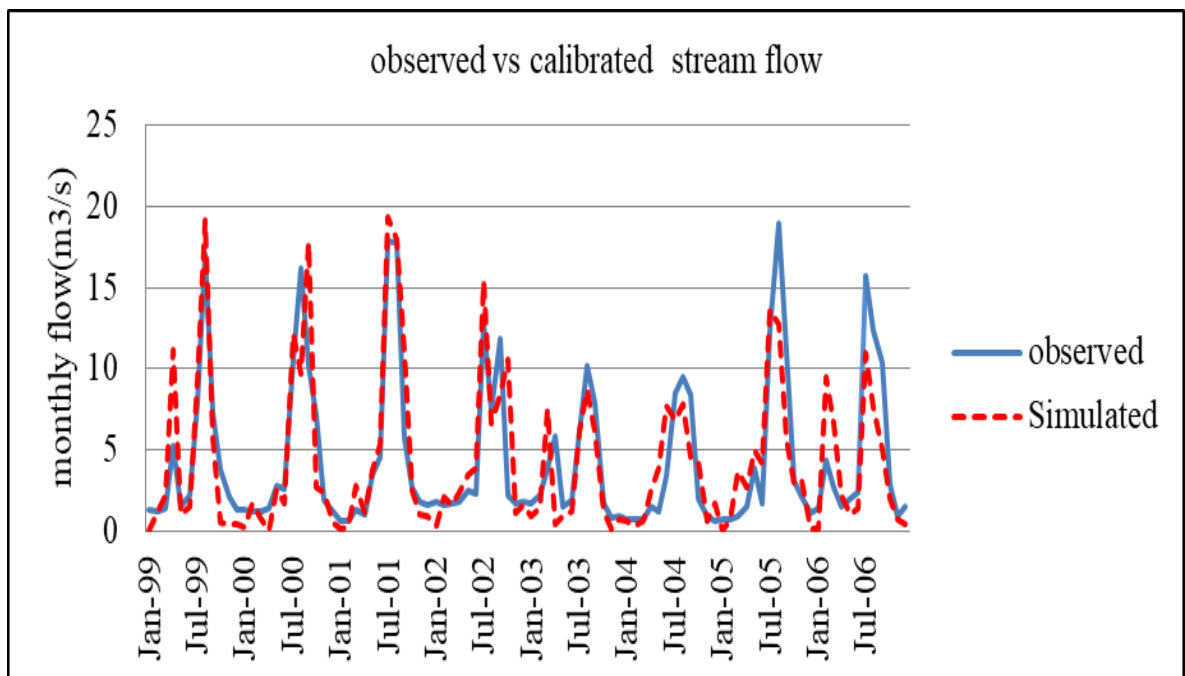


Figure 4.1 Observed vs. Simulated streamflow during the calibration period

The fitted model parameters during the calibration period were validated using an independent dataset. The reliability of the fitted model parameters was validated using an independent dataset from 2011 to 2015 based on monthly time step streamflow data. The computed error indices for the validation period were (i) $R^2 = 0.80$ and (ii) $NSE = 0.79$ showing good agreement between simulated and observed streamflow data (Figure 4.2).

According to the finding (Leta and Teka, 2018) at Upper Awash river basin the calibration was less than the validation result ($R^2= 0.69$, $NSE = 0.69$ during calibration and $R^2= 0.88$, $NSE =0.74$ during validation) which is agreed with the calibration and validation result of this study.

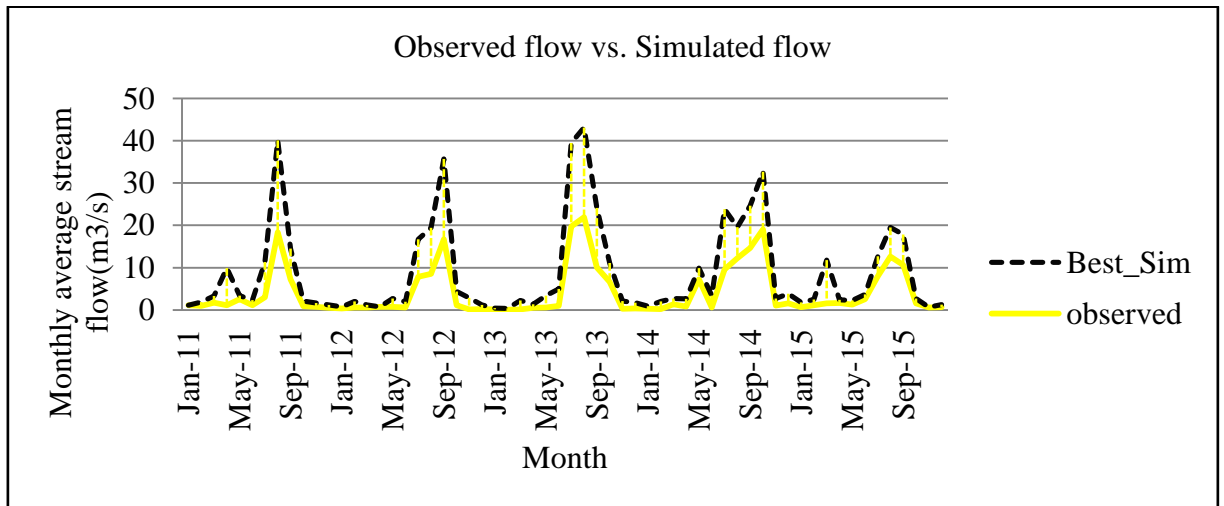


Figure 4.2 Observed vs. simulated monthly streamflow during the validation period

4.1.3 Simulated water balance

After all, necessary SWAT input data were prepared according to a compatible format, and the model calibration and validation were accomplished, simulation activities were carried out. The simulations using the SWAT model were performed for 30 years from 1987 to 2017 on monthly and annual bases to predict the amount of runoff in the watershed. The total water yield or stream flow that reaches the headwork was computed as the sum of surface runoff, lateral soil flow, and groundwater contributions minus transmission loss (water lost from tributary channels in the HRU via transmission through the bed and becomes recharge for the shallow aquifer during the time step), whereas the change in soil water storage was computed as the difference between inflow and out flow (Teso et al., 2014).

The highest surface flows observed in this study were in July, August and September with values of 56.0, 42.1 and 20.1 mm, respectively (Table 4.2). The result was in agreement with Bekele et al. (2019) who reported that the mean monthly surface runoff reached its maximum value during the main rainy season in July, August, and September. The lowest surface flows were observed from November to February with discharge depths varied from 1.5 to 2.9 mm (Table 4.2), respectively, which differed from Bekele et al. (2019) who obtained the lowest from March to May.

The mean annual rainfall over the entire Western Catchment was 850 mm and over the headwaters of the Awash (Kerim et al., 2016). The mean annual rainfall, evapotranspiration and surface runoff in the Keleta Watershed were 831.1, 451.4 and 165.5 mm, respectively (Table 4.2). The water balance component of the simulation indicated that 54 and 42% of the precipitation were lost through evapotranspiration and contributed to streamflow, respectively. The remaining 13 and 1% of the precipitation percolated down to the soil and recharged the deep aquifers, respectively (Figure 4.3 and Table 4.2).

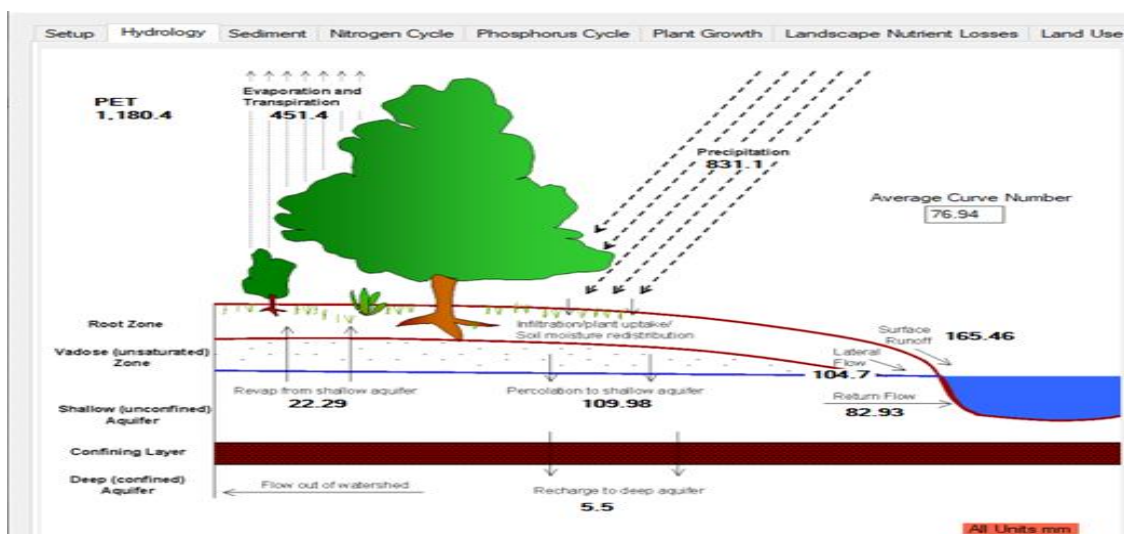


Figure 4.3 Schematic representation of the hydrological cycle for the Keleta Watershed generated using the SWAT model

Table 4.2 Mean monthly hydrological component the Keleta Watershed generated using the SWAT model

Month	Rain (mm)	Surf Q (mm)	LAT Q (mm)	Water yield (mm)	ET (mm)	PET (mm)
1	14.11	1.98	0.94	3.63	12.64	90.00
2	15.66	2.94	1.43	4.90	13.43	90.30
3	51.54	7.78	4.17	12.60	53.38	110.95
4	59.39	6.91	4.85	12.49	62.41	107.89
5	55.71	5.91	4.70	11.64	39.91	112.94
6	70.20	8.55	6.31	16.00	33.25	100.83
7	207.00	55.97	29.36	89.17	55.65	90.46
8	182.62	42.09	29.92	88.31	59.57	91.34
9	106.74	20.14	15.12	60.29	58.08	101.79
10	43.00	10.24	5.75	37.76	30.21	102.40
11	12.36	1.55	1.34	15.32	18.42	93.26
12	12.64	1.54	0.79	6.50	14.37	87.38
Total	830.97	165.60	104.68	358.61	451.32	1179.54

Where Surf Q is surface flow, LAT Q is Lateral flow, ET is Evapotranspiration and PET is potential evapotranspiration.

4.2 Estimated current water demand using the WEAP model

Once the amount available water within the watershed was estimated by the SWAT model and all input data were prepared, the water demand in the study area was estimated by Water Evaluating and Planning (WEAP) model. The schematic view of the WEAP model is shown in Figure 4.4. The first step in the WEAP model is to add a GIS-based vector layer to the project area to orient, construct, and refine the boundaries. The main components of the system such as water sources (Main River), demand and supply sites, and transmission links were added to the schematic area. The prepared current demand sites, water use rate, and annual activity levels were feed to the WEAP model.

The amount of water that is allocated to the environment is a decision made by society, and is to some extent arbitrarily will always be less than what the environment would ideally require (Engdaw, 2016). Globally, the rational level of environmental freshwater requirement to maintain the ecosystem sustainability ranges from 20 to 50% of the mean annual river flow in the basin (Smakhtin, 2004). The other research conducted at Somodo watershed in Southwest of Ethiopia, however, considered 10% of the total flow for the satisfaction of the environmental demand (Tilahun, 2019). The environmental flow was considered 10% of mean annual surface runoff, which is 0.40 m³ s⁻¹ for this study. Thus, the annual environmental water demand of Keleta River Watershed was estimated as 12.45 million cubic meters (MCM) per year.

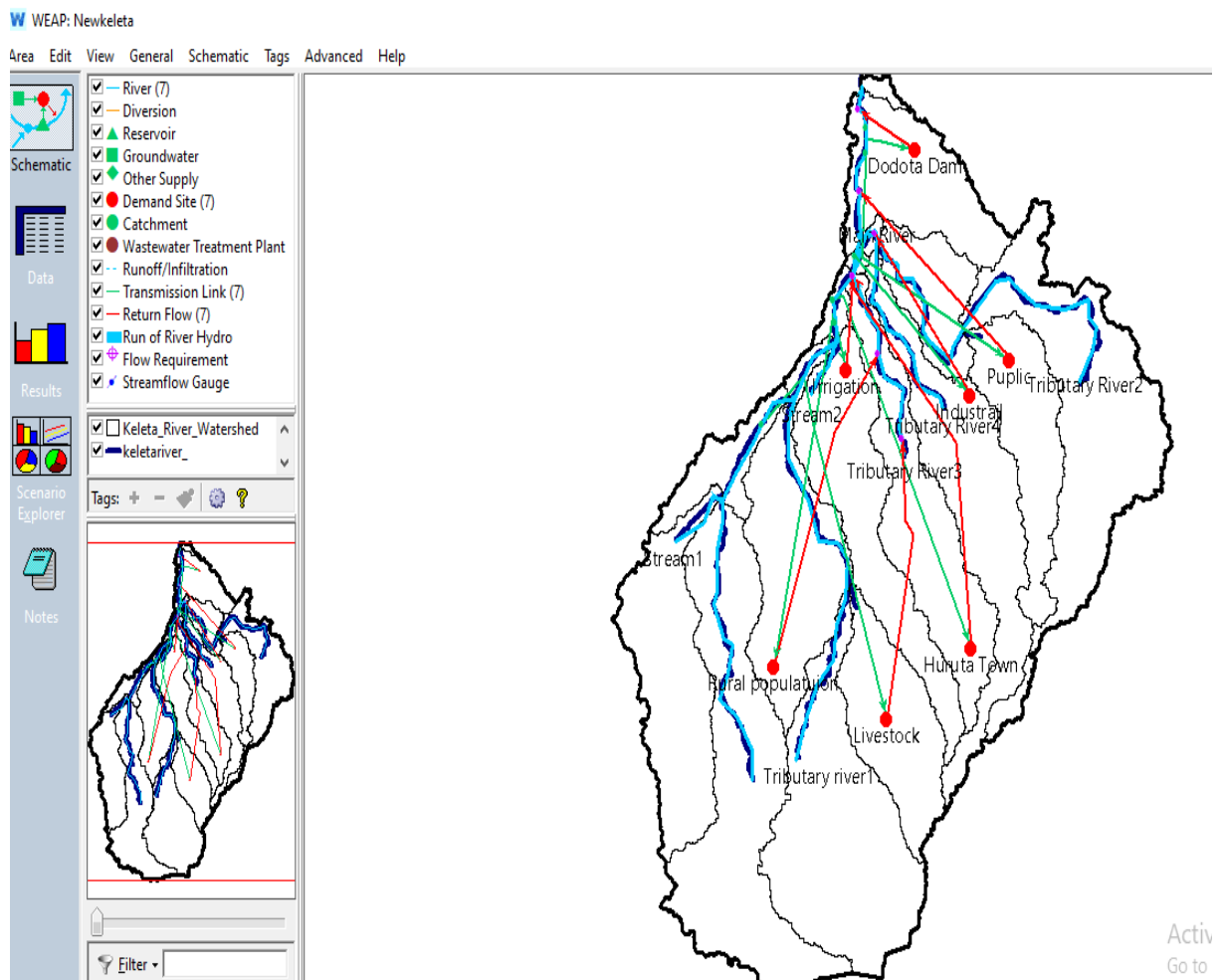


Figure 4.4 Schematic view WEAP model

4.2.1 Current water demand

The current (in the year 2020) total water demand for all sectors within the Watershed was estimated to be 20.26 MCM, which is 18.07% of the total available surface water at the catchment (Figure 4.5). The result of this study showed that the irrigation sector was found the highest consumer of water within the watershed accounting for 9.31 MCM followed by the demand for livestock (3.68 MCM) and rural domestic demand (2.58 MCM) (Figure 4.5). The amount of irrigation water demand is attributed to 46% of the total current demand. The current result is in agreement with Gedefew et al. (2019), who reported that irrigation consumed 44% of the total surface water resources in the Awash River Basin.

Considering the monthly irrigation water demand, the maximum was observed in March, April, May, and June whereas the minimum water demand was obtained in July, August, and September (Figure 4.6). The lowest irrigation water demand during those months was attributed to the supply of water from precipitation. The peak water demand through the year occurred during March, which was 2.97 MCM. The minimum water demand occurred in July (0.93 MCM), August (0.93 MCM), and September (0.90 MCM) (Figure 4.6). The lowest water demand during those months was due to the nonexistence of irrigation activities. During the summer season (June to September), there was usually a sufficient amount of effective rainfall, which could meet the demand crops for optimum production (Tilahun, 2019).

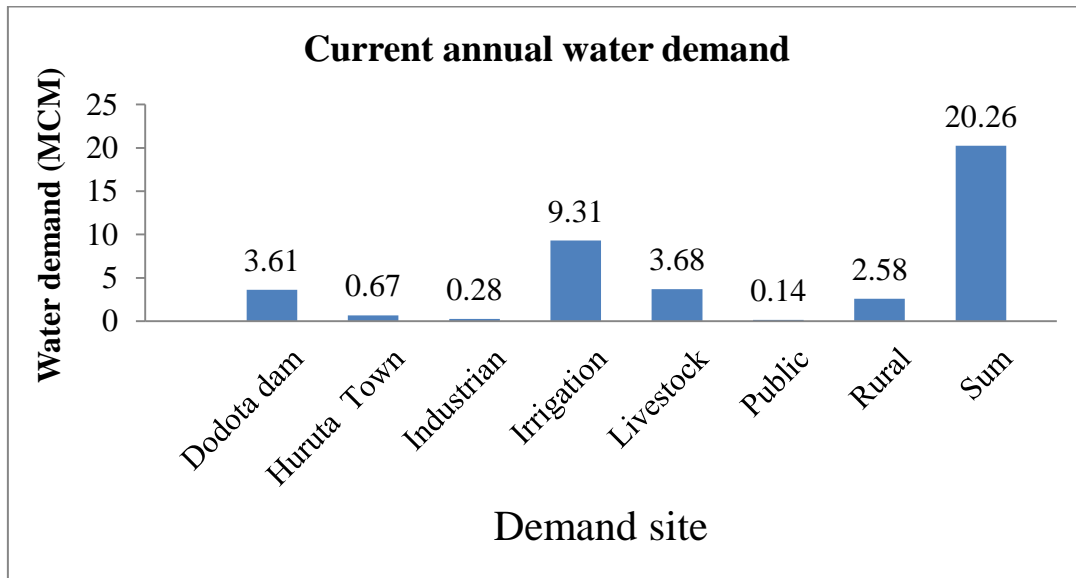


Figure 4.5 Current annual demands

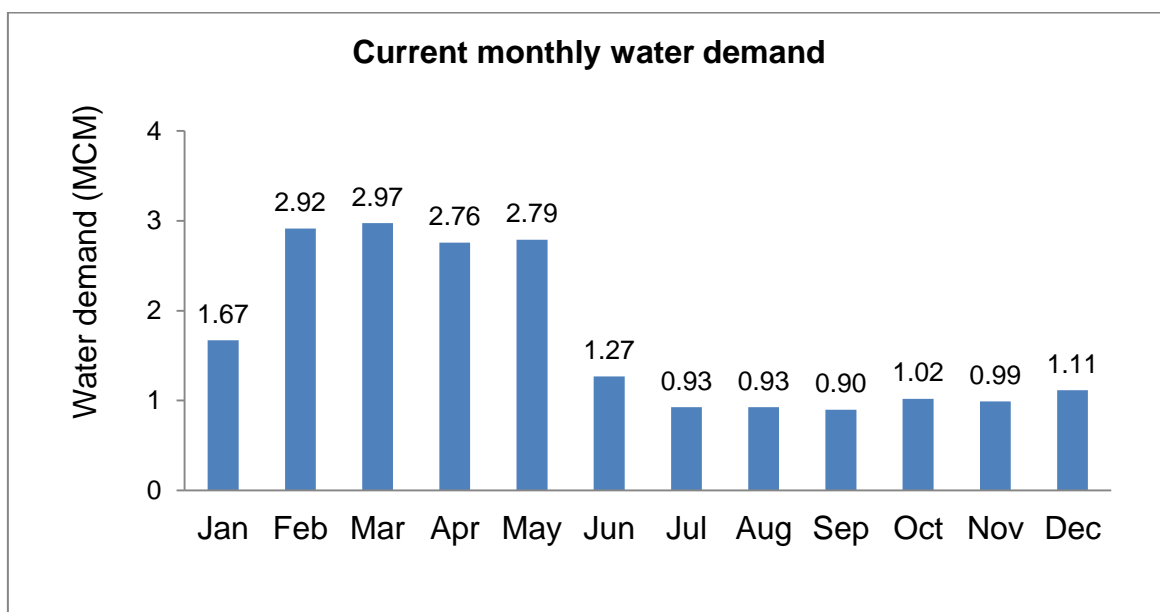


Figure 4.6 Monthly current water demands

4.2.2 Currently unmet water demand

The current account for water demand showed that there was no water shortage in all sectors except for demand related to irrigation (Figure 4.7). The deficit in irrigation water demand from the current account in the study area was estimated to be 0.74 MCM

indicating that only 3.63% of the irrigation water demand was unmet currently. In other words, it meant that 96.37% of the irrigation water demand could be fully satisfied with the surface water available in Kelata watershed. Fufa (2016) in their studies at Koka Reservoir, also found that from the total irrigation water requirement 0.1% of the total demand was unmet, which agreed well with the result of the current study. A similar study was conducted in the Awash River basin and was found that the average annual water demand exceeded the available surface water. The overall evaluation revealed that the available surface water in Keleta Watershed could not fully meet the existing demands.

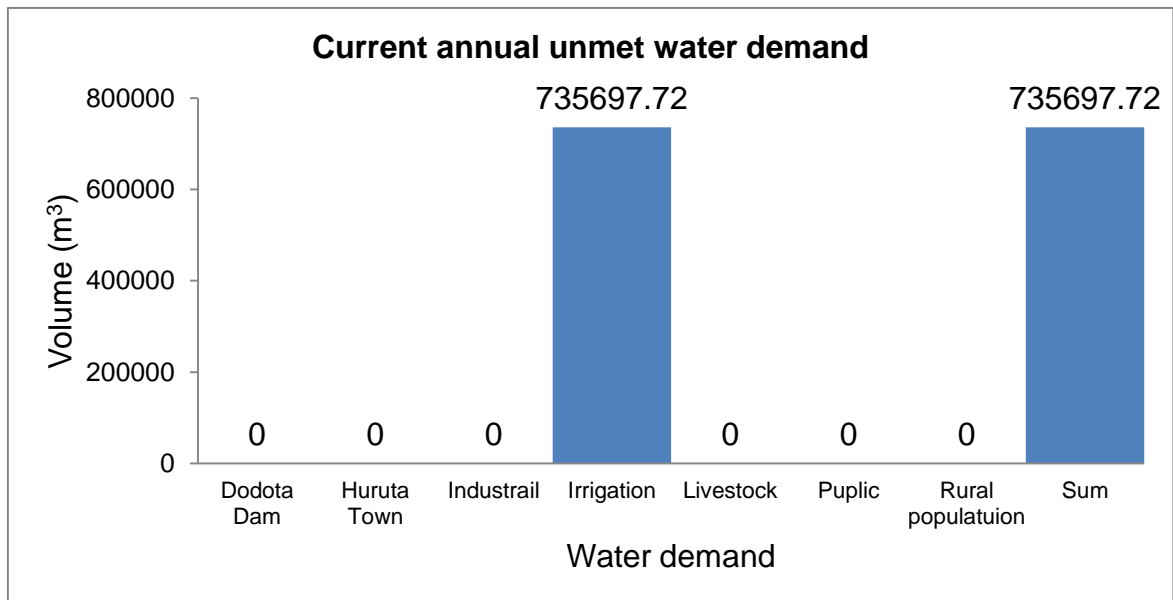


Figure 4.7 The unmet current water demands in Keleta Watershed

4.2.3 Estimated scenario based water demand

4.2.3.1 Water demand at the reference scenario

The reference scenario was projected from the current account of 2020 based on a linear population growth rate of 2.57% per annum from the year 2021 to 2045. The assumption

made for this projected scenario was that the currently available streamflow continues in the future with a similar condition. All the demand sectors are unchanged for the future except for the population increment at the aforementioned growth rate. A similar assumption was also made in the study conducted in China on optimal water resource allocation in which they projected the water demand based on the balance between supply and demand under a single source without considering the dynamics of water resources each year (Wang et al., 2016).

This scenario showed that if the population increases at a rate of 2.57% annually, the water demand at the watershed in 2045 will rise to 22.98 MCM (Table 4.3). This implies that the total annual water demand in the watershed increases by 13.42% in 2045 compared to the current total annual water demand. The projected scenario revealed that the annual water demand of Huruta town and rural population increase from 0.67 and 2.58 MCM in 2021 to 1.23 and 4.73 MCM, respectively in the year 2045. This shows that if the population continues increasing at the current rate, the domestic (rural and urban) water demand increases; thus, the capacity of the existing surface water resource needs to be enhanced to meet growing demand. Due to the growing requirement for domestic purposes in the watershed, the annual unmet demand for irrigation water raises from 0.78 MCM in 2021 to 1.19 MCM in 2045 (Table 4.4).

Table 4.3 Annual water demands of different sectors in the reference scenario (2021–2045)

Demand Site	Water demand in the year					
	2021	2025	2030	2035	2040	2045
Dodota Dam	3.61	3.61	3.61	3.61	3.61	3.61
Huruta Town	0.67	0.74	0.84	0.96	1.09	1.23
Industrials	0.28	0.28	0.28	0.28	0.28	0.28
Irrigation	9.31	9.31	9.31	9.31	9.31	9.31

Livestock	3.68	3.68	3.68	3.68	3.68	3.68
Public	0.14	0.14	0.14	0.14	0.14	0.14
Rural population	2.58	2.85	3.24	3.67	4.17	4.73
Sum	20.26	20.61	21.09	21.64	22.27	22.98

Table 4.4 Annual unmet water demands at the reference scenario (2021–2045)

Demand site	Unmet water demand in the year					
	2021	2025	2030	2035	2040	2045
Dodota Dam	0.00	0.00	0.00	0.00	0.00	0.00
Huruta Town	0.00	0.00	0.00	0.00	0.00	0.00
Industrials	0.00	0.00	0.00	0.00	0.00	0.00
Irrigation	0.78	0.81	0.88	0.97	1.03	1.19
Livestock	0.00	0.00	0.00	0.00	0.00	0.00
Public	0.00	0.00	0.00	0.00	0.00	0.00
Rural population	0.00	0.00	0.00	0.00	0.00	0.00
Sum	0.78	0.81	0.88	0.97	1.03	1.19

4.2.3.2 Monthly demand coverage at the reference scenario

The analysis of the projected scenario showed that all the demand sites are fully covered its monthly requirement except for January and February. During January and February, 9.48, and 42.11%, respectively water deficits could be encountered (Figure 4.8).

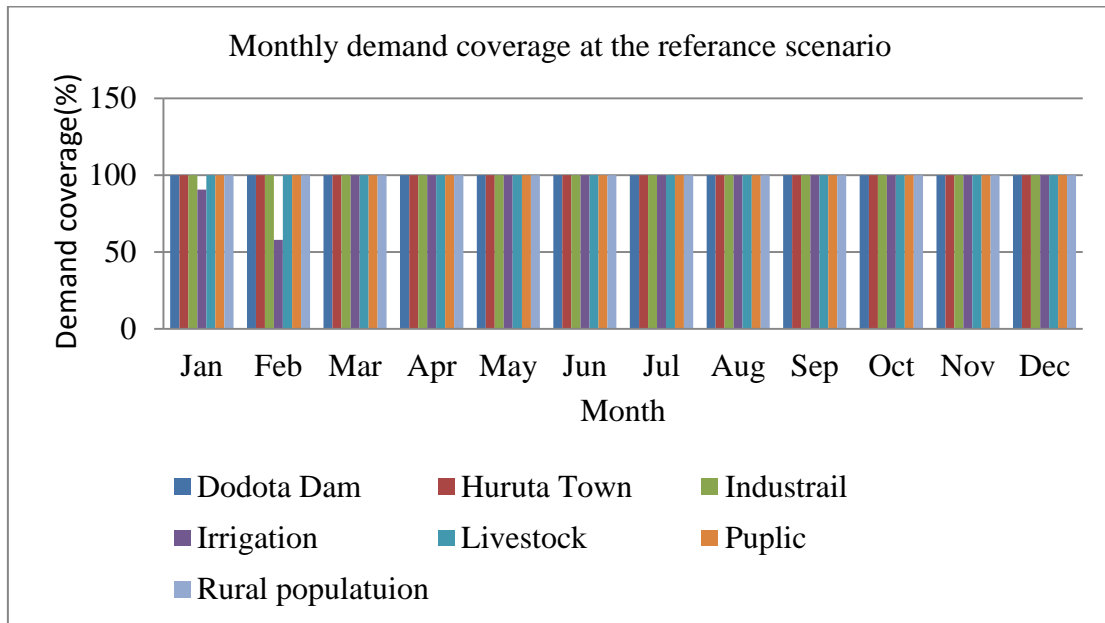


Figure 4.8 Monthly demand coverage at the reference scenario

4.2.3.3 Water demand high population growth scenario

According to the United Nations report (2019), the historical population growth rate varies annually. Considering the population growth rate of Ethiopian from 1950 up to now, the historically highest growth occurred in 1993 with a rate of 3.64%. This study evaluated what would be the water demand if the population growth rate approaches 4% annually. If the population of the watershed grows at a rate of 4%, the water demand rises from 20.26 MCM in 2021 to 25.65 MCM in 2045 (Figure 4.9). This means that the alarmingly increasing population in the watershed raises the water demand by 26.60% during the 25-year period 2021 to 2045. Thus, by 2045, there would be additional 5.39 MCM water demand compared to the reference scenario due to the growing population.

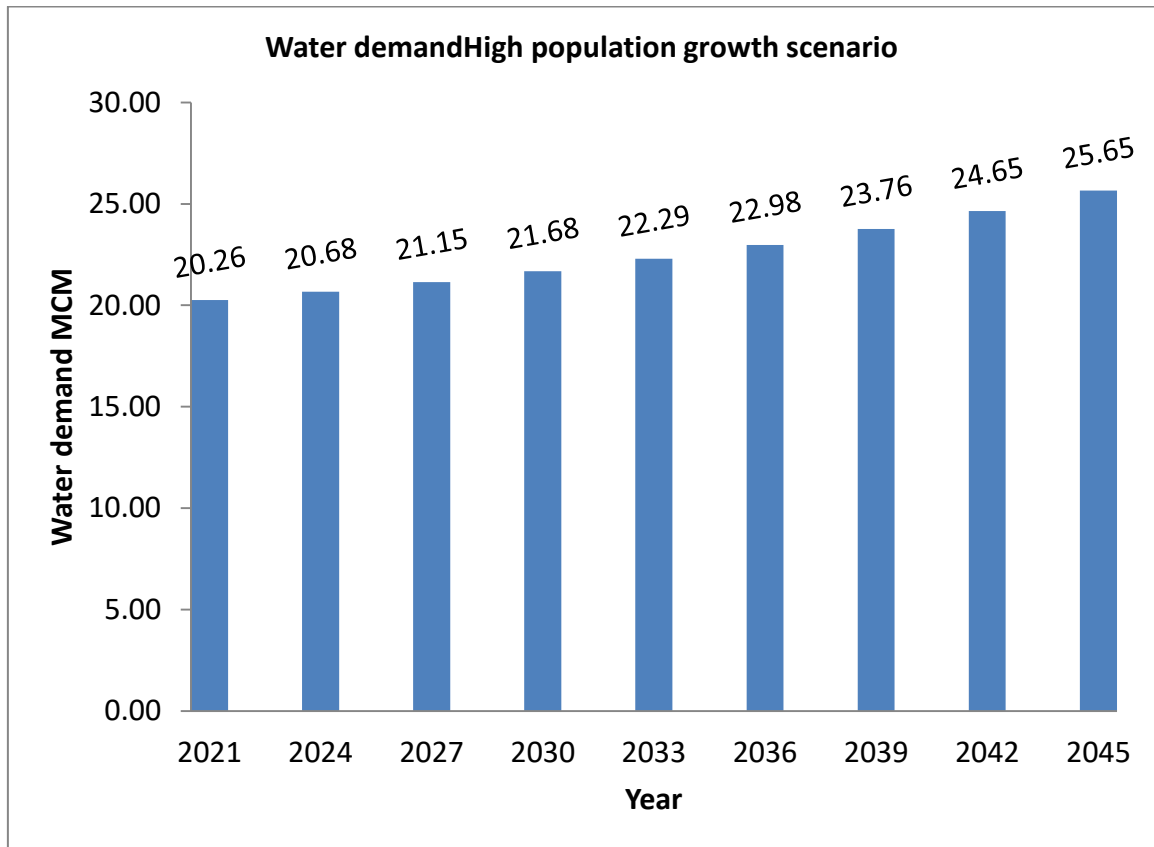


Figure 4.9 Projected water demand under high population growth rate scenario

4.2.3.4 Unmet water demand under high population growth rate scenario

Considering the higher population growth rate, the unmet water demand increases from 0.78 MCM in 2021 to 1.83 MCM in 2045 (Figure 4.10). This means that the annual unmet water demand increases by 134.6 % during the 25 years due to a higher population growth rate concerning the reference scenario. Despite the population growth, the water demand for domestic purposes is fully covered. The water demand shortage appears only in the irrigation sector during November, December, January, and February (Figure 4.11).

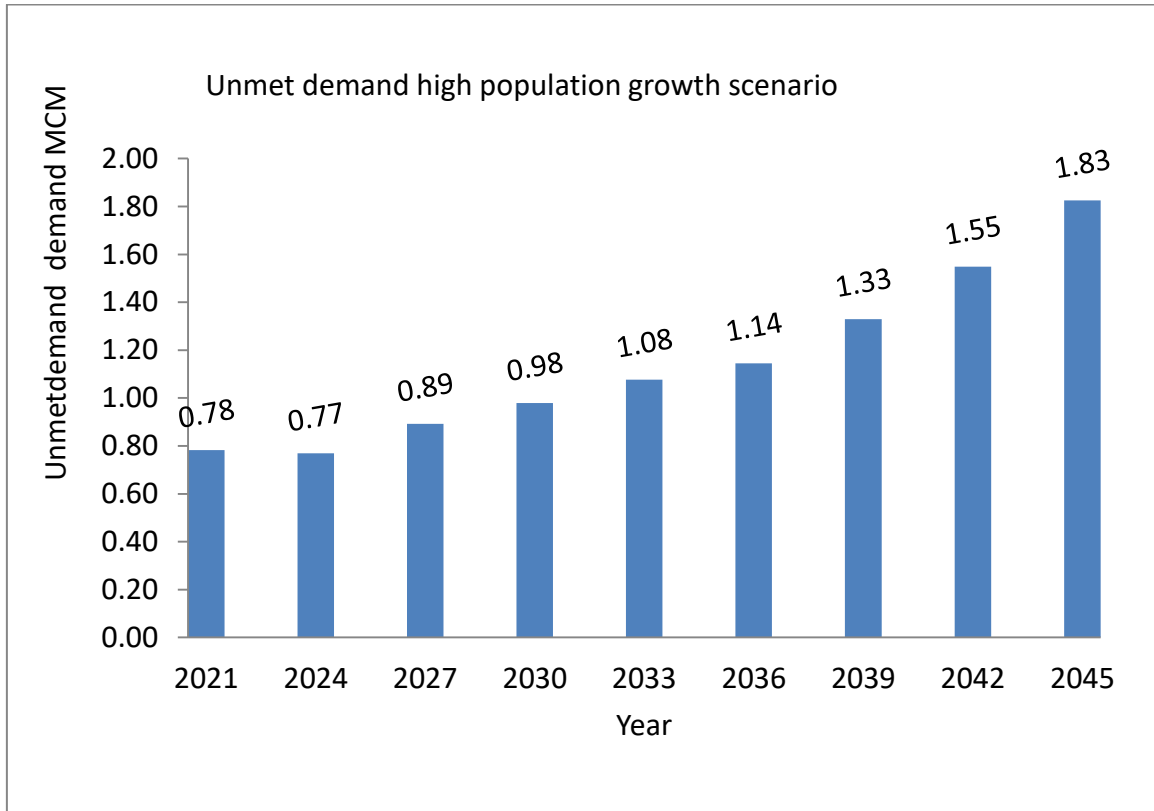


Figure 4.10 Unmet water demands under high population growth rate scenario

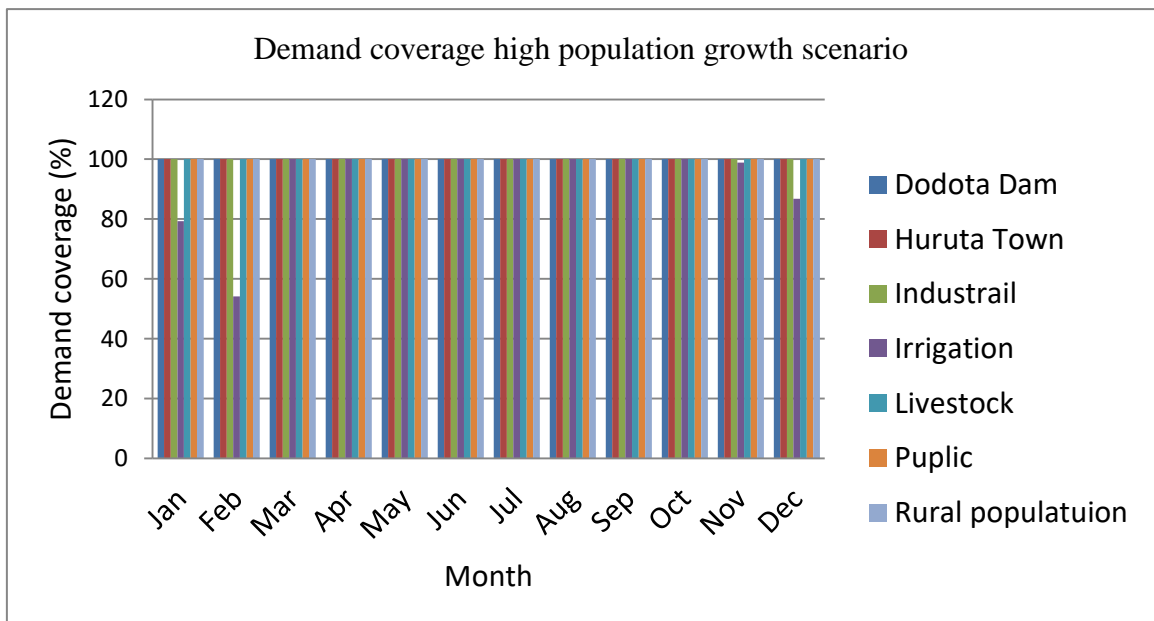


Figure 4.11 Water demand coverage under high population growth rate scenario

4.2.3.5 Water demand at irrigation expansion scenario

World Bank report (2013) indicates the necessity to forecast future water demand with different assumptions such as improved water use efficiency, irrigation intensity, irrigation area expansion, and water recycling to feed the expected high population. Thus, to feed the ever-growing population particularly in developing countries like Ethiopia, expansion of irrigable areas is needed. Agriculture also requires more water to increase crop yields and productivity. Water demand is likely to increase with population growth, expansion of agriculture, industries, and urbanization (Wang et al., 2016; Taye et al., 2018). In the context of this scenario, the analysis was carried out to investigate what would be the water demand in the watershed if the irrigable area increases by 5% by 2045. This scenario aligns with the goal of the Ethiopian water sector strategy, which aims to expand the irrigable area to a greater extent as a major way of securing the national food demand (Merish et al., 2018).

The projection showed that the water demand of the watershed needs to be increased more than double the current level by 2045 to align with the expansion of the irrigable area. This implies that the total annual water demand of the watershed increases from the current volume of 20.26 MCM to 43.69 MCM in 2045 as illustrated in Figure 4.12. The average irrigation water demand in the watershed from February to May was projected to be high whereas from July to September it was found relatively low (Figure 4.13). Figure 4.12 and 4.13 shows the annual and monthly demand at irrigation area expansion scenario respectively.

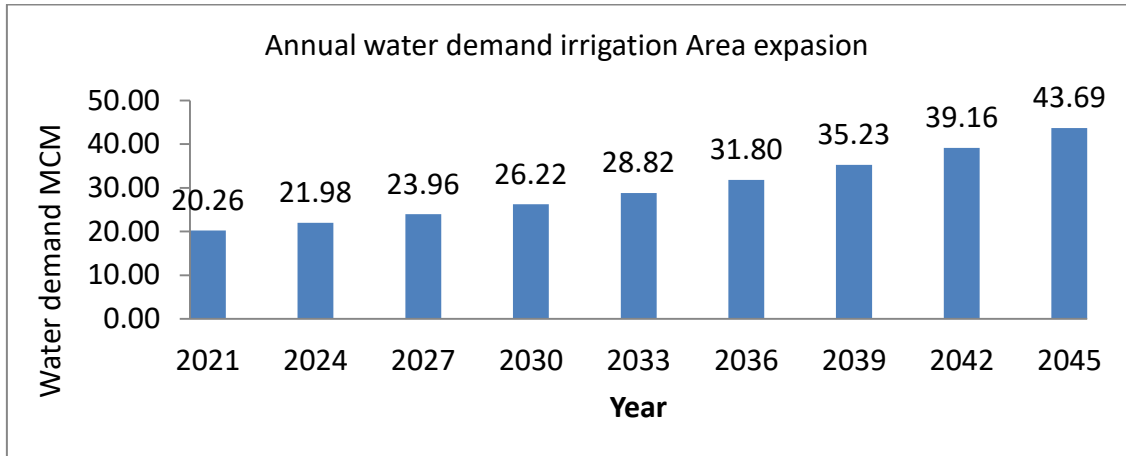


Figure 4.12 Annual water demands Irrigation Area Expansion Scenario

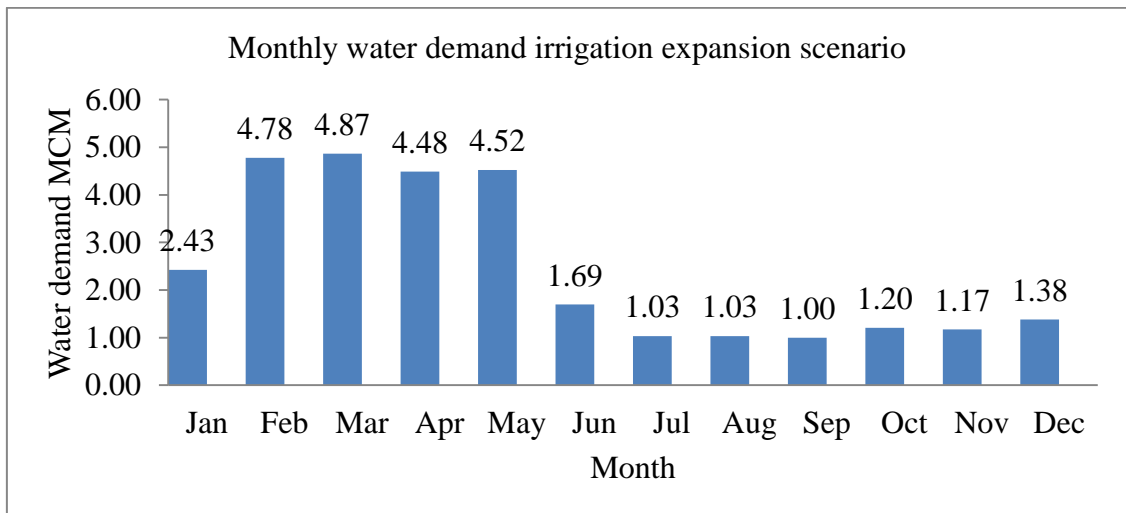


Figure 4.13 Monthly water demand at irrigation expansion scenario

Monthly average water demand increases by 54.69%, 56.40%, and 52.68%, and 49.59% on January, February, March, and April respectively as compared to the reference scenario. Monthly average demand from June up to September both reference and Irrigation expansion scenario demand is near to similar because of irrigation agriculture are replaced by rain-fed agriculture. Figure 4.14 shows monthly water demand at the reference scenario and Irrigation expansion scenario.

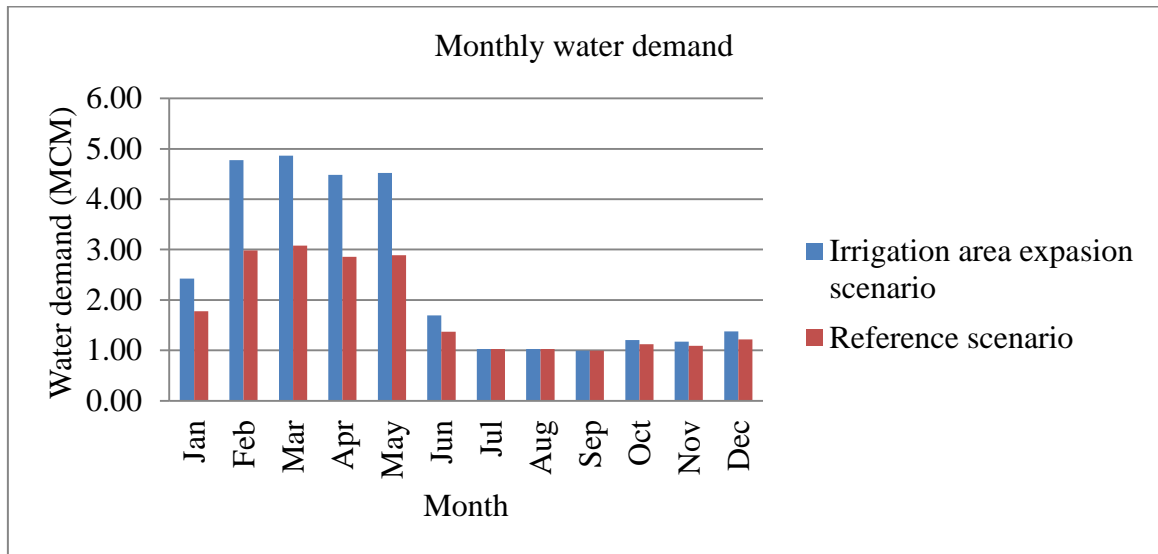


Figure 4.14 Monthly water demands at reference and irrigation area expansion scenario

4.2.3.6 Unmet water demand under the irrigable area expansion scenario

The water allocation conducted using the WEAP model showed that the annual unmet demand highly increases in 2045 if the irrigable area extends (Figure 4.15). The result of this study shows that the unmet irrigation demand increases from the current volume of 0.78 MCM to 15.19 MCM in 2045 due to irrigable area expansion in the watershed (Figure 4.15). The growing demand poses deficits in irrigation water from December to May with acute shortages in January and February. Based on the result of this study, only 85, 57, 35, 93, and 85% of the monthly irrigation water demand will fully be covered in December, January, February, March, and April, respectively (Figure 4.16). A study conducted in the Awash River basin particularly along the main Awash River line reported similar high water stress during the pick irrigation time (January to April) due to the intensive irrigation development activities (AWBA, 2017). The water shortage is aggravated owing to the expansion of irrigable lands and this, in turn, failed in production (Gedefew et al., 2019).

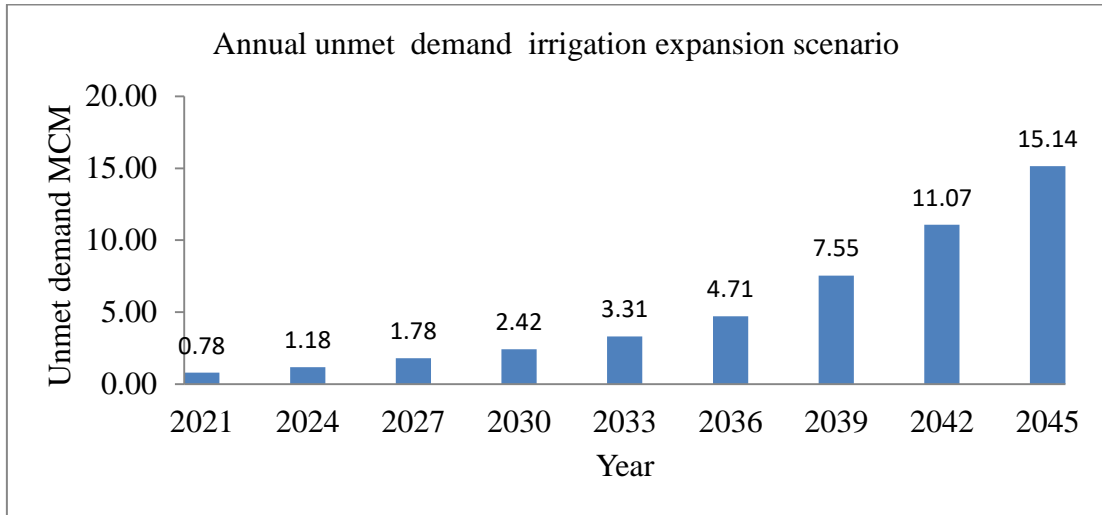


Figure 4.15 Annual unmet water demand at Irrigation expansion scenario

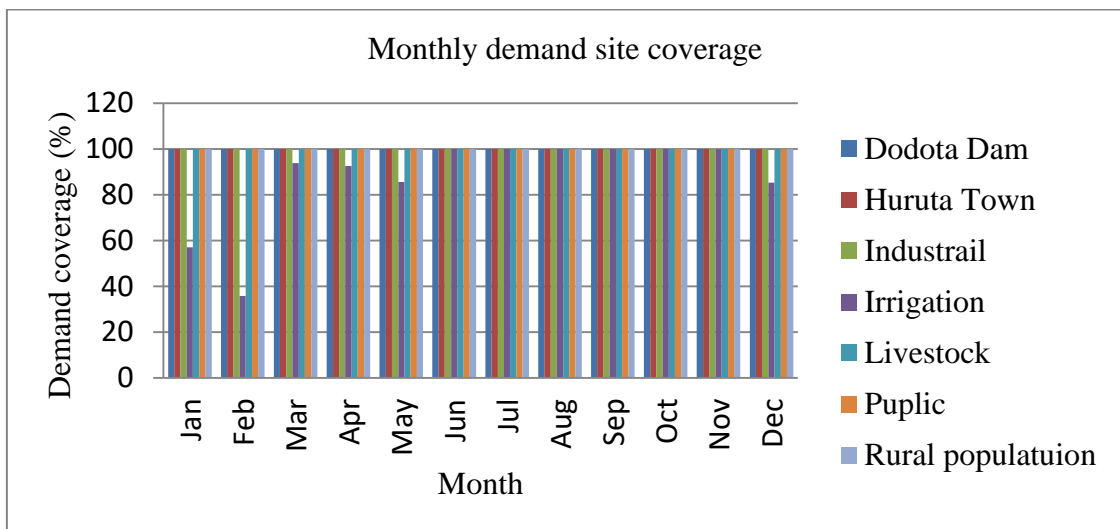


Figure 4.16 Monthly water demand coverage at irrigation expansion scenario

5 SUMMARY AND CONCLUSION

5.1 Summary

In Ethiopia, natural and socio-economic activities have significantly been changed in the current conditions, which affect the availability and demand for water resources (Mosello et al., 2015). Because of its geography and climate, Ethiopia has been characterized by

high hydrological variability, almost the absence of water storage, and vulnerable watersheds (World Bank, 2006). Today, Ethiopia's development is extremely constrained by a complex water resource legacy and lack of access to water supply and demand too, and management of the water resource (World Bank, 2006).

Therefore, knowledge and understanding of water availability and fair distribution of the existing water based on demand priority is essential for the present and future socio-economic and environmental sustainability. Surface runoff is an important component in the circle of water balance and different environmental issues, such as the causes for soil erosion, water pollution, degradation of the land, floods, and habitat distraction due to excessive runoff (Zeberie, 2019). The main objective of this study was, therefore, to assess surface water potential, and current and future demand at Keleta River watershed using ArcSWAT and water evaluation and planning (WEAP) models. Climate data required for this study were collected from the National Meteorological Agency (NMA). The missing data from NMA were generated by ArcSWAT software. Land use land cover, soil map, DEM, and streamflow data were collected from the Ministry of Water Irrigation and Electricity, which were used as input data for the determination of surface runoff.

The WEAP tool was used to evaluate the water demand at current and future conditions by assuming population growth and irrigable area expansion scenarios. The major demand sites identified were irrigation, domestic (urban and rural), livestock, industrial, and environmental sustainability. During the WEAP model set up, domestic and livestock demand sites were assigned the priority and other the second priority.

The analysis and simulation of surface water and demand assessment were conducted with the availability of limited data and included assumptions to evaluate and determine water demand at the watershed setting different scenarios. The ArcSWAT model uses spatial data such as DEM, land use, soil map, and slope data while the climatic data were considered to predict surface water available at the watershed. The measured streamflow data from 1999 – 2006 and 2011 – 2015 were used for the calibration and validation of the ArcSWAT model, respectively. The calibration and validation of the ArcSWAT model were performed manually and automatically employing SWAT CUP software in which the performance during calibration time was assured by the coefficient of determination ($R^2 = 0.72$) and Nash-Sutcliffe's efficiency ($NSE = 0.70$) and during validation time by $R^2 = 0.80$ and $NSE = 0.79$. The study area covers 754.58 km^2 that has mean annual precipitation, evapotranspiration, and surface runoff of 831.1, 451.4, and 165 mm, respectively.

The WEAP model was used to assess water demand at the current condition and projected future water demands assuming a high population growth rate and irrigable area expansion scenarios. The current water demands in the watershed are domestic (rural and urban), irrigation, livestock, Industrial and public and environmental sustainability. The assessment of water demand starts from the current account year (2020), which was used as the base for the other scenarios and extends until 2045. The result of the WEAP model indicated that the total water demand in the watershed at baseline year (2020) was estimated to 20.26 million cubic meters (MCM) and the total demand in 2045 reaches 24.80 MCM at the reference scenarios. Among all the demand sites, the highest was from irrigation (45.95%) while the lowest water demand was consumed by the public (0.63%). The water demand increases highly in the future due to a higher rate of population growth and expansion of the irrigable area. The water demand in Keltta River watershed increases

to 43.69 MCM due to the expansion of irrigable areas, which shows a 100% increment in demand in 2045. The total water demand at the current condition and future projection is much lower than the available surface water resource in the entire watershed. Thus, all demand sites are not fully supplied because of the variation between demand and supply..

The highest volume of surface water is available in July, August, and September while the lowest is in January, February, and April. On the other hand, the highest monthly demand appears in January, February, March, and April. During this period, the unmet irrigation demand in the current year (2020) is 0.78 MCM and grows to 15.19 MCM in 2045. Irrigation water demands are not fully covered in all references, high population growth, and expansion irrigable areas scenarios. The total unmet demand in the watershed through all years reaches 1.19, 1.83, and 15.14 MCM at the reference, high population growth, and irrigable area expansion scenarios, respectively. The analysis using the WEAP model indicated that monthly water deficit would be 0.02 – 0.15 and 0.07 – 2.65 MCM at high population growth and irrigable area expansion scenarios during December to April, respectively.

The occurrence of those unmet demands from December to May is attributed to the low rainfall records. Similar studie in the Awash River basin has already reported water stress, higher water demand than supply. During the dry season, water shortage is a common challenge for various activities such as irrigation and domestic water supply (Taye et al., 2018). This shows that the sole surface water cannot fulfill the water demand due to population growth and irrigable area increments at Keleta Watershed.

5.2 Conclusion

Comprehensive understanding of the hydrologic process and water demand in the watershed is the pre-request for successful water resource management and environmental protection. The main objective of this thesis was to determine the available surface water resource and water demand in the watershed. The SWAT and WEAP models were employed for the simulation of the water availability and demand in the watershed. The average annual rainfall over the study area was found to be 831.10 mm, where 60% of it occurred during the wet season (June to September). The average monthly runoff follows a similar pattern to the average monthly rainfall in the watershed. The average annual surface runoff depth released from the entire watershed was estimated as 165.45 mm, which is equivalent to 124.80 MCM.

The current water users in the watershed are domestic, livestock, public, industrial, and irrigation. The analysis using the WEAP model showed that the total water demand at the current condition is estimated as 20.26 MCM, which is 18.07% of the total available surface water in the watershed. Although the available surface water is greater than the total annual estimated water demand, 0.74 MCM water deficits occur from December to January to cover the total annual demand in the watershed. The temporal occurrence of those unmet demands is due to the low rainfall followed by low surface runoff during the dry season in January and February (3.71MCM) despite higher water demand during the same months (4.59 MCM).

The analysis using the WEAP model also showed that the water demand is increasing to 43.69 and 25.65 MCM in the future due to the expansion of the irrigable area and fast population growth. The analysis further showed that 37% of the demand will be unmet in the year 2045. This study concluded that the sole source of surface water in Kelata

watershed can't satisfy the demand from December to April at the current and future conditions. Based on the findings of this study, the following recommendations are forwarded.

The scope of this study was limited to surface water resources only. Thus, it is highly recommended that further studies need to be conducted on other sources of water resources in Kelata watershed such as groundwater potential. The groundwater development is recommended to be considered as the best alternative source of water supply to overcome the identified water scarcity periods in this study. The quality of the groundwater resource needs to be studied. It is also highly recommended to develop water-harvesting structures to store wet season surplus water while increasing the irrigable area for enhancing more production to feed the growing population in Kelta watershed in particular and other areas in general. Finally, studies are recommended to be conducted on water demand management and climate change scenarios to foresee their impacts on the availability of water potential and water demand.

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APPENDICES

Metrological data at a different station

Appendix Table1. monthly precipitation within and around Keleta watershed (mm) (1987-2017)

Month	Melkasa	Huruta	Eteya	Sirie	Nazret	Abomsa	Kulumsa
Jan	12.76	27.35	21.66	8.75	13.92	25.52	16.64
Feb	20.26	31.05	22.96	11.70	25.89	31.39	34.08
Mar	52.35	70.81	62.74	61.72	52.93	73.74	73.86
Apr	57.79	107.43	78.49	95.73	58.03	94.27	91.14
May	52.64	108.05	90.67	72.34	51.23	76.54	87.92
Jun	69.43	103.27	105.58	94.29	61.65	66.40	92.34
Jul	202.82	176.76	229.08	172.21	248.42	161.53	127.98
Aug	188.81	174.09	189.66	200.90	214.70	180.79	133.43
Sep	101.22	138.22	142.84	138.11	109.36	112.99	108.41
Oct	36.33	56.22	45.07	52.30	34.68	65.62	43.15
Nov	10.01	22.58	16.75	11.47	11.33	27.15	10.93
Dec	10.76	14.89	6.60	10.11	7.34	12.73	9.25

(Source ENMA, 2019)

Appendix Table 2. Maximum temperature in different stations with in and near Keleta Watershed (1987-2017)

Months	Huruta	MARC	Nazret	KARC	Abomsa
January	24.35	28.08	27.23	23.14	26.50
February	25.78	29.51	28.92	24.53	28.06
March	26.76	30.42	29.82	25.34	29.52
April	26.74	30.31	29.97	24.89	29.36
May	27.00	31.45	30.87	24.71	30.40
June	26.52	30.39	30.02	23.51	31.00
July	24.72	26.80	26.40	21.40	28.24
August	24.16	26.09	26.01	21.07	27.23
September	24.36	27.65	27.31	21.61	27.43
October	24.64	28.75	27.76	22.76	27.64
November	24.28	28.53	27.21	22.73	26.93
December	23.72	27.73	26.54	22.30	26.00

(Source ENMA, 2019)

Appendix Table 3. Monthly average Minimum temperature in different station ($^{\circ}\text{C}$) (1987-2017)

Months	Huruta	Melkasa	Nazret	Kulumsa	Abomsa
January	9.22	11.84	12.95	8.35	13.89
February	10.61	13.18	14.70	9.29	14.84
March	12.17	14.82	15.36	10.54	16.27
April	12.96	15.25	15.71	11.42	17.32
May	14.49	15.35	16.29	11.17	17.97
June	13.27	16.35	17.29	10.82	17.81
July	12.72	15.58	15.79	10.77	16.66
August	12.60	15.14	15.86	10.58	16.37
September	12.57	14.26	15.24	10.18	16.27
October	11.45	11.76	13.27	10.25	15.06
November	9.74	10.78	12.76	8.99	13.61
December	8.42	10.63	12.24	8.09	12.96

(Source ENMA, 2019)

Appendix Table 4. Weather generator input parameter for Kulumsa station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TMP -MAX	22.9	24.4	25.2	24.8	24.7	23.7	21.5	21.1	21.7	22.7	22.7	22.2
TMP -MN	8.4	9.4	10.6	11.5	11.2	10.8	10.9	10.7	10.2	10.4	9.1	8.1
TMPSTDMX	1.9	2.1	2.3	2.2	2.0	1.9	1.8	1.4	1.3	1.5	1.6	1.6
TMPSTDMN	2.5	2.5	2.2	2.1	1.9	1.8	1.7	1.6	1.8	2.2	2.4	2.5
PCPMM	17.0	35.1	77.1	89.3	91.8	92.2	122.3	128.3	108.9	44.0	11.0	9.3
PCPSTD	3.2	4.8	6.9	7.0	6.5	5.7	6.1	6.8	5.5	5.9	2.0	2.0
PCPSKW	9.3	6.3	4.9	3.6	3.3	3.2	2.2	3.2	3.5	8.2	8.0	10.6
PR_W1	0.1	0.1	0.2	0.3	0.3	0.4	0.6	0.6	0.5	0.1	0.1	0.0
PR_W2	0.4	0.5	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.6	0.4	0.4
PCPD	3.4	5.3	9.8	12.1	13.5	16.4	20.6	22.0	21.0	6.1	2.5	2.4
RAINHHMX	8.5	17.5	38.5	44.6	45.9	46.1	61.2	64.1	54.5	22.0	5.5	4.7
SOLARAV	19.8	21.0	21.5	20.7	20.6	19.9	18.1	18.2	19.0	19.1	19.2	19.2
DEWPT	8.3	9.6	11.2	11.6	11.7	12.2	12.4	12.4	10.2	8.6	7.8	8.7
WNDVAV	2.4	2.3	1.9	1.9	1.7	1.5	1.7	1.3	1.0	2.4	2.7	2.6

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TMP -MAX	27.9	29.5	30.6	30.7	31.2	30.4	27.2	26.4	27.8	28.6	28.7	27.5
TMP -MN	9.1	10.6	12.3	13.0	14.7	13.4	13.0	13.0	12.8	11.7	9.8	8.6
TMPSTDMX	2.1	2.3	2.4	2.3	2.2	2.5	2.4	2.0	1.7	1.6	3.0	1.6

TMPSTDMN	3.5	3.0	3.0	2.8	8.6	2.6	2.4	2.6	2.3	2.6	3.1	3.2
PCPMM	13.0	19.5	52.8	57.1	54.6	68.4	199.5	190.1	103.9	37.7	10.4	11.0
PCPSTD	2.7	3.5	6.0	5.6	5.1	5.9	12.0	10.0	7.2	5.2	2.2	2.3
PCPSKW	9.9	7.8	5.0	4.8	5.0	4.2	3.0	2.7	3.9	7.3	9.6	9.7
PR_W1	0.0	0.1	0.1	0.2	0.1	0.3	0.5	0.6	0.4	0.1	0.0	0.0
PR_W2	0.5	0.4	0.4	0.5	0.6	0.5	0.6	0.6	0.6	0.5	0.5	0.5
PCPD	2.2	3.2	6.4	8.1	8.7	10.2	18.0	19.1	15.4	5.1	2.6	2.6
RAINHHMX	6.5	9.7	26.4	28.5	27.3	34.2	99.7	95.0	52.0	18.8	5.2	5.5
SOLARAV	22.4	23.5	24.0	23.9	23.6	22.9	20.8	20.6	21.6	22.3	22.6	22.1
DEWPT	13.2	15.2	15.8	15.7	16.7	16.4	15.6	13.7	11.3	10.1	9.9	10.6
WNDVAV	6.3	6.6	6.1	5.6	5.3	6.4	6.2	4.8	3.2	4.3	5.4	6.0

Appendix Table 5. Weather generator input parameter for Melkasa station

Irrigation water requirement selected crops at keleta watershed

Appendix Table 6. Onion Irrigation water requirement

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jan	1	Init	0.60	2.71	27.10	3.80	23.30
Jan	2	Deve	0.62	2.83	28.30	4.00	24.30
Jan	3	Deve	0.78	3.63	40.00	4.80	35.10
Feb	1	Mid	0.94	4.56	45.60	5.10	40.50
Feb	2	Mid	1.00	4.99	49.90	5.60	44.30
Feb	3	Mid	1.00	5.10	40.80	9.10	31.80
Mar	1	Mid	1.00	5.22	52.20	13.60	38.60
Mar	2	Mid	1.00	5.33	53.30	17.10	36.20
Mar	3	Mid	1.00	5.34	58.70	17.20	41.50
Apr	1	Mid	1.00	5.34	53.40	17.20	36.20
Apr	2	Mid	1.00	5.35	53.50	17.90	35.60
Apr	3	Late	0.98	5.30	53.00	17.30	35.80
May	1	Late	0.94	5.16	51.60	16.00	35.60
May	2	Late	0.90	5.02	50.20	15.30	34.90
May	3	Late	0.87	4.69	46.90	15.50	29.80
Total					704.40	184.0	519.0

Appendix Table 7. Tomato Irrigation requirement

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jan	1	Init	0.5	2.26	22.6	3.8	18.7
Jan	2	Init	0.5	2.26	22.6	4	18.7
Jan	3	Deve	0.5	2.35	25.8	4.8	21
Feb	1	Deve	0.62	3.01	30.1	5.1	25
Feb	2	Deve	0.81	4.04	40.4	5.6	34.8
Feb	3	Deve	0.98	4.99	39.9	9.1	30.9
Mar	1	Deve	1.15	5.98	59.8	13.6	46.2
Mar	2	Mid	1.25	6.66	66.6	17.1	49.5
Mar	3	Mid	1.25	6.67	73.4	17.2	56.2
Apr	1	Mid	1.25	6.68	66.8	17.2	49.5
Apr	2	Mid	1.25	6.69	66.9	17.9	49
Apr	3	Late	1.24	6.69	66.9	17.3	49.6
May	1	Late	1.14	6.28	62.8	16	46.8
May	2	Late	1.05	5.8	58	15.3	42.7
May	3	Late	0.97	5.25	26.2	7.7	17.7
Total					728.8	176.2	551.8

Appendix Table 8. Potato Irrigation requirement

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jan	1	Init	0.5	2.26	22.6	3.8	18.7
Jan	2	Init	0.5	2.26	22.6	4	18.7
Jan	3	Deve	0.54	2.51	27.6	4.8	22.8
Feb	1	Deve	0.71	3.46	34.6	5.1	29.4
Feb	2	Deve	0.9	4.5	45	5.6	39.4
Feb	3	Mid	1.05	5.34	42.7	9.1	33.6
Mar	1	Mid	1.06	5.53	55.3	13.6	41.7
Mar	2	Mid	1.06	5.65	56.5	17.1	39.4
Mar	3	Mid	1.06	5.66	62.2	17.2	45
Apr	1	Mid	1.06	5.66	56.6	17.2	39.4
Apr	2	Late	1.02	5.46	54.6	17.9	36.8
Apr	3	Late	0.95	5.15	51.5	17.3	34.3
May	1	Late	0.88	4.83	48.3	16	32.3
Total					580.2	148.7	431.5

Appendix Table 9. Wheat Irrigation water requirement

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jan	1	Init	0.30	1.35	13.50	3.80	9.70
Jan	2	Deve	0.34	1.52	15.20	4.00	11.20
Jan	3	Deve	0.56	2.61	28.70	4.80	23.80
Feb	1	Deve	0.80	3.88	38.80	5.10	33.60
Feb	2	Mid	0.99	4.92	49.20	5.60	43.60
Feb	3	Mid	1.00	5.10	40.80	9.10	31.80
Mar	1	Mid	1.00	5.22	52.20	13.60	38.60
Mar	2	Mid	1.00	5.33	53.30	17.10	36.20
Mar	3	Mid	1.00	5.34	58.70	17.20	41.50
Apr	1	Mid	1.00	5.34	53.40	17.20	36.20
Apr	2	Mid	1.00	5.35	53.50	17.90	35.60
Apr	3	Late	0.97	5.23	52.30	17.30	35.00
May	1	Late	0.90	4.95	49.50	16.00	33.50
May	2	Late	0.84	4.67	46.70	15.30	31.40
May	3	Late	0.78	4.21	42.10	15.50	25.00
Total					647.80	179.40	466.80

Soil textural class and water holding capacity of different soil

Appendix Table 10. Soil texture and its water holding capacity

SOIL TEXTURE	FC		PWP		ASM	
	%	mm/m	%	mm/m	%	mm/m
Sand	6 to 12	100 - 200	2 to 6	30 - 100	4 to 6	70 - 100
Sandy loam	10 to 18	140 - 270	4 to 8	60 - 120	6 to 10	90 - 150
Loam	16 to 18	250 - 360	8 to 12	110 - 170	10 to 14	140 - 190
Clay loam	23 to 31	300 - 430	11 to 15	140 - 210	12 to 16	170 - 220
Silt clay	27 to 35	340 - 460	13 to 17	160 - 230	14 to 18	180 - 230
Clay	31 to 39	370 - 500	15 to 19	180 - 250	16 to 20	190 - 260

(FAO33)

Crop information

Appendix Table 11. Crop growth stage, crop coefficient, root depth and depletion factor information.

				Length of growing stage					Crop coefficient(Kc)			
Crop	Root depth (cm)	Depletion coefficient	Yield response (Ky)	Initial	Dev't	Mid	Late	Total	Initial	Dev't	Mid	Late
Tomato	100	0.3	1.05	30	40	45	30	145	0.5	0.8	1.25	0.95
Potato	60	0.5	1.1	25	30	45	30	130	0.5	0.8	1.06	0.85
Onion	50	0.3	1.1	15	25	70	40	150	0.6	0.8	1	0.85
Wheat	110	0.55	1.05	15	30	65	40	150	0.3	0.7	1	0.75

(FAO33)

Population projection

Appendix Table 12. Population number at the Watershed current and projected

Population	population census (2007)	Projected population(2020)	The projected population at 2045	
			2.57 % increment (Reference)	4% increment High population
Rural	113007	146909	277049	391634
Urban	11768	15298	28850	40782
Total	124775	162207	305899	432416

