ASSESSMENT OF SURFACE WATER POTENTIAL AND DEMAND EVALUATION IN TEJI WATERSHED, UPPER AWASH RIVER SUB-BASIN, ETHIOPIA

MSc. RESEARCH THESIS

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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ASSESSMENT OF SURFACE WATER POTENTIAL AND DEMAND EVALUATION IN TEJI WATERSHED, UPPER AWASH RIVER SUB-BASIN, ETHIOPIA

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DEDICATION

This work is dedicated to my lovely wife Lomi Olkeba**,** for her continuous support in the success of my life.

DECLARATION

I, Dejene Serbo Bokan, hereby present for consideration by the Institute of Technology at Hawassa University, my thesis in partial fulfillment of the requirement for the Degree of Masters in Water Resource Engineering and Management which is entitled “Assessment of Surface Water Potential and Demand Evaluation in Teji Watershed, Upper Awash River Sub-Basin, Ethiopia”, under the supervision of Mihret Dananto (PhD). I sincerely declare that this thesis is the product of my own efforts. The work has not been presented elsewhere for assessment. I have followed all ethical and technical principles of scholarship in the preparation, data collection and data analysis and assembling of this thesis by my own. Any bookish matter that is included in this thesis has been given recognition through citation.
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ABBREVIATION AND ACRONYMS

a.m.s.l : Meters above sea level
BBM : Broad Bed Maker
BCM : Billion Cubic Meter
CSA : Central Statistical Agency
CUP : Calibration Uncertainty Program
DEM : Digital Elevation Model
DSS : Decision Support Systems
FAO : Food and Agriculture Organization
GIR : Gross Irrigation Water Requirement
GIS : Geographic Information System
GTP-2 : Growth and Transforming Plan-II
HRU : Hydrologic Response Unit
ITCZ : Inter-Tropical Convergence Zone
IWR : Irrigation Water Requirement
IWRM : Integrated Water Resources Management
MCM : Million Cubic Meter
mmH_2O : Millimeter of Water
MoA : Ministry of Water Resource
NIR : Net Irrigation Water Requirement
MoWIE : Ministry of Water and Irrigation Engineering
NMA : National Meteorological Agency
SCS-CN : Soil Conservation Service Curve Number
SEI : Stockholm Environmental Institute
SUFI2 : Sequential Uncertainty Fitting-version 2
SWAT : Soil and Water Assessment Tool
TLU : Tropical Livestock Unit
UTM : Universal Transverse Mercator
WEAP : Water Evaluation and Planning

ABSTRACT

In Teji watershed the livelihoods of the dense population are confirmed on the river streamflow. The competition for water resources between water users has prominently led unbalanced water demand and a limited supply that resulted in serious conflicts between water users. The goal of this study was to assess the surface water potential and evaluate demands using the Soil and Water Assessment Tool (SWAT) and Water Evaluation and Planning (WEAP). The 12.5 m x 12.5 m resolution DEM was used in watershed delineation and multiple slope classification and the 30 m x 30 m land use/cover, soil data, were used to hydrologic response unit classification. The watershed divided into 9 sub-basins, and 123 hydrological response units were identified. The model was calibrated with 2000-2010 data and twelve most sensitive flow parameters which gave very good correlation between observed and simulated streamflow with statistical criteria Coefficient of determination (R2=0.81), Nash-Sutcliffe efficiency (NSE=0.81) and Percent BIAS (PBias=+1.6). The model validation was carried out for the year 2011-2016 data and the model performance was resulted very good correlations between observed and simulated streamflow. The performance criterial of the model, R2, NSE and PBias were 0.77, 0.78 and +2.3 respectively. The mean annual water balance were simulated with a mean precipitation of 1039.30mm. Surface runoff, lateral flow, and groundwater flow were 198.63 mm (19 %), 28.78 mm (2.8%), and 17.53 mm (1.9%), respectively. The mean evaporation losses of the area were estimated as 461.40 mm which accounting for 44.34% of the mean annual water budget. The mean annual surface runoff of the watershed was 130.25 MCM. WEAP model was run to evaluate the current and future water demand under four different scenarios. At the current account year (2021) about 43.22 MCM of water was required for all water demands. The future water demand evaluation shows water supply deficit in all developed scenarios. Scenarios show that in each water demands there would be both monthly and annually unmet water demands. However, the absolute deficits were varied between scenarios.

Key words: Teji watershed, Surface water potential, water demand, SWAT and WEAP

1. INTRODUCTION

1.1.Background

Water is the basis of life and is a driving force for economic and social development and for poverty reduction. It is needed to ensure that met our most basic needs. These basic needs ordinarily include having water for the purpose of drinking, food preparation, and washing of clothes, hygiene, and sanitation (Semanaz, 2018). Additionally, water is crucial for the wellbeing of humankind and it acts an important role in supporting production of human activities, such as agricultural, energy and industrial production, transportation services, fishing and tourism, and more fundamentally, without water, getting out of the poverty cycle is nearly impossible (Kılıç, 2021).

Today, the availability of water, in quantity and quality have been reduced, as the result of natural and anthropogenic factors. Climate change, population growth, economic development and lack of good management in existed water resources are some driving factors which increase the pressure on the water availabilities in many areas of the world (Engott et al., 2017).

Ethiopia is not a water poor country or has plentiful both surface and groundwater resources, (Berhanu, 2020), or even if the country is endowed with large physical water potential, the resource could not be made available for use due to inadequate water infrastructure. The limited financial, technical capacity and capability and lack of good governance in the water sector make considered the country as economical and technical water scarce (Koyra, 2020). Also the natural factors of water bodies, hinder the development of water sector to encouraging the trans-boundary water resources into production; since most rivers carry 97% of annual streamflow and fertile sediments drained out of the country (Berhanu et al., 2014).

The growing pressures on the fresh water resources which are imposed to increase demand for water would likely bring conflicts between different water users. (Tessema, 2011).Water demand is steeply increasing due to urbanization, industrialization, climate change, agriculture production and vigorous population growth. In addition to threatening the human food supply, water shortages severely reduce biodiversity in both aquatic and terrestrial ecosystems. (Abraha et al., 2022).

The successful realization of any water resources activity is vital to a country like Ethiopia for the development of the national economy. The proper planning, design, construction and operation of water resource are very essential (Kerim et al., 2016). The careful assessment of surface water potential of a river basin is very important for the future development of any kind of water-related projects to enhance the economic growth by strengthen the way of utilization the available water potential for hydropower, irrigation, and water supply, since surface water is the primary source of water with the ease of accessibility. So, studying surface water potential and demand evaluation is important because it provides information to the decision makers about the river basin on how much water is available and how much of the available water is utilized for various uses (Adeba et al., 2015;& Kemal, 2021).

Unlike other river basins of the Ethiopia, Awash River Basin is the first basin in which irrigation was introduced earlier and most highly utilized basin for various levels of irrigation developments, industrial activities and water supplies (Hailu et al., 2018). Various water users and ongoing governmental and private irrigation projects (more than 60%) are implemented in the basin (Mulugeta et al., 2019). However, it is understandable that, in traditional irrigation; scientific measurement and systematical allocation of water is not possible so that it is difficult to quantify or estimate the amount of water abstracted from source. The unimproved water usage and misallocation of water resources can be brought that the emergence of water scarcity in the area, which requires an adequate water resources assessment and demand management (Duguma et al., 2021).

1.2.Statement of the Problems

The number and diversity of water related challenges are large and are expected to increase in the future. Even today, the ideal condition of having the appropriate amount of good quality water at the desired place and time is most often not satisfied (Tadese et al., 2020).

The upper Awash River sub-basin supports the expanding urban and industrial areas, with increasing water demands. In this sub-basin the livelihoods of the dense population are confirmed on the rivers streamflow (Kerim et al., 2016). Teji watershed is one of the watershed which drains to Upper Awash River sub-basin. The river serves as an important source not only for domestic water but also vital for the development activities like agricultural sector. Farmers used to irrigate their crops by abstracting water using individual pumps or simply diverting water from river channel. However, they are do irrigation without knowing how much volume of water or when to apply. Such application create the prominently unbalance demand for water over the limited supply. As a result, serious conflicts are likely to contrive between water for irrigation and other water users in the watershed.

In other cases, factors such as the spatial and temporal variations in rainfall, lack of technical assistance and gaps in effective water management, are likely not provide chances of adequate water for most farmers to produce more than one season per land per year. There are crops failure in the rain fed agriculture, due to dry spells and droughts. These issues are brought that the use of surface water very critical to resist crop failures.

The increase stresses on water resources in Teji watershed were enforced by the unlimited demand, wastage use of water, and inter or intra sectoral competition for water. Settling the water challenges and conflicts between water users, as well as to improve the livelihoods of the communities, the accurate and comprehensive assessment of water resources should be carried out. The study by (Eshetu, 2008) was one of the studies carried out at watershed level and it has estimated the groundwater potential of Teji, but the gap of this study was that it has not included the surface water and demand evaluation. In this study basically it was tried to fill the gap by assessing the surface water potential, evaluating the current and future water demands, by using hydrological models.

1.3.Objectives

1.3.1. General objective

The general objective of this study was to assess the surface water potential and evaluate how it reacts to the current and future water demands of different sectors in Teji River watershed by using hydrological models.

1.3.2. Specific objectives

The specific objectives of this study were:-

1. To estimate the current water budget of the Teji watershed.
2. To evaluate of current water demands in the watershed.
3. To determine the future water demands from 2022 -2060, under different scenarios.

1.4.Research Question

To achieve the objective of this study following research questions should be addressed.

- What are the water budget components and how much quantities are available in the Teji watershed?
- What are the quantities of water demands for each demand sites, in the current year?
- What will be the future trends of water demands in the watershed under selected demand scenarios?

1.5.Scope and Limitations of the Study

The general focuses of this study were the assessment of water balances and evaluation of water demands under consideration of scenarios by using hydrological models. SWAT model was used to simulate streamflow using available meteorological and observed hydrological data. The evaluation of the current and future water demands were executed by using WEAP21 model.

The assessment of water budget was based on current available meteorological, hydrological and spatial data. The future water demand was evaluated under high population growth rate, increase irrigation area and increase daily per capita water demands scenarios. However, due to the constraints of time, available data and other resources, the assessment of water balances did not considered the effects of land use land cover changes and climate changes. Also, the evaluation of future water demand has not considered the impacts of scenarios such as climate change, urbanization, migration and changes in behaviors and norms etc.

2. LITERATURE REVIEW

2.1. World Water Resources

A large amount of water resources in our world is non-usable for our daily consumptions. From the world's total water resources about 97% is salty water reserved mainly in oceans and leaving only 3% as fresh water of which slightly over two thirds is frozen in glaciers and polarice caps. Out of the 3% freshwater around 2.2% is available as surface and 0.6% as groundwater. Even out of the 2.2% of the surface water, 2.15 % is fresh water in the form of glaciers and ice caps and only 0.01 % of the freshwater is available in streams and lakes, the left 0.04 % is contained in other forms. From the 0.6 % of the stored groundwater, only around 0.25 % can be economically extracted with present technological equipment, the rest being at greater depth (FAO, 2011).

The total water resources in the world are equal to 43750 km^3/year distributed according to the patchwork of climates and physiographic structures. At the continental level, America has the largest share of the world's total freshwater resources with 45%, followed by Asia with 28%, Europe with 15.5% and Africa with 9% (FAO, 2016). However, the small amount of the Earth's abundant water is actually accessible and suitable for human needs across the globe and it is true for Africa. Africa has only about 3931km3/year of renewable water resources of the total freshwater.

2.2. Overview of Surface Water Availability

Surface water, generally, lakes, dams, streams and rivers, is water that is open to the atmosphere and fed by runoff from the land surface. The majority of surface water is precipitation which falls on the earth as surface water and shapes the surface, creating streams that result in lakes and rivers. Surface water usually, lost through discharge to the oceans, evaporation, and sub-surface seepage.

The entire area of a river basin whose surface runoff (due to rainfall) drains into the river in the basin is considered a hydrologic unit and is called a drainage basin, watershed or catchment area of the river. The total amount of water available to the earth is finite and remains constant, although the spatial/temporal distribution is continually changing. Estimates of the total amount of water on the earth and in various processes show that most of it is in the oceans (96.5%), with only a small proportion of the total water as fresh water (2.5%) and mainly stored as ice (Abanish et al., 2018).

2.3. Water Resources in Ethiopia

Ethiopia is endowing with a substantial amount of water resources. Most river basins are originating from the highlands areas where receive high rainfall, they have larger amount of water running in the river systems that considers Ethiopia is the "**water-tower"** in the Horn of Africa (UN-Water, 2016).

Among the total land mass of Ethiopia, the land area and water bodies are covered 99.3% and 0.7% respectively (Shiferaw et al., 2015).

Ethiopia has 11 fresh and 9 saline lakes, 4 depression lakes and over 12 major swamps or wetlands. Majority of the lakes are found in the Rift Valley Basin. The total surface area of both natural and artificial lakes is about 7,500 km^2. Ethiopia has twelve major river basins; eight of them are the river basins, one the Rift Valley and the remaining threes are dry basins which have no or insignificant flow out of the drainage systems. All the river basins except Awash River are trans-boundary Rivers, in which over 97% flow is drained into the neighboring countries. The amount of water obtained from the major river basins are estimated to reach more than 124.4 BCM (Berhanu et al., 2014).

Almost all of the basins of the Ethiopia are discharged from the central plateau and are separated into two divisions, due to the interfering of Rift Valley. The river basins which are originated from the mountains west of the Rift Valley are draining toward the west and joining the Nile River basin systems. These are including Abbay, Baro-Akobo, Mereb, and Tekeze river basins which covers 39% of the land mass of the country. The estimated surface water flows in this division is accounting more than 70 % of the total flow of the country. The second division is including the basins originated from the eastern highlands and flowing towards to east. These covers 33 % of the country's land mass and accounting only 8 % of surface water of the country (Berhanu et al., 2014).

Ethiopia manages its surface water through 12 basins which are part of four transboundary basins: the Nile, Rift Valley, Shebelle-Juba, and North East Coast. With the exception of the Nile Basin, all river basins experience water shortages. Almost no perennial rivers can be found below 1,500 meters, leaving much of eastern Ethiopia without reliable surface water.

The western Abay (Blue Nile), Baro-Akobo, Mereb, and Setit-Tekeze/Atbara Basins are part of the Nile Basin, which generates 70 percent of the country's renewable surface water, mostly through the Abay Basin. Collectively, these basins provide 86 percent of the Nile's annual flow. The central and northeastern Afar-Denakil, Awash, Omo-Gibe, and Rift Valley Basins account for over 20 percent of surface water resources and are part of the Rift Valley Basin, which spans much of East Africa (Abtew, 2019).

Water supply is concentrated in the southern Omo-Gibe and Rift Valley Basins. Four percent of the national supply is in the Awash Basin and water availability is negligible in the northernmost Afar-Denakil Basin. The Awash Basin has limited supply and high demand, with low average annual precipitation. The eastern Wabi-Shebelle and Genale-Dawa Basins are part of the Shebelle-Juba Basin and contain eight percent of Ethiopia's surface water. The North East Coast Basin encompasses the Ogaden and Aysha, but they are considered dry basins with rivers that only flow after rainfall (Berhanu et al., 2014).

Awash is the only river basin that flow to the northeast direction and terminated to Lake Abe inside of the country near the Ethio-Djibouti boundary. It holds 10% and 4% of the country land mass and surface flow respectively. In the Awash River basin, the inflow is 18.5 BCM, the outflow to the groundwater system 10.3 BCM and the outflow at the outlet of the basin 4.6 BCM and the storage at open water systems that include lakes, reservoirs, and wetlands of the basin account 3.6 BCM. Therefore, the surface and groundwater potential of the basin accounted to be 8.2 BCM and 10.3 BCM respectively, (Adeba et al., 2015).

2.4.Water Resources Utilization in Ethiopia

Even though, Ethiopia has both surface and groundwater potential, the country's water resources are not fully utilized yet. The backbone of Ethiopian economy, Agriculture, is highly rainfall dependent and the energy source relays on fuel wood. Even though the country has enough amounts of water resources potential, the current clear and reliability of water resources potential especially in groundwater part, utilization constraints and future water resources utilization opportunities is not clearly known (Worku, 2018).

According to the report of Worku, among the country's total potential of 3.6 million hectares of irrigable potential land only 3-5% is supported by irrigation. The higher demand of the current generation is never satisfied without supporting by artificial application of water in the form of fully and supplementary. The transboundary River management system is not properly implemented with the riparian countries. Due to this, the downstream countries are always complaining when the Ethiopian Government wants to construct the dam and other infrastructures to use it for different purposes. The economic development of the country is never go far without utilization of water resources properly. But under current situation, the country is not used their water resources properly due to different political, natural, technical and economic factors (Asmamaw, 2015).

The country water and energy office actively involved to increase the utilization of water resource in the form of irrigation, more than 500 irrigation schemes and 30,000 MW of power can be developed using the available potential and clean water supply to its entire people. Finding of the studies indicate that the insufficiently application of irrigation and rainfall dependent farming system and timely incremental distractions of nature resources leading to the progression of famine and poverty in the country. Only, about 10:12% of the total irrigable water potentials are currently under production using traditional and modern irrigation schemes and 670 MW hydropower potentials have been developed and the clean water supply coverage is about 34% (Kiran et al., 2020).

2.5.Water Demands

Water demand is defined as the quantity or volume of water required by users to fulfill their needs. Estimation of water demand is the process achieved through several techniques and is typically used to predict future water requirements for different uses including hydropower, domestic, manufacturing, environmental flow and agriculture water demands. Demand management can bring about physical savings of water by improving the efficiency of water use especially in agriculture (Tortajada, 2013).

Efficiency in water use should be improved in urban and industrial water uses. The technique depends on the availability of the data needed, the general scope of the region and the resources available the future is being conducted. For instance, municipal demand is generally projected using population size and the number of households, industrial demand is often based on number of employees, and agricultural demand commonly relies on crop type and irrigated land.

The key variables such as population growth, climate conditions, urbanization, increase irrigation water consumption, changes in cropping patterns, increase productivity of rain fed agriculture and the water demand for environment and pollution controls were considered in estimation of future water demand.

It can be measured for an existed project scheme or calculated using local data or, more typically, established norms and standards. Such calculations also take into account the number and type of users to be served. It is also important to take into account the seasonal influence on water demand (UN-Water, 2016).

Demand management can bring about physical savings of water by improving the irrigation water use efficiency and avoiding overuse of water in demand sites. Efficiency in water use should also improve in urban and industrial uses. Supply management can be another option to address the problem of water scarcity (Gurmessa, 2015).

2.5.1. Agriculture water demand

Water is one of the major important factors for crop production. In Ethiopia, it is obvious; agriculture is the backbone of the country’s economy. In the areas where, the spatial and temporal uneven rainfall distribution as well as to produce more than one per year; irrigation would play a significant roles. Agriculture provides both the farmers and national economy by sustained livelihoods and improves the general well-being of the communities. Practicing irrigation is the only option to produce crops more once per year. Water demand to irrigation production is an integral part of food self-sufficiency and employment opportunity to the community (FAO, 2016).

Yet, the country's potential irrigable land and water have not been fully utilized. Only 4% to 5% of the potential area has been developed by irrigation; comparatively Awash River basin is the most extensively utilized basin. The river has been used for irrigation in several small and large schemes which owned by private or state (Ayana, 2014).

The progression of irrigation practices in Ethiopia looks up difficulties and challenges. The main challenges to the irrigation activities are lack of provision in awareness of irrigation water management such as irrigation scheduling techniques, lack of techniques to save water, operation and maintenance of irrigation facilities, inadequate knowledge on improved and diversified irrigation agronomic practices (Tadesse, 2009).

At a current, government gives emphasis to the sub-sector by way of enhancing the food security situation in the country. Efforts and involvements of farmers are made in the progression of small-scale to large-scale irrigation practices during the planning, implementation and management in water distribution and operation and maintenance to improve the performance of irrigation (Dost et al., 2013).

Most crop productions in irrigation practices are subjected to the surface water. Irrigation is the main water consumer because irrigation efficiencies are low with 30-40 percent. A great deal of water can be saved by increasing the efficiency of irrigation and narrowing the gap between the stated policy and the actual practice regarding water resources management.

2.5.2. Domestic water demand

Domestic water demand includes all water needed by the people in households for drinking, cooking, washing and bathing. Domestic water demand is determined basically based on the information how many people are living and how much amount does an individual need per day. It is difficult to estimate the exact amount of water needed to maintain the acceptable or minimum living standards. However, different organizations and studies at different time are put the minimum ground root of total water consumption per time. For domestic purposes the quantity of water consumption depends on the living standards of the community. The international organizations and water providers adopt an overall basic water requirement of 50 liters per capita per day (Lpcd) for a minimum standard to meet four basic needs: drinking, sanitation, bathing and cooking.

Approving to some feasibility studies on water supply in Ethiopia per capita per day requirement ranges between 20-40 liters. The general design standards were adopted to 30: 50 liters per capita daily for urban centers and 15-25 l/p/c/d for rural areas. For both rural and urban areas, the per capita water demand is assumed to increase over the time. Since the majority of the urban population uses public fountains, a ratio of 60 percent to 40 percent is considered (Shiferaw et al., 2015).

2.5.3. Environmental flow

The specification of an environmental water requirement varied depend on the objective of environmental water management. It can be a complex and its estimation should be viewed in the context of natural variability of flow regimes. The most appropriate methodology depends on the individual case, including the specific objectives of the task, the amount of data and other available information. The total environmental water requirement consists of ecologically relevant low-flow and high-flow components. Up to 75 percent of the annual flow may come during rainy seasons. The river flows may reduce to a great extent during dry periods. It has estimated that approximately 20-50 percent of the mean annual river flow in different basins needs to be allocated to freshwater-dependent ecosystems to maintain fair conditions (Asmerom, 2015).

For the Awash River basin, the environmental flow requirement estimated to be about 35 percent of the mean annual river flow which, equivalent to 1.64 BCM/year. The seasonal deficit (Intra annual shortage) of water is more challenging than inter annual shortage because the precipitation. Rainfall in the basin is highly variable in space and time, resulting in seasonal water surplus and deficit (Duguma et al., 2021).

2.5.4. Livestock Water Demand

Livestock takes a significant demand on water resources. The water requirement of domestic animals varies between species, between breeds or varieties within species and between individuals within breeds. Consumption rates can also be affected by environmental and management factors (Sileshi et al., 2003). Since the livestock water consumption rate is varied, the common reference unit used to convert the total livestock population is called Tropical Livestock Unit (TLU). Tropical Livestock Units are the aggregation of livestock from various species and ages as per convention. The use of specific coefficients established initially based on the nutritional or feed requirement of each type of animal (FAO, 2011).

According to (Sileshi et al.,2003), the water requirement by livestock appears to be a very different and specific. Because of the water demand for the individual animal is the function of animal species, development stage and a specific environment in which the animal living.

2.5.5. Commercial and Institutional water demand

Ministry of Water Resources of Ethiopia in 2013, has prepared policies and guidelines for the linkage and relation between population size and water requirement for commercial and institutional. The water requirements in towns include the needs for commercial and institutional consumers such as public gardens, schools, clinics, hospitals, offices, shops, bars, restaurants, and hotels.

Commercial and institutional water demand is usually linked directly to population size. For small and medium-size towns, the commercial and institutional water demand was estimated at 5 percent of the domestic water demand. For larger towns, the commercial and institutional water demand estimate was 10 percent of domestic water demand. Those allowances were applied to all towns. No allowances were made for commercial and institutional water demand from rural communities (Shiferaw et al., 2015).

2.6. Approaches of Assessment water balance and Demands

2.6.1. Approaches of assessing water balance

Water balance allows studying the hydrologic process in a watershed and determining the unknown parameter based on the known. It is based on water accounting principles in which water inflow to the watershed, leaving the watershed, and change in storage may be groundwater, water in the soil, ponds, micro dams, and vegetation for the period considered is taken into account.

The water balance approach supports quantifying the relationship between rainfall, evapotranspiration, surface runoff and groundwater runoff (Dejene, 2020). Hence, water balance is the sum of the total mass of water inflow to the watershed system minus the total mass of the water flowing out of the system.

Studying water balance plays a significant role in understanding and auditing water in close or specific boundary systems in the watersheds or basins within a given time. Assuming the boundary of the surface water in the watershed coincides with that of the groundwater, the net groundwater flow has taken to be zero.

The water inflow into the watershed area is, therefore, considered to be only from rainfall while, the water leaving the watershed area includes runoff and actual evapotranspiration. The difference between them constitutes the change in groundwater and soil moisture storage. The change in water storage on water balance depends on the period over which the water balance has been computed. The general approach is the accounting of water flowing into the watershed from different sources of inflows, while total water outflows are considered at the watershed outlet (Abanish et al., 2018).

2.6.2. Surface water availability

Water is the finite single most important element of the environment and all life and human social and economic activities are built on. Water is the main controlling element of the human's activities. Surface water is the water that is opened to the atmosphere and its primary source is precipitation feeding by runoff from the surface, such as in a stream, river, lake, or reservoir. It is the essential resource that can use for different anthropogenic activities like public, industrial, navigation, agricultural and energy supply purposes.

Efforts should be intensified, on the efficient use of all water resources (surface water, groundwater, and rainfall) and on water provision that maximizes the resultant economic returns. Surface water resources are most assessable to users and sensitive to be damage. Therefore, awareness and consideration should be growing on the surface water. Assessing the abundance of water resources is the aspects of water conservation, developing and effective management water resources in the watershed (Mango et al., 2011).

A systematic assessment of water resource with high spatial and temporal resolution is essential in a watershed for strategic decision making on water resource related development projects. A comprehensive understanding of hydrological processes in the watershed is a prerequisite for successful water management and environmental restoration. Water availability and use are the functions of the total flow of water through a basin, its quality, and the structures, laws, regulations, and economic factors that control its use. Assessing surface water potential and evaluating the demand available are the key issues to provide information to the decision makers on how much water is available and how much of the water is utilizable for different users (Tadesse, 2006).

For instance, describes how significant changes in land use may have an impact on the river flow regime and changes in land moisture over time. The potential for water to be maintained for agriculture, water supply, and hydropower generation; the water's major source is surface water, and it is more easily accessible than other sources of water (Adeba 2021).

2.6.3. Water demand approach

Water demand is the summation of water needed to meet various users in the specific water system such as watershed or basin. Knowing and managing of water demand is the fundamental issue for the watershed water resource planning and governance. Proper and effective water demand management among water user play roles in stabilize water use tensions and conflict resolution of intra or external water users. Therefore, the water demand management requires comprehensive and holistic approaches, instruments, implementation and strategies to support in the water conservation, water pricing, public private partnership, and society engagement (Tortajada, 2013).

The key variables such as population growth, urbanization, increase irrigation water consumption, changes in cropping patterns and the water demand for the environment and pollution controls were considered in estimating future water demand. The accelerated growth of the world population, the rapid advances made in industry and agriculture have resulted in a rapid increasing use of water, to the extent that the availability of water as well as the control of excessive water has become a critical factor in the development of every areas of the world. As a result, the way things are going may cause competition for water to emerge, which may affect how different sectors utilize water (Amisigo et al., 2015).

One of the possibilities for determining the concrete requirements for providing everyone with access to water is the accurate and sustainable evaluation and projection of water demand. These are the key instruments for water usage planning, supply design, and operation to satisfy the rising demands in the short: and long-term is the water demand projection. A crucial method for aiding water managers in better water distribution based on priority of requests for balancing water demand is assessment of water demand. It is required to evaluate domestic, livestock, irrigation, hydropower plant, and industrial practices, as well as environmental water requirements in the watershed, in order to determine the water demand. The method used to gauge water demand is determined by the region's general policies (Thivet, 2010).

2.6.4. Approaches to developing Scenarios

The basic benefit of water demands model is to develop scenarios that are inherited from current account year scenario. Scenarios are conceivable scenarios that can be used to examine the impact of shifting demand conditions. Scenarios can provide "what-if" scenario answers. For all of the scenarios, Current Accounts serves as the first year of the simulation period. With the information we have, it gives the fundamental description of the current water system. The future water demand can be predicted by creating many scenarios based on the fundamental existing water consumption. These scenarios may take into account the quantity and type of users to be accommodated, the projected pace of population increase, the predicted expansion of industry, climate conditions, an improvement in living standards, and the impact of seasonal factors on water demand (Khalil et al., 2018).

Forecasting future water requirements usually take important factors into account, including the phase of population growth, urbanization, expansion of irrigation systems, and the development of hydropower and climate change.

2.7.Hydrological Models and Selection Criteria

Hydrological models are used to characterize the real world system. A wide range of hydrological models are used by the researchers, although the applications of the models are highly dependent on the purposes for which the modeling is made. Before developing the hydrological models, it is important to understand how the catchment responds to rainfall under different conditions. Understanding all water flows and storage changes in the watershed are needed for assessing water resources. The hydrological models are essential for determining the quantity, quality, timeliness, and dependability of water in the watershed. Understanding hydrological and meteorological characteristics are the foundation for studying the complexity of hydrological processes for sustainable watershed management (Abbaspour et al., 2017).

There are many different reasons why modeling of the rainfall-runoff processes of hydrology is needed. So many researchers classified hydrological models based on; the basis of their function and objectives, their structure, and their level of spatial disaggregation. The main reasons behind are a limited range of hydrological measurement techniques in space and time (Megebo, 2020).

Various water resource models that can simulate groundwater recharge and storage, surface runoff, rainfall patterns, as well as water demand in a watershed or basin. These models area conceptually condensed portrayal of the hydrological systems found in the actual world. It exchanges information between the known (input) and the unknown (output) through the use of mathematical formulas. Models used to correlate the inputs and outputs (such as flow forming components) on a quantitative and qualitative basis. Thus, hydrological modeling establishes the mechanism by which precipitation is transformed into hydrological components, including runoff, deep aquifer storage, evaporation, transpiration, etc. In order to get sufficient findings for a particular study, it is crucial to choose a model that takes into account the data that is available and the expected study outputs (Talila et al., 2015).

The criteria which can be used to select the right hydrologic model are always project dependent, since every project has its own specific requirements and needs. Further, some criteria are also user depended, such as personal preference for graphical user interface, computer operation system, input or output management and structure, or users add on expansibility (Asmerom, 2015).

Among the various project-depended selection criteria, the main common, fundamental that must be considered are; -

- Availability of the model on minimum investment of time and cost.
- Ability of the model to produce the intended output to meet the objective of the project.
- Ability of the model considered to produce the outputs needed to meet the aims of a particular project.
- Possibility to prepare a list of assumptions made by the model and ability to check the assumptions likely to be limiting in terms of known response of the catchment.
- Ability to make a list of inputs required by the model and deciding whether all the information required by the model can be provided with in time and cost constraints.

2.7.1. Soil and Water Assessment Tool (SWAT) Model

SWAT model is created by Dr. Jeff Arnold for the Agriculture Research Service of the United States Department of Agriculture (USDA-ARS). It operates on a continuous time step and a conceptual physical based, computationally effective, uses readily available inputs, and allows users to examine long-term implications (Arnold et al., 2012).

SWAT simulates the hydrologic processes in a basin, through dividing the basin into the smallest and unique of the sub-basins which are referred as the hydrologic response units (HRUs). HRUs have a unique combination of soil and land use characteristics and are considered to be hydrologically homogeneous. The model scheming is performed on a HRU basis, and flow variables are routed from the HRU to the sub-basin and subsequently to the watershed outlet. The model estimates relevant hydrologic components such as surface runoff and peak rate of runoff, evapotranspiration, groundwater flow and sediment yield for each HRUs. The governing force behind everything that happened in the watershed is water balance. As simulated by the model, the water cycle must conform to what is happening in the watershed to accurately predicting the movement of sediments. The hydrology is simulated in two major ways: the Land Phase, which controls transport sediment, nutrient and pesticide loading to each channel from sub-basins and the Water or Routing Phase that controls the movement through the channel network to the outlet (Demissie, 2013).

SWAT model is the most popular model to assess water quantity, quality, and characteristics of the watershed. SWAT uses physical based inputs like weather variables, soil properties, topography, vegetation and land management. SWAT model can simulates surface runoff, evapotranspiration, streamflow, interception storage, infiltration, reservoir water balance and shallow and deep aquifer have been developed (Singh et al., 2014).

The SWAT model is easily available on-line and enables water managers to model the quantity of surface water and quality of catchments worldwide. It is a comprehensive model integrating surface land and channel environmental processes. SWAT model has its own strength and drawbacks (Glavan, 2012). The strengths and drawbacks of the SWAT model has discussed as the follow.

Strength of SWAT model:-The SWAT model is easily available on-line and enables water managers to model the quantity of surface water and quality of catchments worldwide. It is a comprehensive model integrating surface land and channel environmental processes. It combines studies of water quantity (river discharge, surface flow, subsurface flow, lateral flow, base flow, drains, irrigation, reservoirs, lakes), water quality (weather, erosion, plant growth, nutrients cycles, pesticides, soil temperatures, agricultural land management, crop production, urban land management, agro-environmental measures) and climate change. SWAT is capable of yearly, monthly, daily or sub-hourly simulation over long periods. SWAT editor is a standalone program which reads the project database generated by Arc SWAT interface. Flexible framework that allows simulation of agro-environmental measures and best management practices.

Drawbacks of SWAT model: - The model is a non-spatial representation of the HRU inside each sub-catchment. This kept the model simple and supported application of the model to almost every catchment. Land use, soil and slope heterogeneity of the model is accounted through sub-catchments. This approach ignores flow and pollutants routing between HRUs. Wide range of different data needs to be obtained to run the model and numerous parameters needed to be modified during the calibration which discourage modelers to use SWAT. However, environment is a complex system and disregarding or underestimation of importance of parameters could lead to inaccurate model results and evaluations. More extensive use of the model would be expected with adding more groundwater routines and algorithms or with permanent coupling of the model with groundwater model. The model does not allow simulations of multicultural plant communities. Sensitivity analysis, manual and auto-calibration tools in the SWAT model is time demanding in the complex catchments with numerous HRUs.

2.7.2. WEAP Model and its application

Water Evaluation and Planning (WEAP21) is a computer modeling tool for integrated water resources planning developed by the Stockholm Environment Institute (SEI). It was developed in 1988 and has become a popular model that has been used widely in many river basins and sub-basins for water planning.

WEAP is used to estimate future water availability and demand against different scenarios, like population growth, climate change, economic development, improving irrigation efficiency, projecting irrigation area, etc. (Berredjem, 2017). The study was conducted by Berredjem and Hani in the Lower Seybouse sub-basin, located in the northern part of Algeria. They assessed the current water use and used WEAP to estimate water demand in three different sectors, namely household, industrial, and agricultural sectors. Their findings show that the water demand in the sub-basin will increase significantly, leading to insufficient water supply issues. The researchers also modeled climate change impacts with scenarios of extended drought.

Operating on these basic principles, WEAP is applicable to many scales, including municipal and agricultural systems, single catchments, and complex trans-boundary river systems. WEAP does not only incorporate water allocation but also water quality and ecosystem preservation modules. This makes the model suitable for simulating many of the freshwater problems that exist in the world nowadays (Dereje, 2015).

Water Evaluation and Planning Version 21 (WEAP21) is an integrated and easy-to-interact model that tries to address the problems in water management and watershed hydrology. It has the advantages of effective IWRM, ease of use, affordability, readiness, and availability to a broad range of water resources communities. WEAP is not developed to be used in the design of new water systems. Rather it is a tool that helps in ongoing analysis and management of existing water systems and also the water resources. It shows the user to consider the potential impacts that may happen if different changes introduced to the system. And it greatly assists in the optimized decision-making process on resources allocation. If a given system need to be redesigned or 3D modelling of the watersheds' infiltration and runoff unfortunately, WEAP will not be recommendable (Adgolign et al., 2016).

2.7.3. CROPWAT model and its application

CROPWAT is a Decision Support System (DSS) developed by the Land and Water Development Division of Food and Agriculture Organization (FAO) for planning and management of irrigation (Tiahun Ashine, 2019). It is a practical tool to carry out standard calculations for reference evapotranspiration, CWR, IWR, and more specifically the design and management of irrigation schemes. CWR and irrigation timing are particularly important in water resources management.

Arku *et al* (2012) used CROPWAT model version 8.0 to determine water requirement and irrigation timing for Amaranthus Hybridus in Maiduguri Metropolis, North-Eastern Nigeria. Based on his result the theoretical values of water requirements and irrigation timing were computed using the Penman Monteith equation in CROPWAT 8.0 for dry season drip irrigation system as water saving measure and optimum yield.

(Mahtsente et al., 2017) have applied the CROPWAT model after analyzing water demand and irrigation requirement for major Crops at Holeta Catchment, Awash Sub basin, Ethiopia. In her study, Reference evapotranspiration, effective rainfall, crop pattern, and soil data were used for analysis. The major crops were identified from the survey analysis and used in the calculation of CWR.

2.7.4. SWAT-CUP Program

Models approximate the reality of natural systems. Both graphical methods and statistical tests are used in model calibration and validation. It is a program developed to do various calibrations and uncertainty analysis programs for SWAT using the same interface. Currently, the program can run SUFI2 (Schuol et al., 2008).

Calibration is the process of estimating model parameters by comparison of model predictions or output for a given set of assumed conditions with observed or measured data for the same conditions. Calibration of physically based, distributed watershed models should be done before they are used in the simulation of hydrologic processes in order to reduce the uncertainty associated with the model prediction.

Watershed scale model calibration is challenging and is impeded by uncertainties like watershed processes unknown to the modeler, processes not captured by the model, and simplification of the processes by the model. After every sub-basin is calibrated with the hydrological parameters, the model is going to be validated. Validation is performed to compare the effects of using different spatial scales on model output. The SUFI2 algorithm is suitable for the calibration and validation of the SWAT model because it represents uncertainties (Mango et al., 2011).

The calibration or sensitivity program can easily be linked to SWAT through a generic interface called SWATCUP (Calibration and Uncertainty Procedures), which is a standalone program developed for SWAT calibration (Abbaspour et al., 2017). It is an interface that provides sensitivity analysis, calibration, and validation of SWAT models. Sequential Uncertainty Fitting Algorithm (SUFI2) is very efficient, not only in terms of localizing an optimum parameter range but also in terms of the number of simulations (Tejaswini, 2018). SUFI2 is very convenient to use, but the only drawback is that it is semi-automated and requires the interaction of the modeler to check a set of suggested posterior parameters that require good knowledge of the parameters and their effects on the output. This drawback may add an additional type of error called "modeler’s uncertainty" to the list of other types of uncertainties.

2.8. Previous Studies in or near Teji Watershed

There are a number of studies that have been conducted in and near the Teji watershed.

(Eshetu, 2008), has done research under the title of "Evaluation of groundwater resources potential in the Teji River Catchment." He get that the water sample analyses made in the catchment indicate the water is suitable for domestic and agricultural purpose.

(Dejene, 2020) has conducted his study in the title of “Flood Damage Analysis, for Teji Area (Illu Woreda)" using the HEC-GeoHMS Arc GIS extension. The physical characteristics of a catchment are obtained from the study area's digital elevation model. He get that the flood plain mapping near the Teji River was generated depend on the peak flow of the river for different return periods and quantified the damaged economy by flooding in the Illu Woreda.

(Tajin, 2015), studied "Water Allocation for Existing and Future Demands under Changing Climate Conditions: Case of the Upper Awash Sub River Basin" by using the HEC:HMS hydrologic model and get the annual water demand and supply for the reference period were found to be 1716.3 MCM while the demand increased to 1953.3 MCM for the future scenarios.

(Kurkura., 2011), carried out his study under the title "Water Balance of the Upper Awash Basin Based on Satellite-Derived Data (Remote Sensing)". He has found that the annual rainfall, evapotranspiration, and runoff from the Upper Awash Basin were 1049.60 mm, 905.76 mm, and 143.84 mm, respectively.

Even though the above and other studies were conducted in the watershed, there is still a gap in the assessment of surface water potential and water demand evaluation in the watershed.

As clearly stated in the statement of the problem, in order to settle water stress and conflict arisen through water users, an accurate and comprehensive assessment of available water resources is important, which can help in effective water development as well as applying integrated water resources management.

3. MATERIALS AND METHODS

3.1.Description of the study area

Teji River watershed is a tributary of Awash River basin, it drains to the Awash River basin on its upper reach. It is located in the South-West Shewa Zone of Oromia Regional State. The river originates from Kondaltiti woreda, near the foot of the Fula-Debitu highlands at elevation 3576 m a.m.s.l. and drains into north-east direction to meet the Awash River.

The watershed is geographically found between Latitude 8^{0}23’04’’N and 8^{0}48’50’’N and Longitude 38^{0}07’20’’E and 38^{0}26’44’’E. The watershed covers an average area 65564 ha and the altitude ranged from 2075m to 3576m above sea level. The river streamflow gauging station is located at elevation, 2075 m.a.m.s.l. near Asgori town, at a distance of about 65 Km from Addis Ababa, the capital of Ethiopia. The Addis Ababa–Jimma asphalt road possibly crosses the watershed. The watershed is also served by all-weathered roads from Asgori to Bantu, Tulu-Bolo to Harbu-Chulule, and all villages in the entire watershed (Gonfa et al., 2021).

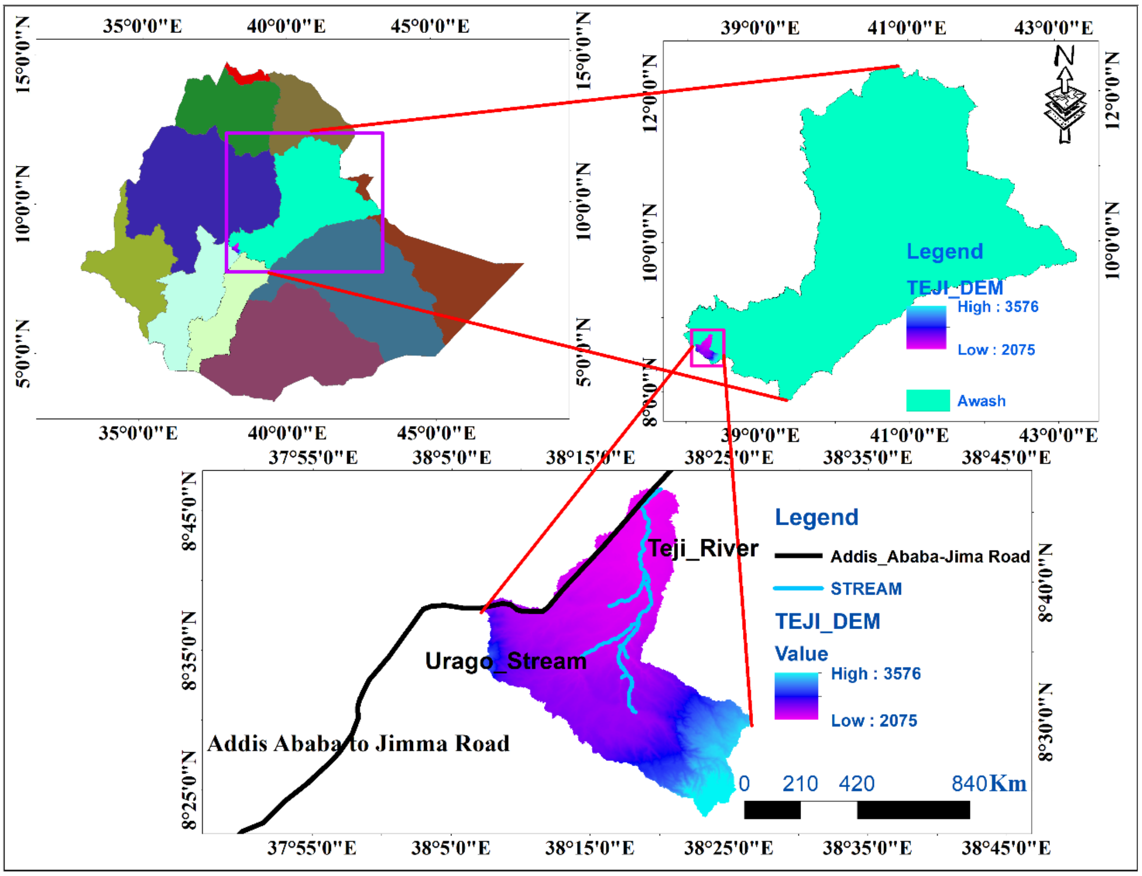


Figure 3.1: Map of the study area

Teji River flows in the several woreda of South West Shewa zone, such as Becho, Ilu, Kondaltiti, Seden Sodo, Tole and Woliso. The majority land mass of the watershed is located in Becho followed by Seden Sodo Tole and Woliso woreda.

The watershed is one of the hydrological catchments established in a flat topographical area with fertile soil. The Teji River is one of the river, having more land suitable for agriculture and providing enough food to feed the densely populated communities. The area was dominated by rain fed agriculture and traditional livestock grazing. The agricultural land used for crop cultivation accounts for 87% of the total area. Teff is the most dominant rain fed crop in the area.

3.1.1. Climate

I. Rainfall and Rainfall Coefficient

The rainfall data recorded at Asgori, Bantu Liben, Teji, Tulu Bolo, Herbu Chulule, and Woliso are used in the estimation of the mean rainfall of the study area. Accordingly, the over-year average annual rainfall of the area was shown below in

Figure *3.2*. The average annual rainfall was estimated to 1103.43 mm, while the average minimum and maximum rainfalls were 909.59 mm and 1537.37 mm, respectively.

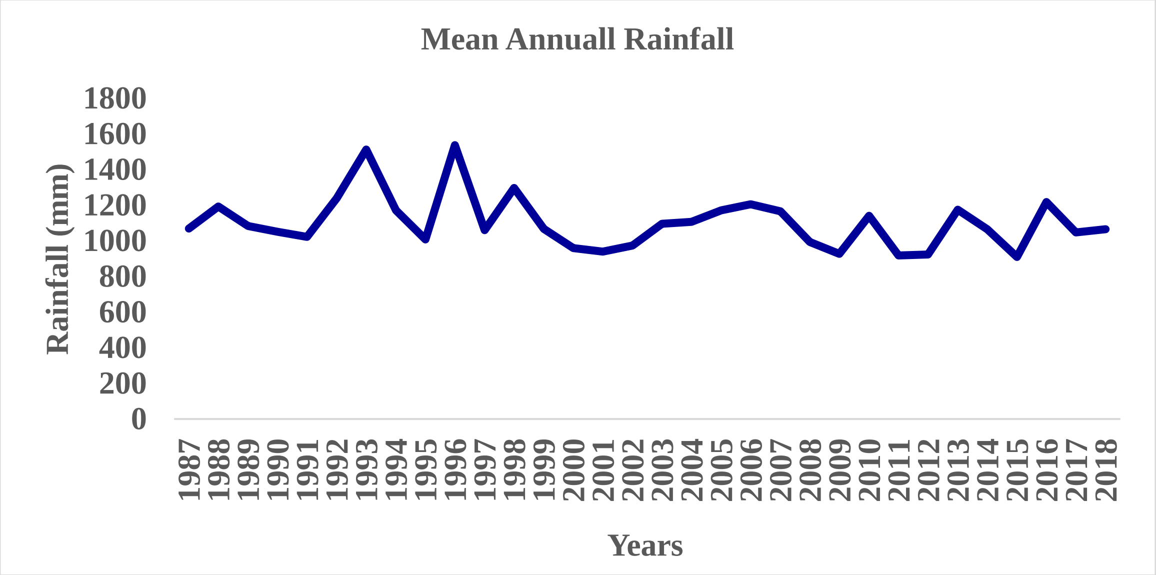


Figure 3.2: Mean annual rainfall of study area (1987-2018)

The average monthly rainfall distribution of the study area was varied based seasonal variation, and reached the maximum and minimum during July and December respectively.

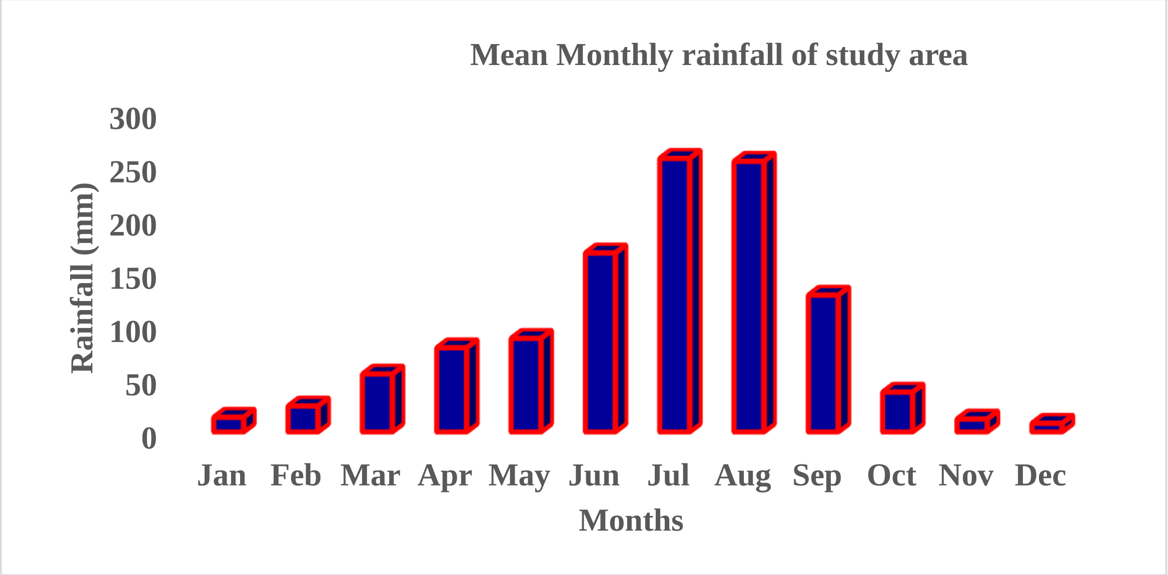


Figure 3.3: Mean Monthly rainfall of study area (1987-2018)

II. Temprature

The mean annual temperature of the study area is about 18.10 °C and with a fluctuation of 5.50 °C on December to 29.40 °C recorded during the month of March. The mean monthly temperature variation of the area was shown in the Figure 3.4, below.

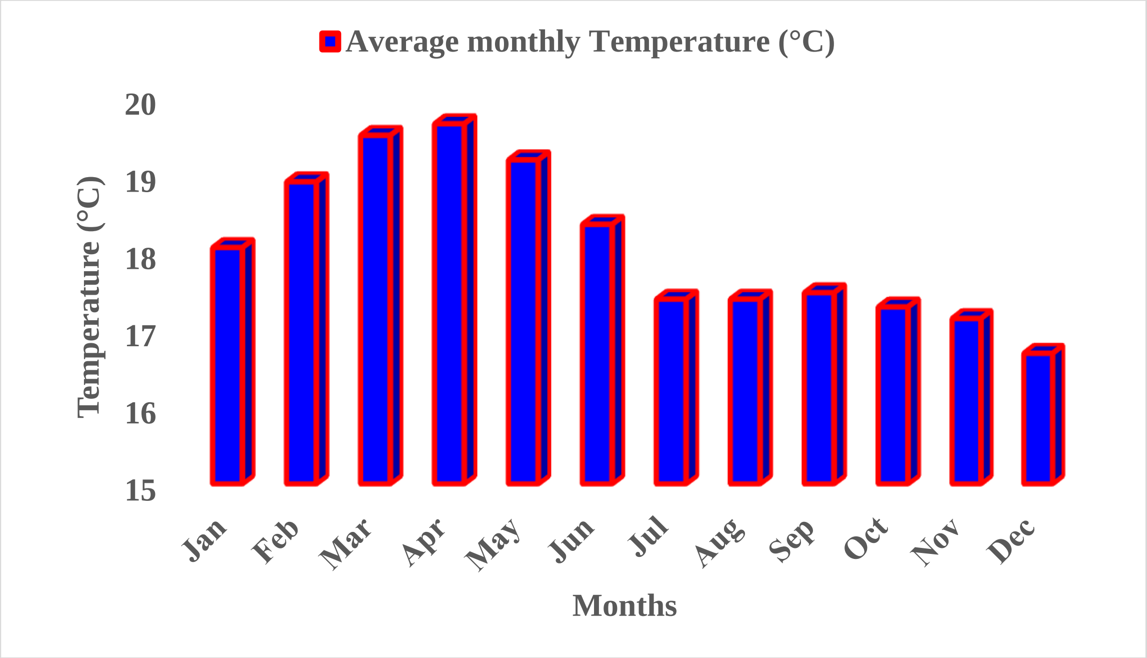


Figure 3.4: Mean monthly maximum and minimum temperatures of the study area

III. Wind Speed and Relative Humidity

The exact position of the ITCZ changes over the course of the year, oscillating across the equator from its northern most position over northern Ethiopia in July and August, to its southern most position over southern Kenya in January and February. The movements of the ITCZ are sensitive to variations in Indian Ocean sea-surface temperatures and vary from year to year (SUZUKI, 1969).

The Teji watershed and its surroundings are influenced by the seasonal ITCZ. The direction of the wind blows from east to west during the months of September to May, but it reverses from June to August in the direction of south-west to north-east.

The mean monthly wind speed in the study area ranges from a minimum value of 0.99 m/sec in July to maximum values of 3.8 m/sec in December, at 2 m heights from the ground surface. The maximum and minimum relative humidity are calculated to be 83.9% and 42.2%, respectively.

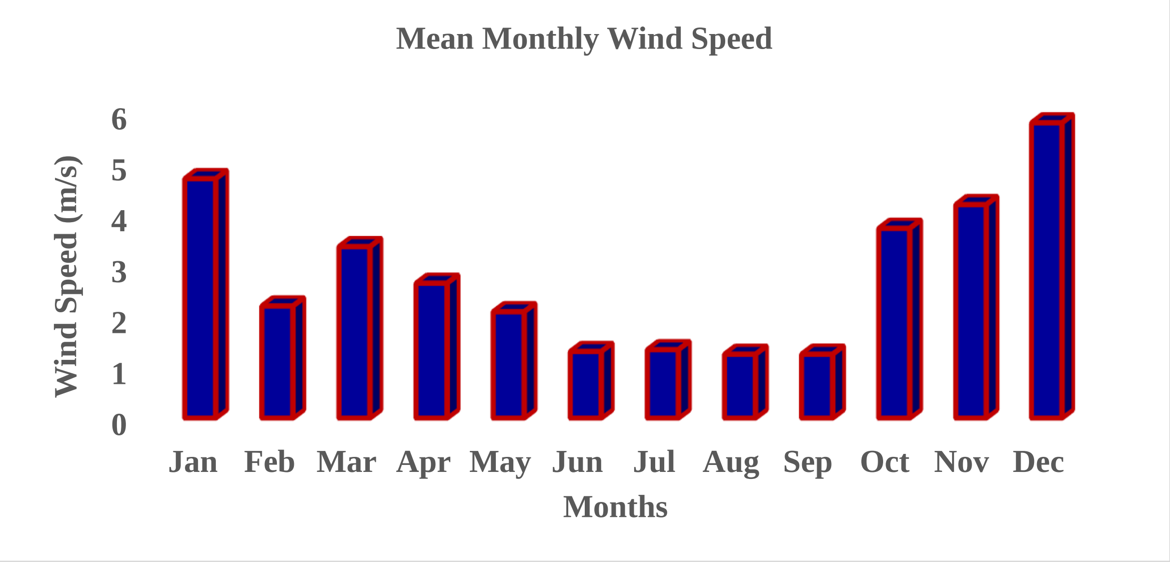


Figure 3.5: Average monthly wind speed

3.1.1. Land use land cover and Soil type

The land use and cover (LULC) of the area consists mainly of cultivated agricultural land (Kurkura., 2011). Because of altitudinal and seasonal differences, there are varieties of crops growing in the area, including Teff, Wheat, Barley, and Baize; Cereal crops like Chickpea, Lentil, and Vetch; and false banana, or Enset (Ensete ventricosum). In addition, Tomatoes, Onions, Cabbage, Peppers, and Potatoes are the common vegetables grown in and around the area (Gonfa et al., 2021). Most forest land is covered by Eucalyptus (Keyi Bahir Zaf), followed by Acacia trees.

The main soil type in the study area is Vertisols (Gonfa et al., 2021). The Vertisols are dark in color which forms deep cracks in dry seasons and swelling in rainy seasons due to the presence of the montmorillonite clay mineral The Vertisols are chemically fertile and generally not much fertilizers are used, but demand careful management. The hard state when dry and sticky, plastic state when wet makes tillage difficult and limited to certain periods. Water will infiltrate rapidly through the cracks with the first rains after the dry season, but when the clays are wet and expanded, the infiltration is very low (Critchley, 2010). This clay soil is known as "**Koticha Guracha**" in the local language. Vertisols are the most suitable soils in agriculture for Teff and Cereal crops like Chickpea, Lentil, and Vetch production. But, it is hard for wheat and barley production without the help of extra land drainage by Broad Board Maker (BBM).

3.1.2. Socio-economic conditions

The majority of the population in the study area is rural (*CSA*, 2014). The livelihood of the population in the area is predominantly dependent on agriculture. Agriculture is the subsistence industry in which crop production is predominant and livestock rearing is intimately integrated with crop production.

Crop production is the main occupation of the majority of households. In and near the area more than 77% of the population in the study area is involved in crop production. The dominant crop cultivated in the area is Teff (Simegnew, 2019). Most crop production is largely dependent on rainfall. In addition, for decades there has been some farming by irrigation that is dependent on the Teji River.

Livestock plays a key role in the economic activities of the peasants. Major rural farming, transportation, energy sources, and the basis of income are directly or indirectly linked with livestock. Most farmers have 3:5 tropical livestock units. Oxen are primarily used for draught power. In terms of population, poultry production and cattle production stand first and second, comprising about 49% and 42%, respectively, followed by sheep and goats at 6%.

3.2. Data collection and analysis

The data required in the assessment of surface runoff and demand analysis were classified as primary and secondary data. The secondary data were the general and relevant sources of data related to the study that were consulted to supplement the primary data. Written documents, books, CSA, government, and non-governmental documents, journals, and research works on the subject were reviewed. National policies and strategies were considered to complement the study of assessing surface water and examine current and future water demand. The contents of secondary data included the spatial, hydrological, meteorological, socio-economic, and inhabitant’s data in and around the watershed.

3.2.1. Meteorological Data

Hydrological models are essentially dependent on meteorological data such as precipitation, temperature, relative humidity, wind speeds, and sunshine hour data. All meteorological data might be recorded in time steps of hourly, daily, monthly, or yearly; that could either be measured in gauge stations or generated by the weather generator.

In this study, the daily recorded data for 32 years (1987–2018) were collected from the National Meteorological Agency of Ethiopia. The meteorological data in and around the watershed were collected and the six gauging stations were selected based on the quality and values of the missing data.

Two stations; Asgori and Tulu Bolo have rainfall, and maximum and minimum temperature data. The remaining three; Bantu-Liben, Teji, and Herbu-Chulule have only rainfall data, while Woliso station is Class-I and holds all the meteorological data. So the daily precipitation, maximum and minimum air temperature, sunshine hour, wind speed, and relative humidity of Woliso meteorological stations were used in the SWAT Weather Database. The monthly parameters of the wind speed, sunshine hours, and relative humidity, were estimated in the.txt format.

Initially, the sunshine hours were converted into daily solar radiation (Rs) energy in MJ/m^2/day using the Angstrom-Prescott equation (sunshine hour to radiation conversion equation), which depended on the two local coefficients, "a_s" and "b_s."

$$\mathrm{Rs} = \left(\mathrm{as} + \mathrm{bs}\frac{\mathrm{n}}{\mathrm{N}}\right)\mathrm{Ra} \qquad (3.1)$$

Where

Rs is daily solar radiation [MJ/ m^2-day]

n is actual sunshine duration [hour] observed at weather station

N is maximum possible sunshine duration or daylight hours [hour] calculated as

$$N = \left(\frac{24}{\pi}\right) \times \omega \qquad (3.2)$$

Where, n/ N is relative sunshine duration, Ra is extra-terrestrial radiation [MJ/m^2-day], a_s is local coefficient, expressing the fraction of Rs/Ra on overcast days (n = 0) and $a_s + b_s$ = fraction of Rs /Ra on clear days (n= N).

3.2.2. Geo-Spatial Data

3.2.2.1.Digital Elevation Model (DEM)

DEM is one of the essential spatial inputs for Arc GIS in watershed delineation as well as SWAT simulation in hydrological modeling. In this study, a DEM of 12.5 m x 12.5 m resolution was downloaded from the website (https://vertex.dac.asf.alska.edu) of the Alaska Satellite Facility. The DEM, used to delineate watershed boundary, elevation differences, flow directions creation and sub-basin calculation, recondition and to characterize the stream cross-section.

3.2.2.2.Land use land cover

The 2016 Awash River Basin land use land cover map data of 30m x 30m resolution was collected from the MoWIE of Ethiopia under the GIS department. Then the land use/cover map of Teji watershed was clipped from Awash River Basin land cover map by using ArcGIS. The land cover data in a projected shape file format was loaded in to the Arc SWAT interface to determine the area and the hydrologic parameters.

3.2.2.3.Soil Map

The spatial soil data was obtained from the Ethiopian Ministry of Water, Irrigation, and Electricity (MoWIE), which is prepared according to FAO, Harmonized World Soil Database classification (FAO, 2010).

3.2.2.4.Hydrological data

The 19 years (1998-2016) streamflow data of Teji gauging station, near the Asgori town was collected from the MoWIE. This the daily recorded streamflow data used in SWAT-CUP calibration and validation.

3.2.2.5.Human and Livestock Population Data

The population data was assessed in a 2007 survey and projected in 2014 by the Central Statistical Agency of Ethiopia and projected further for 2021.

Table 3.1: Projected population number in the study area

Year	2007 Surveyed		2014 Projected		2021 current	
Woreda	Rural	Urban	Rural	Urban	Rural	Urban
Woliso	59540	14476	72452	21298	79923	4637
Seden-Sodo	66268	2947	80643	4334	88961	5232
Kondaltiti	74479	6536	90631	9610	99977	11653
Tole	60000	2895	73013	4258	80542	5164
Ilu	54500	7485	66319	11013	73157	13359
Becho	140807	2584	171352	3803	189026	25834
Sub-total	455594	36923	554410	54316	611586	65878
Total	455594		608726		677464	

Source: (*CSA*, 2014)

In other cases, the data on livestock that private peasants hold in the area was collected from the South West Showa zone Agricultural and Natural Resources Management office. As animals vary in species and age, the specific coefficients of the conversion factor should be used based on the nutritional or feed requirements of each type of livestock. The number of livestock was converted to Tropical Livestock Unit using TLU conversion factors for different livestock species as the following relation.

$$Total\ TLU\ =\ Livestock\ population\ *\ TLU\ \text{factor} \qquad (3.3)$$

Live Weight = TLU * 250 (1 TLU is equivalent to the weight 250 kg).

Measuring 250 kg of live weight, the TLU has been used as the reference point to factor livestock of different species was taken as 1 TLU.

After all the livestock population of each species were multiplied with the associated conversion factors, the TLU livestock population number were prepared in the Table 3.3, below. The livestock water demand was estimated based on the livestock standard water demand in semi-arid regions, particularly sub-Sahara, Africa (Kemal, 2021).

Table 3.2: Conversion factors Livestock number into TLU

S.No	Livestock Type	Conversion Factor
1	Camel	1.0
2	Cattle	0.7
3	Sheep	0.1
4	Goat	0.1
5	Horse	0.8
6	Mule	0.7
7	Donkey	0.5
8	Poultry	0.01

Source: (Sileshi, 2003)

Table 3.3: Livestock number in Tropical Livestock Unit of the study area

Woreda	Cattle	Sheep	Goat	Donkey	Horse	Mule	Poultry
Becho	481950	33750	30375	31390.8	27000	2599	11812
Sed/Sodo	122489	13460	10431	12610.2	10768	130	3701
Kondaltiti	123777	10104	8083	9298.8	8083	176	3031
Tole	98659	7047	8104	6553.8	5638	1637	1585
Ilu	18188	928	835	1720.2	1485	233	556
Woliso	14713	1261	966	2091.6	1345	116	462
Total	859778	66550	58796	63665	54319	4893	21150

3.3.Data Analysis

Before using hydrological and meteorological data, it is important to check whether the data are complete, homogenous, correct, and sufficient. Both the metrological and hydrological data that were received from the NMA and MoWIE of Ethiopia have the missing data.

3.3.1. Filling missing of rainfall data

The continuity of recorded rainfall data might be fragmented with missing data due to lack of periodic observation, damage of recording materials, failure, and mechanical or electrical malfunctioning in the stations. Using such incomplete data may result in an unexpected fault output. Several methods of filling in missed data are available in hydrological modeling and design. The two most commonly used methods are the simple arithmetic mean method and the normal ratio method.

In this study, most of the missed rainfall data were filled using the arithmetic method (in which the missed values were less than 10%) and the rainfall data of one station was filled using the normal ratio method with the consideration of the data of neighboring stations. It is the average value of rainfall at various stations during a particular and specified time period. The method is applied when the percent of missed data is greater than 10%. The missed data were filled by the arithmetic and normal ratio methods which given into the following equation (3.4) and (3.5), respectively.

$$\mathrm{Rx} = \frac{1}{n}(\mathrm{R1} + \mathrm{R2} + \mathrm{R3} + \cdots + \mathrm{Rn}) \tag{3.4}$$

$$\mathrm{Rx} = \frac{\mathrm{Nx}}{\mathrm{n}}\left(\frac{\mathrm{R1}}{\mathrm{N1}} + \frac{\mathrm{R2}}{\mathrm{N2}} + \frac{\mathrm{R3}}{\mathrm{N3}} + \cdots + \frac{\mathrm{Rn}}{\mathrm{Nn}}\right) \tag{3.5}$$

Where, N1, N2, Nn are Normal annual rainfall of the neighboring stations, Nx is the rainfall station with missed data, R1, R2, Rn are Rainfalls at particular time and stations, Rx is the missing value of rainfall data at the particular time and N is Number of neighboring stations

3.3.2. Weather Generator

The Arc SWAT automatic weather generator fills the missed data of the station from the neighboring station. The weather generator initially needs the first-class stations of all recording data to fills the missed data of the second or third, stations.

The weather generator and first-class stations are first prepared, and the parameters are calculated using PcpSTAT, Dewpoint, and an Excel sheet. Initially, the missed rainfall data were filled independently, based on the dry and wet days probabilities, then it generates the maximum and minimum temperature, solar radiation, and relative humidity. Finally, the weather generator generates the missed wind speed independently for the day.

When the weather generator fills the missing rainfall data, the missed data in the cells of the excel sheet are coded as (-99) to indicate the SWAT that the data is missing and is going to be filled (Talila et al., 2015).

In this research, Woliso rainfall station is the only first-class station that is used to fill in missing values of other stations in and vicinity of the watershed. The weather generator was first prepared in the proper formats that SWAT can read. Then all the necessary weather generator parameters were calculated and fed to the WGEN file in the Arc SWAT database. Once the weather generator parameters were prepared by the WGEN model, they were loaded into the WGEN_User table of the SWAT database.

3.3.3. Data Quality Control tests

A. Checking the Consistency of rainfall data

Inconsistency in recorded rainfall data has plagued the rain gauge stations. The conditions relevantly caused the interruptions and changes to the recording of a rain gauge station during the period of records. It is necessary to make adjustments to the interrupted data, which may cause unexpected fault results.

In this research, the inconsistency of rainfall data, were tested by double mass curve method. The mean annual rainfall data, were arranged by sequential order from the year of the earliest to the most recent recording of data. The cumulative average annual rainfall of the base stations (x-axis) were tested against the cumulative annual rainfall of the target station (y-axis).

As illustrated in Figure 3.6 below, the cumulative sum rainfall stations to be tested or target stations with the base station are plotted against each other and a line (or lines) of best fit were drawn in an excel worksheet. According to the double mass curve test, all the stations were consistent, and therefore, no need adjustments.

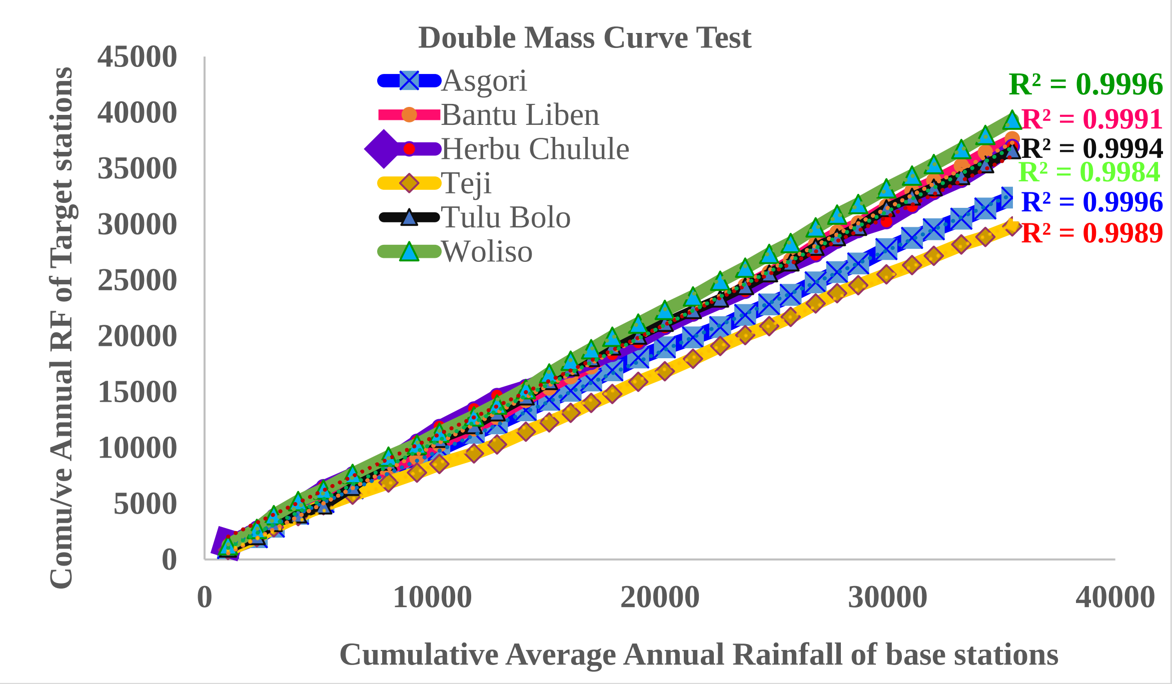


Figure 3.6: Double Mass Curves for the stations

B. Homogeneity Test

Homogeneity tests are used to assess the effects of non-climatic factors such as changes in the instruments, observation practices, station relocations, and station environments on climate time series (Toreti et al., 2011).

The methods for testing the homogeneity of the series can be classified into two groups, namely, the absolute method and the relative method. In this study, the graphical relative homogeneity (non-dimensional plot) analysis was applied. Figure 3.7, illustrates the non-dimensional graphical relative homogeneity of rainfall stations.

The relative method is based on a comparison between the neighboring stations as a reference for the testing process. The non-dimensional monthly value Pi was calculated by using the following equation.

$$\mathrm{Pi} = \frac{pi}{\bar{\mathrm{p}}} * 100 \tag{3.6}$$

Where:

Pi is the Non-dimensional value of rainfall for month i,

pi is the over year-averaged monthly rainfall station i and

$\bar{\mathrm{p}}$ is the over year mean rainfall of the station i.

The non-dimensional relative homogeneity analysis show that the plotted to check the similarity of the other selected group stations. The result of the test shows that the same mood and pattern of the stations are observed and hence a group of rainfall gauging stations are homogenous.

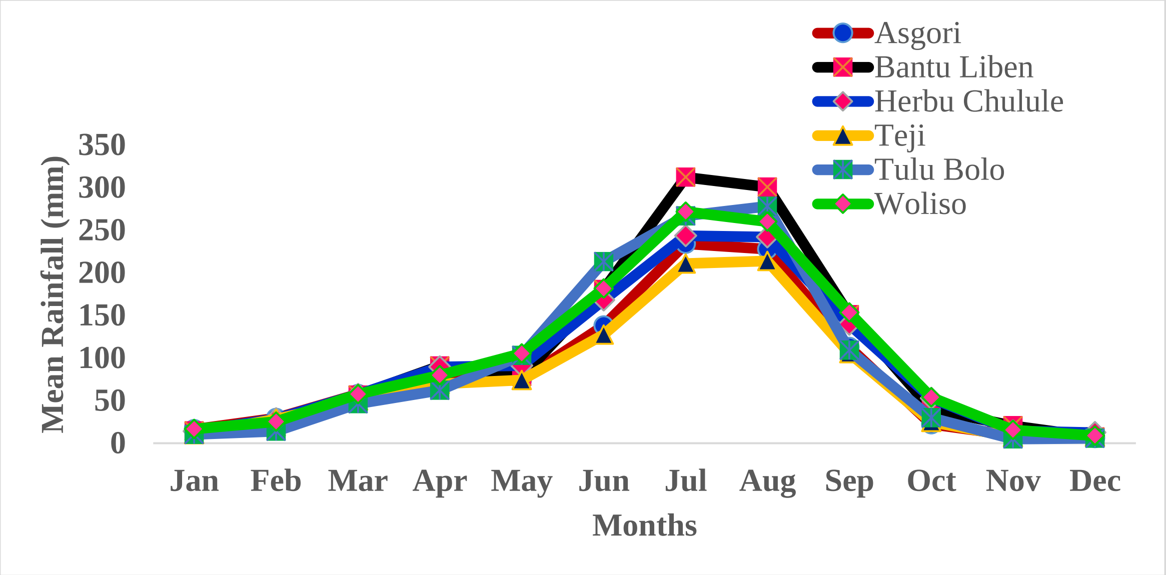


Figure 3.7: Homogeneity test for six basic rainfall recording stations

The collected rainfall data were homogenous, that the measurements have been consistently done by the same method, with the same instrumentation, at the same time and place, and in the same environment. The majority of existing rainfall stations, the graphical relative homogeneity test have drawn similar trend without breakpoints data on different time scales.

3.4. Arc SWAT Model Setup

Arc SWAT 2012, requires input data like DEM, soil and land use spatial data, and daily weather data from the representative stations. All the spatial data, i.e., DEM, land use land cover, and soil map, were projected into the UTM Zone 37N, the projection for Ethiopia.

After watershed delineation was successfully completed, HRU analysis was ready to start classification of the basic SWAT inputs: land use, land cover, and soil data. The weather data and their corresponding locations were loaded into the Write input tables, and finally, SWAT ran the simulation.

3.4.1. Watershed Delineation

The digital elevation model (DEM) is one of the inputs for the SWAT model to delineate the watershed. Topography was defined by a DEM, which describes the elevation of any point in a watershed area. The DEM also helps in understanding the flow behavior and pattern. In the SWAT model, DEM was inserted by using the loading from disk option to specify the dataset in order to create streams, outlets, and inlets or sub-basins of the watershed. The outlets and inlets of sub-basins were edited manually.

Next, the calculation of sub-basin parameters such as the reaches, the minimum and maximum elevation, and the number of outlets of the watershed were completed. After the watershed has been delineated, the topographic report by SWAT could show the area and minimum and maximum elevations of the watershed.

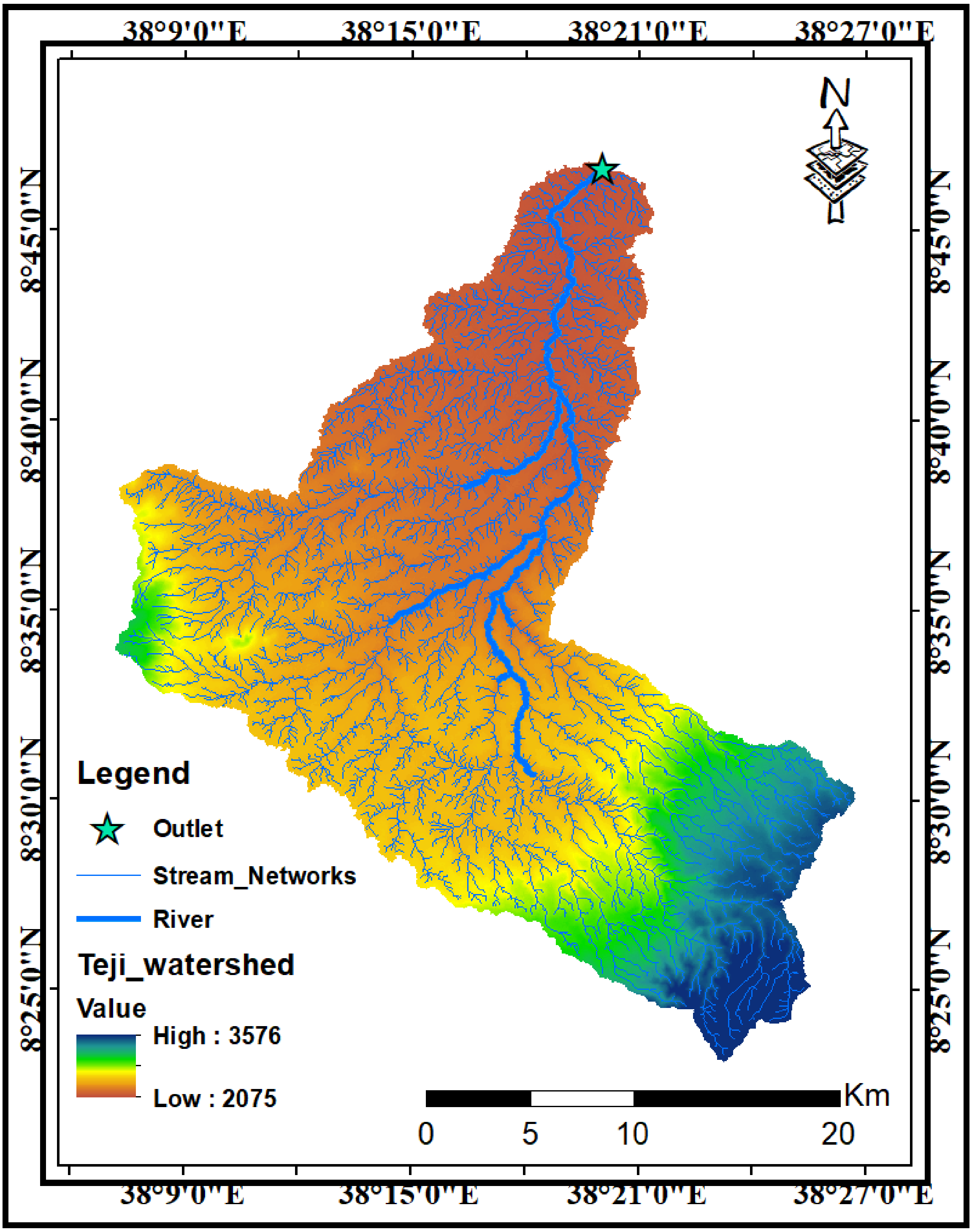


Figure 3.8: DEM, stream networks and outlet of Teji watershed

3.4.2. Hydrologic Response Units Definition (HRUs)

The HRU is the smallest unit of spatial disaggregation as a watershed is divided into the smallest and most analogous land use or land cover, soil, and slope. HRUs enable the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers and soils. The runoff is estimated separately for each HRU, and the total runoff depends on the actual hydrologic condition of each land cover or land use and the soil present in the watershed.

Hydrologic response units are the division of sub-basins according to the unique land use, management, soil attributes, and slope characteristics (Wara et al., 2015). The HRUs are normally defined by lumping similar land use, soil type, and land slope classified based on user-defined thresholds. First, the land cover map, soil map, and slope class were classified separately. Next, the combinations of land use, soil type, and slope classes were overlaid together to create the HRUs.

3.4.2.1.Land cover map

The land use and land cover (LULC) dataset is used to understand hydrological processes and the governing system (Singh et al., 2014). The projected shape file of Awash River Basin LULC was clipped by using the shape file of the Teji River watershed. The land use land cover classes was prepared to identify grid values through adjusting the minimum thresholds.

The look-up table prepared in text format with a 4-letter code so SWAT can understand the land cover-use class used for joining SWAT's land use database into the land use layer. SWAT has done the reclassification to determine the area and hydrologic parameters of each land use group.

Table 3.4: Areal distributions of land cover in Teji watershed

Land use	SWAT Code	Area [Ha]	Wat.Area[%]
Forest-Mixed	FRST	1927	2.94
Range-Brush	RNGB	1195	1.82
Wetlands-Non-Forested	WETN	4	0.01
Agricultural Land-Close-grown	AGRC	57075	87.05
Range-Grasses	RNGE	20	0.03
Residential-Medium Density	URMD	5343	8.15
Total		65564	100

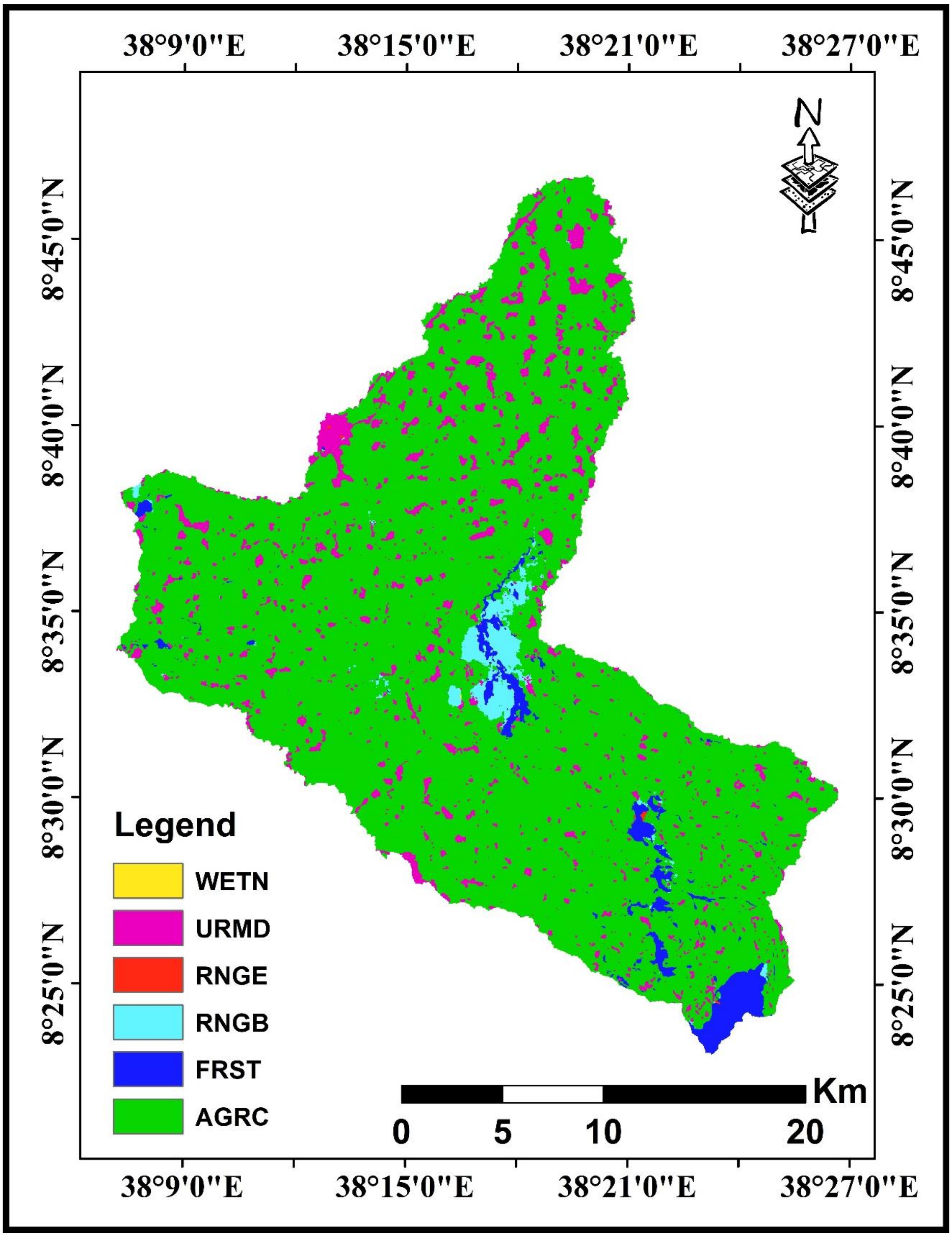


Figure 3.9: Land Use land cover in Teji watershed classified by SWAT

As it indicated in the above Table 3.4 and Figure 3.9, the majority of land uses and land covers the watershed was classified as agriculture land (87.05%), followed by residential medium density (8.15%), range grassland lands (2.94%), mixed forest (1.82%), range brush (0.03%), and non-forested wetlands (0.01%).

3.4.2.2.Soil Map

Soil type and texture are another important layer for understanding hydrological response units. The spatial soil data were obtained from the Ethiopian Ministry of Water, Irrigation, and Electricity (MoWIE), which is prepared according to FAO soil classification (FAO, 2010). The Arc SWAT interface cannot understand the FAO soil database, but it reclassify American soils based on their physical and chemical characteristics (Paudel et al., 2015).

To load and recognize the FAO soil in the SWAT database, it needs another program of the Arc SWAT extension. The extension, known as MWSWAT2012 version 1.2, was downloaded from (http://www.waterbase.org/) and installed. Then, the FAO soil was introduced to the MWSWAT database, and the Arc SWAT database start further processing.

The soil lookup table was loaded to the soil layer in the map and linked into the user's soil database to provide more information, so the reclassification was done. According to this classification, the study area is composed of five soil types, namely: Pellic Vertisols, Chromic Luvisols, Calcaric Fluvisols, Calcic Xerosols, and Eutric Nitisols.

Table 3.5: Areal distribution of soil in Teji watershed

SOIL NAME	SWAT CODE	HYDGRP	TEXTURE	AREA [ha]	WAT.AREA [%]
Calcaric Fluvisols	Jc6:2a:118	D	LOAM	1261	1.92
Chromic Luvisols	Lc13:1a:127	C	SANDY_LOAM	7902	12.05
Eutric Nitisols	Ne13:3b:158	C	CLAY	486	0.74
Pellic Vertisols	Vp14:3a:286	C	CLAY	55319	84.37
Calcic Xerosols	Xk19:2a:324	D	LOAM	596	0.91
Total				65564	100

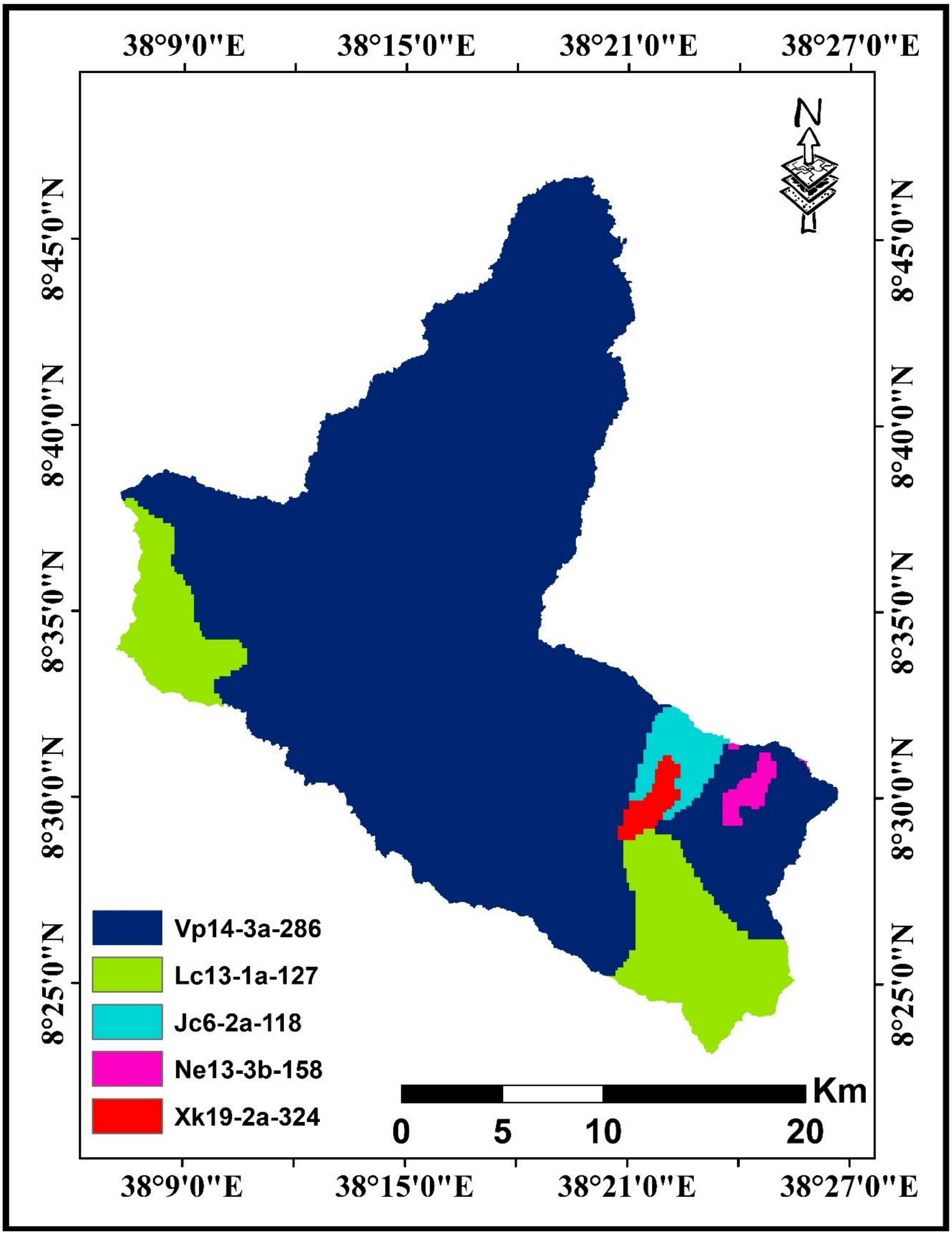


Figure 3.10: Type of soil in Teji watershed classified by SWAT

3.4.2.3.Slope Map

The slope map is the basic input and one of the factors influencing the runoff processes in the watershed. The classification of the slope does not require any other data collection. But, from the DEM used in the watershed delineation, the slope of the terrain can be prepared with the help of Arc SWAT. For this study, the multiple slope option classes for HRU definition was selected. The multiple slope class option used to classify the slope into five classes. The slope class was used to account for lower range in hydrological modelling and the classes were 0-3%, 3-7%, 7-11%, 11-16% and >16% in HRUs.

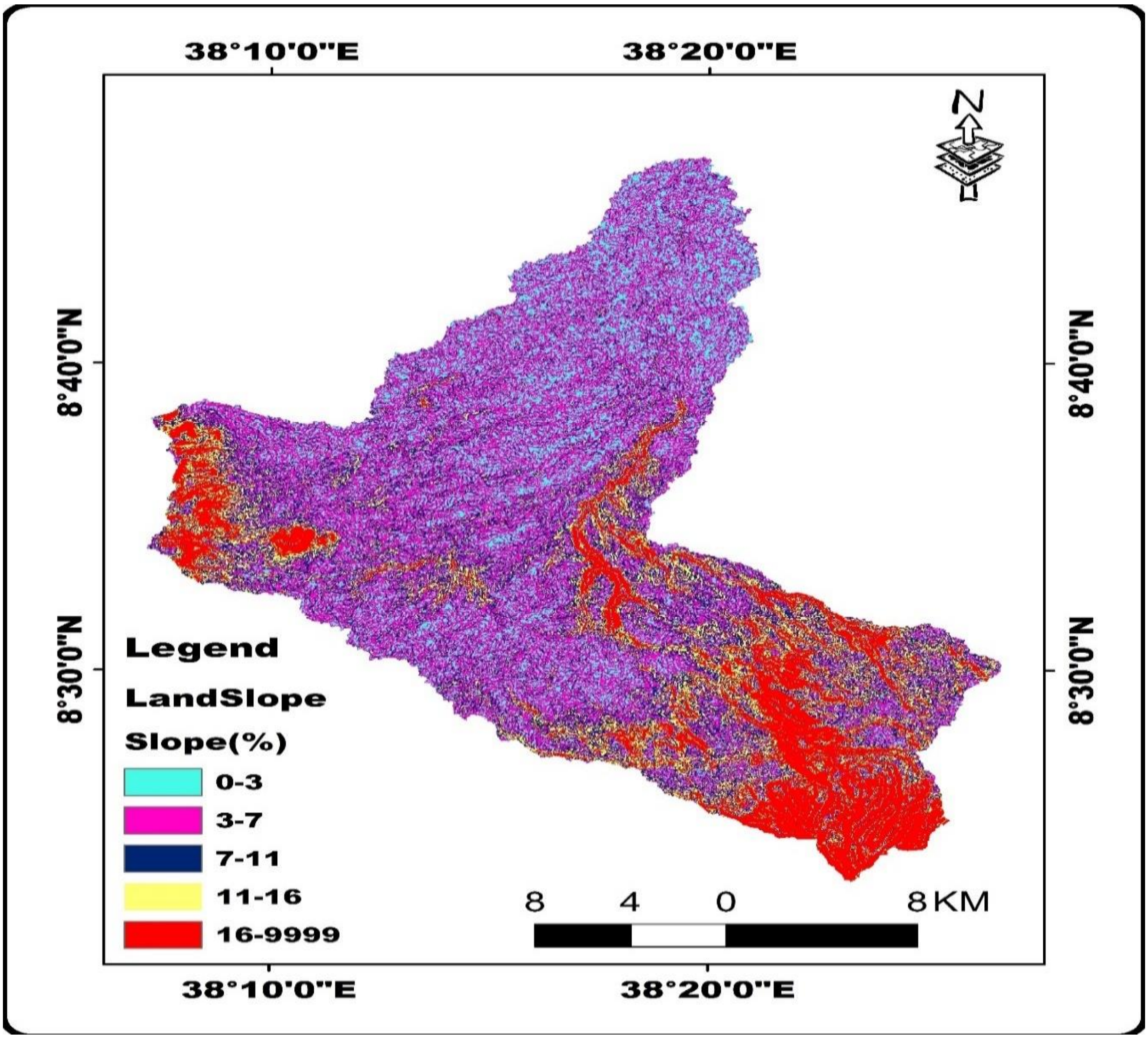


Figure 3.11: Slope classification in Teji watershed classified by SWAT

Table 3.6: SWAT slope classification in the Teji watershed

Class	Area [ha]	Wat.Area[%]
0-3	12308	18.7
3-7	23967	36.6
7-11	12011	18.3
11-16	7070	10.8
>16	10208	15.6
Total	65564	100

The numerous options are available in the HRUs definition in order to produce accurate simulation results. The SWAT user's manual suggests applying 10%, 20%, and 10% thresholds to combinations of land use cover, soil map, and slope map, respectively, in the majority of models in order to get a better estimate of surface runoff.

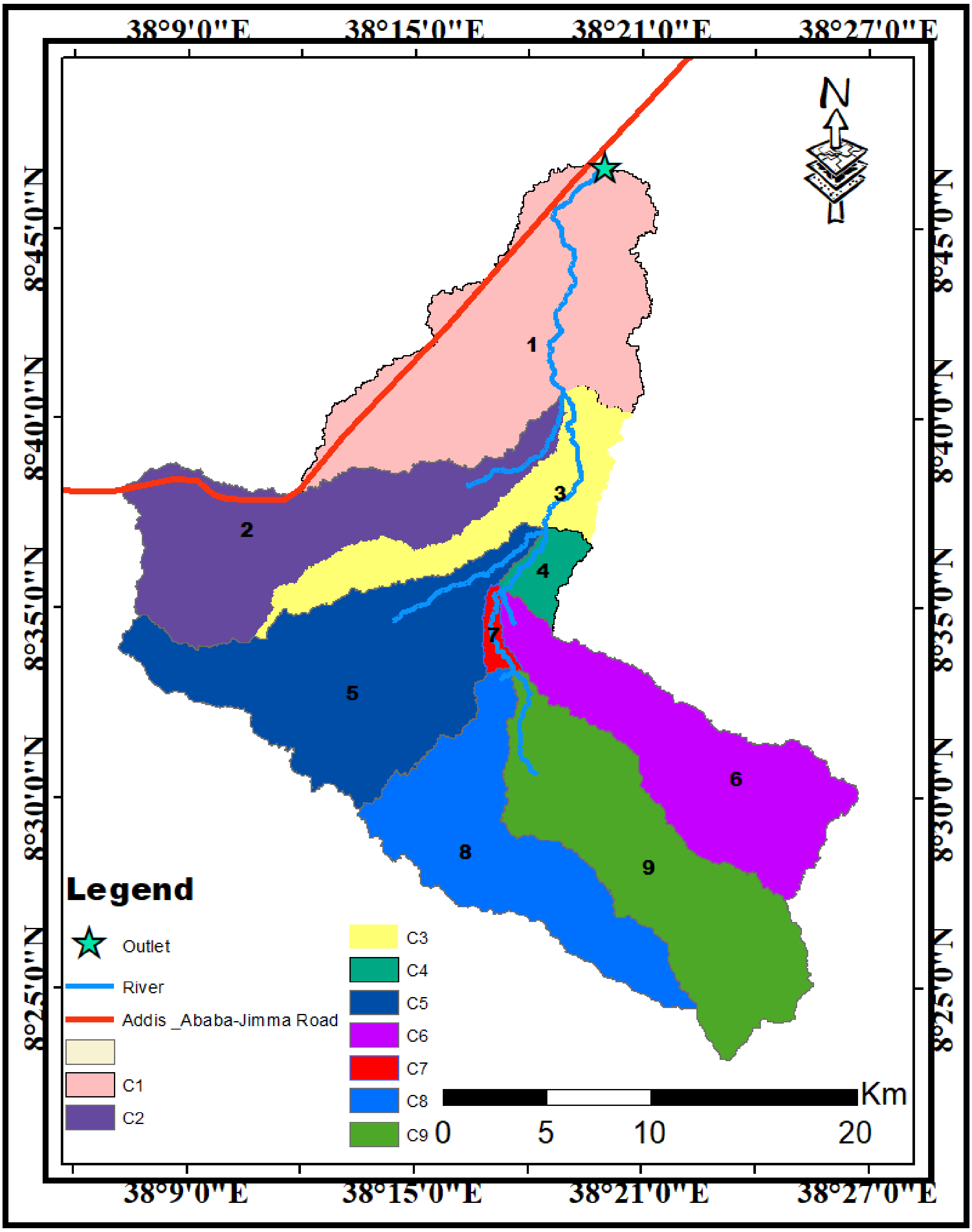


Figure 3.12: Catchments or sub-basins of the watershed

As it was indicated in the Figure 3.12 above, the watershed was defined into 9 sub-basins and 123 unique HRUs by using multiple options of 10% land use, 20% soil, and 10% slope threshold combinations.

3.4.3. Weather Data Definition

The meteorological data were needed to simulate the hydrological processes in SWAT. The meteorological input data needed for SWAT simulation comprises daily data on rainfall, maximum and minimum temperature, relative humidity, wind speed, and sun radiation.

SWAT simulation, in lacking first-order stations like Teji watershed, is difficult because, it is challenging to collect complete meteorological data. For this purpose the model needs some main stations with full data and from that it can generate for the remaining stations. To generate the weather data from the nearby stations, it needs the PcpSTAT and Dewpoint programs. Woliso station, with full data was used to generate the statistics values of missed data for the other station and used to run the model.

Weather data of 1998 to 2018, were prepared in (.txt) file with the relevant location and elevation. Then, the weather generator created the statistical weather data using long-term and copied it to WGEN User of SWAT. Lastly the weather data stored in SWAT2012 database to fill the weather generator data and location of precipitation, temperature maximum and minimum, solar radiation, wind speed, and relative humidity, one by one into the weather station table. SWAT simulation was carried out for 1/1/1998–12/31/2016 based on available observed streamflow data. Two years were provided as a warmup (NYSKIP) and then setup for the SWAT run.

3.4.4. SWAT Model Calibration and Validation

When calibrating a model, the values of the input parameters are carefully chosen, and the model's predictions for a specific set of assumed conditions are compared to the data actually collected. Model validation is the process of proving that a specific site specific model is capable of producing sufficiently accurate simulations, however the definition of "sufficiently accurate" can vary based on project goals (Bahremand, 2008).

The calibration and validation were carried out for the determination of the most sensitive parameters in the watershed based on the selected twelve runoff parameters and the observed streamflow data of the Teji River near Asgori town. The streamflow data were adjusted in the mean monthly time step by using the SWAT-CUP SUFI2 program. To determine whether the model was workable for the watershed, the initial iteration was carried out using the model's default parameter settings. The observed streamflow data at the common outflow of the first watershed or sub-basin, designated as "FLOW_OUT 1," underwent calibration and validation.

Calibration and validation processes were executed using the observed versus simulated data and the twelve flow parameters. The nineteen (1/1/1998–12/31/2016) years observed flow data from the Teji River near Asgori town were used into three datasets. The first two years, 1998–1999 were used to start the model or warmup period. The next datasets 2000–2010 were used for calibration, while the 2011- 2016 used validation.

3.4.5. Sensitivity Analysis

The way of estimating the rate of alteration in model output with respect to rate of change in model input parameter is known as sensitivity analysis. The SWAT model has several parameters that are used to identify the sensitivity of surface runoff. Sensitivity analysis was performed to limit the number of optimized parameters to obtain a good fit between the simulated and observed data (Tejaswini, 2018).

In this study, twelve parameters were identified to have a significant influence in controlling surface water potential and water balance in the watershed. For applying runoff parameter the minimum and maximum ranges were adjusted to have the physical meanings and reflect factors such as land use, soil, and elevation. The goal of sensitivity analysis was to determine the cause and effect relation between model parameters and modeling results. In the case the effects of parameters were ranked as high, medium, and low according to the associated P-value and equivalent t-stat value (Dananto et al., 2022).

3.4.6. Evaluation water balance in the watershed

The SWAT model follows the principle of the conservation of mass to simulate all components of water balances such as surface runoff, evaporation, water flow in the soil profile, groundwater flow, and initial and final soil water content. The Penman-Monteith method used the relative humidity, solar radiation, and wind speed to estimate evapotranspiration, while the maximum and minimum temperature values were used to determine the daily soil and water temperatures (Gassman et al., 2007).

The hydrologic cycle is simulated by SWAT based on the water balance equation.

$$\mathrm{S_{wt}} = \mathrm{S_{wo}} + \sum_{i=0}^{t}\left[\mathrm{R_{day}} - \mathrm{Q_{surf}} - \mathrm{E_a} - \mathrm{W_{Seep}} - \mathrm{Q_{gw}}\right] \tag{3.7}$$

Where, S_{Wt} -is the final soil water content (mmH_2O), S_{Wo} -the initial soil water content (mmH_2O), R_{day}-the amount of precipitation (mmH_2O), Q_{surf}- is the amount of surface runoff (mmH_2O), E_a- is the amount of evapotranspiration (mmH_2O), W_{seep}: the amount of water entering the vadose zone from the soil profile (mmH_2O), and Q_{gw}- the amount of return flow on day *i* (mmH_2O), and *t*- is time (days).

The subdivision of the watershed enables the model to reflect differences in evapotranspiration for multi crops and soils. Runoff is a function of land use, soil permeability, and antecedent soil water conditions. It is predicted separately for each HRU and obtain the total runoff for the watershed. This increases the accuracy and gives a much better physical description of the water balance (Arnold et al., 2012).

The Manning's roughness coefficient, soil data, hydrologic data, and land use land management inputs were created to the model. The sub-basin runoff was routed to simulate the total runoff volumes for the entire watershed. Equation 3.12 is the general equation of the SCS curve number method, which is used to estimate surface runoff.

$$Q_{surf} = \frac{(R_{day} - Ia)^2}{(R_{day} - Ia + S)} \tag{3.8}$$

$Ia = \lambda S$: for λ approximately equivalents to 0.2 and $Ia = 0.2S$

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)} \tag{3.9}$$

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \tag{3.10}$$

Where, Qsurf -is the accumulated runoff or rainfall excess (mmH_2O), R_{day} -is rainfall depth for the day (mmH_2O), Ia- is the initial abstractions which includes surface storage, interception and infiltration prior to runoff (mmH_2O), S- is the retention parameter (mmH_2O) and CN- is curve number.

The SWAT model predicts the retention parameter with the help of two methods; the first method of calculation uses the soil moisture content in its profile, in which runoff is overestimated in shallow soil. CN is mainly governed by the antecedent climate, and the value is rarely governed by the soil storage. The CN estimation is based on evapo transpiration. The other method predicts the retention parameter using the accumulated plant evapotranspiration (Dananto et al., 2022).

$$S = S_{max} * \left(1 - \frac{SW}{(SW + exp(W_1 - W_2 + SW))}\right) \qquad (3.11)$$

Where S is the retention parameter for a specified day (mm), S_{max} is the maximum retention parameter on any specified day (mm), SW is the moisture content of the soil excluding the water held at wilting point (mm), and W_1 and W_2 are shape coefficients. When evapotranspiration governs the retention parameter, the result of the retention parameter at the end of the day can be updated as

$$S = S_{prev} + E_a * exp\left(\frac{-cncoef - S_{PREV}}{S_{max}}\right) - R_{day} - Q_{surf} \qquad (3.12)$$

Where S is the retention parameter for a given day (mm), S_{prev} is the previous day's retention parameter (mm), E_a is the daily potential evapotranspiration (mm per day), cncoef is the average coefficient to estimate the retention coefficient for the daily curve number predictions, S_{max} is the daily higher retention parameter value (mm), R_{day} is the daily rainfall depth (mm), and Q_{surf} is the surface runoff (mm).

Evapotranspiration (PET) is one of the parameters for studying the water balance. The Penman Monteith method which requires solar radiation, air temperature, relative humidity, and wind sped was used to estimate evapotranspiration (Dananto et al., 2022). The Penman Monteith equation that estimates evapotranspiration is as follows

$$\mathrm{ET_O} = \frac{0.408\Delta(\mathrm{R_n} - \mathrm{G}) + \gamma\frac{900}{\mathrm{T} + 273}\mathrm{U2}(\mathrm{es} + \mathrm{ea})}{\Delta + \gamma(1 + 0.34\mathrm{U2})} \qquad (3.13)$$

Where; ET_O - reference evapotranspiration with mm/day. R_n - net radiation at the crop surface in MJ $m^{-2}day^{-1}$, G - Soil heat flux density with MJ m^{-2} day^{-1}, T mean daily air temperature at 2 m height [°C], U_2- wind speed at 2m height [m s^{-1}], es - Saturation vapor pressure [kPa], ea - actual vapor pressure with kPa, (es –ea) saturation vapor pressure deficit with kPa, Δ - Slope vapor pressure curve with kPa $°C^{-1}$, γ - Psychometric constant with kPa $°C^{-1}$.

The groundwater recharged to aquifers was estimated by model using Equation (3.14).

$$aq_{sh.i} = aq_{sh.i-1} + W_{rchg} - W_{gw} - W_{revap} - W_{deep} - W_{pmp.sh} \qquad (3.14)$$

Where $aq_{sh,i}$ is the water accumulated in the shallow aquifer on day I (mm), $aq_{sh,i-1}$. is the water accumulated in the shallow aquifer on the previous day (mm), W_{rchrg} is the recharge percolating to the aquifer on day I (mm), Q_{revap} is the water entering into the soil zone on day I (mm), W_{deep} is the water percolating from the shallow to the deep aquifer on day I (mm), and $W_{pump,sh}$ is the water removed from the shallow aquifer by pumping on day I (mm).

3.4.7. Model Performance Evaluation

In this study, the SWAT hydrological model performance was evaluated based on three well: known statistical objective functions, i.e., R^2, NSE, and PBIAS, which determine the quality of the best fit and reliability of the simulated with observed streamflow data.

i. Coefficient of determination (R^2)

The coefficient of determination is defined as the ratio of the squared value of the coefficient of correlation between the simulated and observed streamflow. It provides a measure of how well observed outcomes are replicated by the model. R^2 lies between 0 and 1, and the closer the value of R^2 is to 1, the higher the agreement between the simulated and measured flow, while a zero value means no correlation at all.

$$R^2 = \frac{[\sum_{i=1}^{n}(Q_S - \overline{Q}_S)(Q_O - \overline{Q}_O)]^2}{[\sum_{i=1}^{n}(Q_S - \overline{Q}_S]^2[\sum_{i=1}^{n}(Q_O - \overline{Q}_O]^2} \tag{3.15}$$

Where,

Q_o - is observed streamflow, Q_s - is simulated streamflow, $\overline{Q}_o$ - is mean observed streamflow and $\overline{Q}_s$ – is mean simulated streamflow.

ii. Nash and Sutcliffe efficiency criteria (NSE)

NSE is a normalized statistic method used for the prediction of relative amount of noise compared with information and is calculated from the following equation.

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Q_O - Q_S)^2}{\sum_{i=1}^{n}(Q_O - \overline{Q}_O)^2} \tag{3.16}$$

Where:

Q_o – is observed streamflow, Q_s - is simulated streamflow, and $\overline{Q}_o$ –is mean observed streamflow

iii. Percent Bias (PBias)

The average tendency of the simulated data to be greater or smaller than the observational data is measured using PBias. Low magnitude values denote better simulations, while the maximum value is zero. Model underestimation is indicated by positive values, whereas model overestimation is indicated by negative values.

$$PBIAS\ (\%) = \frac{\sum_{i=1}^{N}(Q_{O(i)} - Q_{S(i)}) \times 100}{\sum_{i=1}^{N}(Q_{O(i)})} \tag{3.17}$$

Where Q_o –is observed streamflow, Qs - is simulated streamflow

Generally, the correlation between the observed and simulated streamflow is said to be best fitted if the values of the coefficient of determination, Nash and Sutcliffe (1970) coefficient of efficiency, and the percent bias are (R2 > 0.60), (NSE > 0.5), and (PBias ±25%), respectively (Moriasi et al., 2007).

3.5.WEAP Model and Water Demand Evaluation

WEAP model basically used to simulate water balances sequentially down a river system, making allowance for abstractions and inflows. In this study WEAP used in the estimation of water demands and scenarios creation for effective water management. It uses in the integration of water systems and policy orientation in the water resource planning.

One of the main strengths of WEAP is its user-friendly and comprehensive scenario analysis options. In single catchment or complex river systems, it operates on the basic principle of accounting water balance for the water sectors.

Schematically, the WEAP is divided into sections, each of which used to perform its own functions and the schematic view is the starting point for all activities in WEAP. The background vector data of watershed boundaries and river segments, which were prepared in Arc GIS, were added to the WEAP software. The WEAP schematic structure of the watershed system is shown in Figure 3.13.

The "drag and drop" graphical interface was used to describe and visualize the physical features of the water supply and demand system. In this case, it is possible to create, edit, and view any element clearly.

Before adding the vector data into the WEAP project, the file must be projected into the projected coordinate system, in this case Ethiopia UTM37, in order to display it in existing background layers of WEAP. Following the time frame in which the WEAP model called for was stated as 2021–2060.

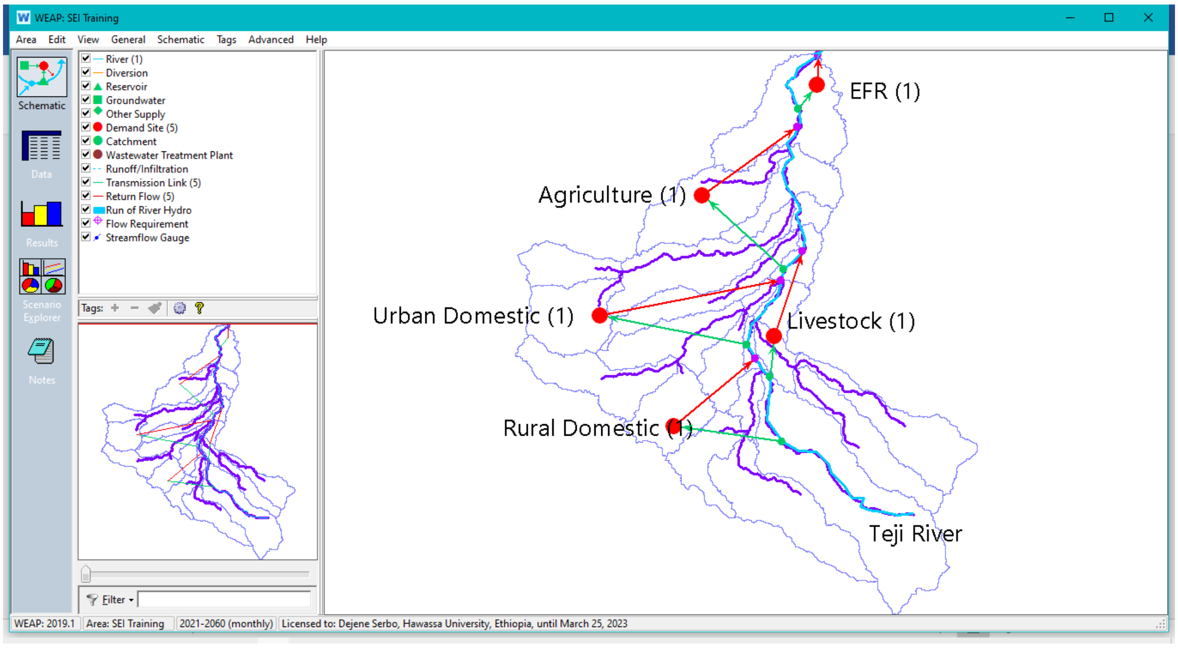


Figure 3.13: Schematic representation of Teji River watershed using WEAP

3.5.1. Evaluation of the Current Account water demand

The current account is what we can basically define with the available original data. It represents the basic definition of the water systems and the starting point for all scenarios. Note that the current accounting year is not meant to be an average year but the best available specification of water supply and demands.

The current account water demands are the collective water requirements, including all the domestic, irrigation, and livestock, commercial, and institutional, and environmental flows. The calculation of demand for domestic, livestock, and agriculture entities is based on a disintegrated accounting for several measures of social and economic activity, such as population served, livestock number, and area of irrigated land.

3.5.1.1.Domestic water demands

The quantity of domestic water demand was determined basically based on how many people are living and how much an individual needs per day. But, to obtain the tangible figure on the amount of water used for each individual need is a difficult task because people's needs are not always predictable.

To establish how much water an individual needs, the standard guidelines have been adopted as in liters per person per day (Lpcd). Based on the Ministry of Water, Irrigation and Energy of Ethiopia guidelines in the specific river basin under their master plan studies that based on the real-world and lifestyle of the communities.

According, to GTP-2, the minimum service level of per capita, water demands of the rural and category-3 towns/cities (50,000-100,000 population) are 25 l/d and 60 l/d respectively.

Even if, the GTP-2 was lasted (2015-2020), and there is no another published policies about water demands, and it has been selected to use the water demand per capita per day of 25 l/d/c and 60 l/c/d for rural and urban respectively(MoWIE , 2015).

The Teji River streamflow helps for the domestic water demands of six (6) woredas namely Becho, Seden Sodo, Kondaltiti, Tole, Ilu and Woliso. The population size which can be used streamflow of the river was projected further and presented in the Table 3.7, below.

The method adopted to forecast the future population number was the geometric increase method which mostly applicable for growing urban and rural areas having the possibility of growth. Geometric increase method is calculated in the following equation.

$$Pn = Po(1 + \frac{r}{100})^n \tag{3.18}$$

Where;

P_o - initial population, P_n - Population at n decade or years, n- Decade or year and r- Percentage (geometric) increase.

Table 3.7: Projection population data in the study area

Year	2007	2014	2021	2031	2041	2051	2060
Rural	455594	554410	611586	744236	905657	1102089	1315057
Urban	36923	54316	65878	96911	142562	209718	296827
Total	492517	608726	677464	841147	1048219	1311807	1611884

Note: Assuming that the population number increases in the same growth rate both in rural and urban areas.

The domestic water demand was calculated by multiplying population number and daily per capita water use. The baseline of GTP-2, the Water Supply and Sanitation Sub-sector of Ethiopia, water demands of 25 liters per capita per day (l/c/d) and 60 l/c/d were selected as current account year for the rural and urban population, respectively.

3.5.1.2.Commercial and Institutional water demand

The normal water needs of the urban community for public schools, clinics, hospitals, offices, shops, restaurants, and hotels is linked directly to the population and has been taken as 5% of the urban domestic water demand.

3.5.1.3.Livestock water demand

The livestock water demand was estimated based on the FAO livestock standard water demand in semi-arid regions, particularly sub-Sahara, Africa. The Ethiopian tropical livestock unit (TLU), need average water about 25 liters of water per day per TLU. The converted livestock into the tropical livestock unit (TLU) and TLU per capita water need are discussed in the Table 3.8, below.

Table 3.8: Livestock water demand (MCM) in the current year (2021)

No	Animal Type	No. of livestock	TLU factor	No. of TLU.	Water Demand	
					(m^3/d)	(MCM/yr.)
1.	Cattle	1228255	0.7	859779	21495	7.85
2.	Sheep	665508	0.1	66551	1664	0.61
3.	Goat	587964	0.1	58796	1470	0.54
4.	Donkey	127331	0.5	63665	1592	0.58
5.	Horse	67900	0.8	54320	1358	0.50
6.	Mule	6990	0.7	4893	122	0.04
7.	Poultry	2115018	0.01	21150	529	0.20
Total				1129154	28230	10.32

3.5.1.4.Irrigation water demand

Actually, there is no a judicious irrigation schemes which are registered as private or public i.e. small, medium or large irrigation schemes in the study area. However, there are the individual’s and scattered irrigations which irrigate crops such as Wheat, Carrot, Tomato, Potato, Cabbage, Maize, Onion, Cereal crops, Pepper and other crops. Report of South West Showa zone Agriculture office and Irrigation Development Authority, shows in 2021 the crops irrigated by Teji streamflow during dry season were accounting total area 1615 ha.

The CropWat 8.0 model was used to estimate the crop water requirement as well as irrigation water requirements for crops cultivated in the watershed. It is a practical tool to carry out calculations for reference evapotranspiration, CWR, IWR, and more specifically, the design and management of irrigation schemes.

Table 3.9: Crops irrigated in the study area

No	Crops	Area (ha)
1	Wheat	154
2	Carrot	83
3	Tomato	267
4	Potato	189
5	Cabbage	209
6	Maize	140
7	Pepper	67
8	Onion	380
9	Others	126
Total		1615

The irrigation water demand was estimated based on the concepts of FAO approach, by using CROPWAT8.0. The revised FAO56, Penman-monteith method was applied which requires the data of meteorological stations, such as air temperature, solar radiation, relative humidity and wind speed. The cropping pattern and calendar are considered the often dry months in the area.

i. Reference evapotranspiration (ETo mm/day)

The reference evapotranspiration (ET_O) was calculated by FAO Penman-Monteith Method using meteorological data. The general equation that used to calculate reference evapotranspiration in Penman-monteith method was discussed earlier in Equation (3.13) of the water balance section.

ii. Potential Evapotranspiration (ETc mm/day)

After reference evapotranspiration, the potential evapotranspiration (ET_C) was calculated based on the crop coefficient, grown season for all crops irrigated in the area. The value of crop coefficient (Kc) were taken from FAO tables. Crop growth stages, rooting depths, critical depletion fraction, yield responses factor, maximum crop height and length of growth stage were taken for crops that were planted in the watershed according to literature (FAO, 2016). The potential evapotranspiration for each crop types was estimated through multiplying reference evapotranspiration (ETO) with crop coefficient (KC) for each growth stage.

$$\mathrm{ETC} = \mathrm{Kc} * \mathrm{ETO} \tag{3.19}$$

Where,

ET_C is crop potential evapotranspiration (mm/period), Kc is crop coefficient and ET_O is reference evapotranspiration (mm/ day).

iii. Effective Rainfall (mm)

The effective rainfall (P_{eff}) was calculated for the growth periods based on the long--term monthly average rainfall (P) values which was recommended by FAO (Allen, 1998). Accordingly, the dependable rainfall which based on the analysis carried out in different arid and sub-humid climates, an empirical formula was developed in the Water Service of FAO to estimate dependable rainfall, the combined effect of dependable rainfall (80% probability of exceedance) and estimated losses due to Runoff (RO) and Deep Percolation (DP). This formula was applied for this study, where 80% probability of exceedance is required (CROPWAT8.0 Rain Module). Monthly step:

$P_{eff} = 0.6 * P - 10$ for Pmonth <= 70 mm

$P_{eff} = 0.8 * P - 24$ for Pmonth > 70 mm

Where, P is actual monthly rainfall mm and P_{eff} is effective rainfall (mm)

The effective rainfall was separated from the actual rainfalls. Then the net irrigation water requirement (mm/dec) in the full growth stage were calculated by subtracting effective rainfall from the corresponding potential evapotranspiration.

$$NIR = ETc - P_{eff} \tag{3.20}$$

According to (Gonfa et al., 2021), the average irrigation efficiency of surface irrigation in the Ethiopia, is equal to 50%. Depend on the assumption the gross irrigation water requirement was calculated by the following equation.

$$\mathrm{GIR} = \frac{\mathrm{NIR}}{\mathrm{E}} \tag{3.21}$$

Where,

P-is Actual rainfall (mm), P_{eff}: effective rainfall (mm), NIR is net irrigation water requirement (mm/time), GIR –gross irrigation water requirement (mm/time), and E is the irrigation efficiency.

3.5.1.5.Environmental flow requirement

Environmental water needs or in-streamflow requirement for sustaining specific ecosystems should be given consideration with regards to water management system. Environmental flows are the flows that are left in, or released into a river system with the specific purpose of managing some aspect of its condition. Their purpose here for the flow down to maintenance of a healthy riverine ecosystem, in a prescribed state (Abera, 2021).

The environmental flows vary from year to year depending on river flow where it ranges from between 10% to 15% of the annual flow. For the case of this study, in the current account year, **10**% of the total available flow was assumed to left for the satisfaction of the environmental flow requirements.

3.5.2. Scenario Development

Scenarios are the alternatives or the set of assumptions such as operating policies, pricing, and demand management strategies and alternative supply sources. The scenarios are used to address the ″what if ″ question, like what if population growth change, ″what if ″ irrigation land will be increase or ″what if ″ the per capita water use will be change. In the water resources planning, the scenarios were developed to forecast what will happen in the future of water systems (okungu, 2017).

Scenarios are self-consistent story lines of how a future system might evolve over time in a particular socio-economic setting and under a particular set of policy and technology conditions. Using WEAP, scenarios can be built and then compared to assess their water requirements, costs and environmental impacts. All scenarios were inherited from the current account to look the future based on the assumptions and increase the expected changes that will be likely to take place in the future over a particular socio-economic setting such as economic condition, demographic patterns and technological situations (Sieber, 1990).

3.5.2.1.Reference Scenario

Reference scenario shows the change that might happen or it is a scenario in which the current situations, in the current account year are extended to the future (2022-2060) without any new policy measures. Often referred to as business as usual scenario. To alter the reference scenario ‘what if’ situation is developed and to evaluate the effects of changes of policy and improvement of technology. In this scenario, no change has made except for the increment of population with yearly constant growth rate of 3.2 % recommended by CSA of Ethiopia and per capita water demand kept constant with value of 25 l/c/d and 60 l/c/d for rural and urban areas, respectively. The livestock population growth rate also assumed as 1.2% annually. The irrigation area and environmental flow requirement were assumed to be constant.

3.5.2.2.Scenario One: High Population Growth Rate

This scenario was developed to evaluate the impact of a high population growth rate, the water demands, if the annual growth rate is increase by 6%. And it will answer the question of what will happen if the annual population growth rate is increased higher than the current account. The per capita water use was assumed remain constant, due to the population growth in the area has impacts on existing water supply and reduce water security in the country (Alemu, 2020).

3.5.2.3.Scenario Two: Projections in the Irrigated Area

In the future the irrigation projects are expected to increase rapidly, in many parts of the country to overcome the unbalanced food securities and unemployment. The national vision of expansion the Ethiopian Winter Wheat (Ye Bega Sinde) and other valuable crops are leading to increase the irrigation projects. It is true in Teji watershed that the expansion of irrigation schemes will be done by state and/or privates. In other case the Becho Plain in the Upper Awash Sub-basin is the maximum potentially suitable irrigable area but not fully developed in terms of irrigation (Gonfa et al., 2021). Teji watershed is one part of Becho Plain which actually suitable for irrigation developments, but not fully developed yet. Therefore, this scenario was developed to evaluate the impacts of increase irrigation expansions by 50% from the existed.

3.5.2.4.Scenario Three: Increased per Capita Water Demand

This scenario was based on the assumption that Ethiopia is the developing country and the living standard of the people will be improved in the future, which results an increment of per capita water usage. The country has a vision to reach to a level of middle income country in its socio-economic development in 2025 (MoWIE, 2015).

The question “what will happen if the water consumption per capita per day is increased by half for domestic water demand”. The scenario was demonstrated to evaluate the effect of consuming more water than the current, which means per capita water demand increased from 25 l/c/d to 50 l/c/d and 60 l/c/d to 100 l/c/d for rural and urban area respectively. The increase water consumption rate for livestock is not considered.

4. RESULTS AND DISCUSSIONS

4.1.1. Sensitivity Analysis

The sensitivity analysis was carried out on twelve runoff parameters to characterize the Teji watershed using the Global sensitivity analysis method in SWAT-CUP SUFI2 (Appendix Table.18). Eleven parameters were shown significant effects on the monthly flow simulation of the watershed. Six parameters were shown a relatively high sensitivity, and being considered the most sensitive.

The t-Stat and P-values

The t-stat is the coefficient of a parameter divided by its standard error. It is a measure of the precision with which the regression coefficient is measured. If a coefficient is “large” compared to its standard error, then it is probably different from zero and the parameter is said to be sensitive. The P-value of the parameters tests the null hypothesis that the coefficient is equal to zero (no effect). A low P-value (< 0.05) indicates that possibility of rejecting the null hypothesis. In other words, a predictor that has a low p-value is likely to be a meaningful added to the model because changes in the predictor's value are related to changes in the response variable. Conversely, a larger P-value tells that the changes in the predictor are not associated with changes in the response. A P-value of < 0.05 is the generally accepted point at which to reject the null hypothesis (i.e., the coefficient of that parameter is different from 0). With a P-value of 0.05, there is only a 5% chance that results you are seeing would have come up in a random distribution, so you can say with a 95% probability of being correct (the user manual of SWAT CUP or http://www.swatmodel.tamu.edu/), that the variable is having some effects on the result.

The most significant parameter controlling the streamflow in the watershed were ranked as high, medium, and low depending on values of the P and t-stat. Therefore, the Groundwater "revap" coefficient of larger P-values and low absolute value of t-stat has no significant effects on the output. The most influential flow parameters, were the Threshold (minimum) depth of water in the shallow aquifer (GWQMN), Groundwater delay (GW_DELAY), initial SCS runoff curve number (CN2), Manning's "n" value for overland flow (OV_N), Soil evaporation compensation factor (V_ESCO) and Available water capacity in soil layer (V_SOL_AWC) were ranked as high sensitive. On the other hand, Alpha base flow recession constant (V_ALPHA_BF.gw), Deep aquifer percolation fraction (R_RCHRG_DP), Plant uptake compensation factor (R_EPCO) Surface runoff lags coefficient (R_SURLAG) and Moist bulk density (R_SOL_BD) were ranked medium most influential flow parameters. The results of global sensitivity analysis view, the p-value and t-stat can be used to eliminate non-sensitive parameters from the calibration process.

Table 4.1: t-stat, p-values and ranks of runoff parameters used in sensitivity analysis

Parameter Name	t-stat	P-value	Sensitivity	Rank
4-V__GWQMN.gw	-25.405	0.000	High	1
3-V__GW_DELAY.gw	11.910	0.000	High	2
1-V__CN2.mgt	-4.899	0.000	High	3
11-V__OV_N.hru	3.267	0.001	High	4
6-V__ESCO.hru	2.352	0.019	High	5
9-V__SOL_AWC (...).sol	2.263	0.024	High	6
2-V__ALPHA_BF.gw	-0.924	0.356	Medium	7
8-R__RCHRG_DP.gw	-0.677	0.499	Medium	8
7-R__EPCO.hru	0.578	0.562	Medium	9
10-R__SURLAG.bsn	0.438	0.661	Medium	10
12-R__SOL_BD (...).sol	0.408	0.683	Medium	11
5-R__GW_REVAP.gw	0.014	0.989	Low	12

4.1.2. Model Calibration and Validation

The model was calibrated and validated using monthly time step data of seventeen years (See, Appendix Table 5), in which the model showed the best performance between the Teji observed streamflow and SWAT simulated. The model, was calibrated both by manual and automated calibration. In Figure 4.1 and Figure 4.2 below, the calibration results were show the overall result assures that the simulated flow was best correlated with the observed data, but in some years there were under and overestimations in the model outputs. These discrepancies may be due to inaccurate meteorological data obtained, errors in other input data sets such as land use and soil maps and also errors during data preparation and processing. The other causes of these discrepancies may be due to dependency of SWAT model entirely on an empirical method known as SCS Curve number method for calculating runoff which does not consider duration and intensity of precipitation (Tejaswini, 2018).

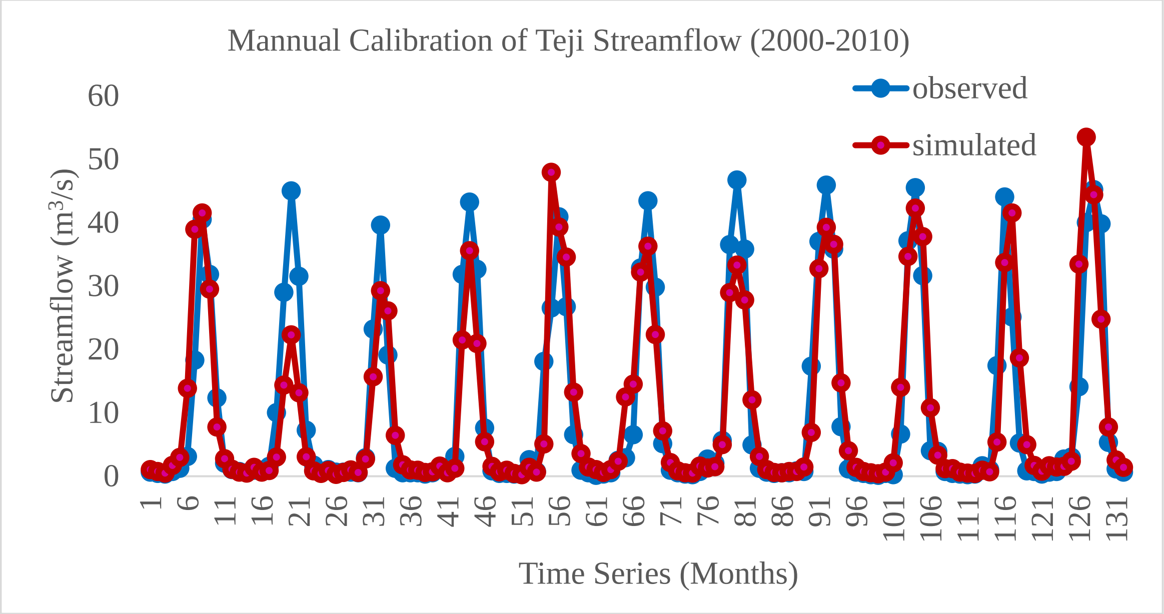


Figure 4.1: Average annual observed and simulated flow calibration (2000-2010)

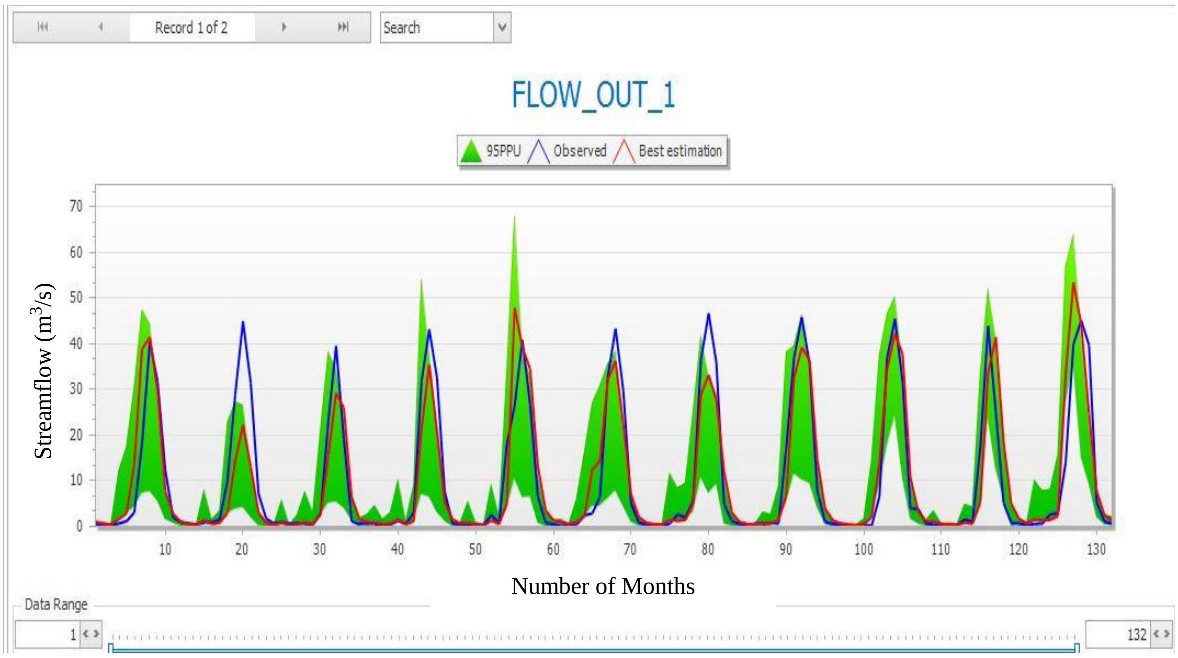


Figure 4.2: Best simulated discharge with 95PPU for calibration (2000-2010) in SUFI-2

Figure 4.1and Figure 4.2 above were illustrate that the Coefficient of determination is best if R^2> 0.60, Nash-Sutcliff Efficient, NSE>0.5 and Percent Bias, PBias<±25%. Therefore the Teji watershed satisfies these criteria. Since coefficients of efficiency is NSE=0.81, coefficient of determination, R^2=0.81 and PBias +1.6%. The calibration results show that model performance evaluation indicated a high quality correlation and agreement between the measured and simulated streamflow was very good.

The model was validated using the second split datasets of Teji observed streamflow. The six years (2011-2016) streamflow and the former runoff parameters were used for model validation.

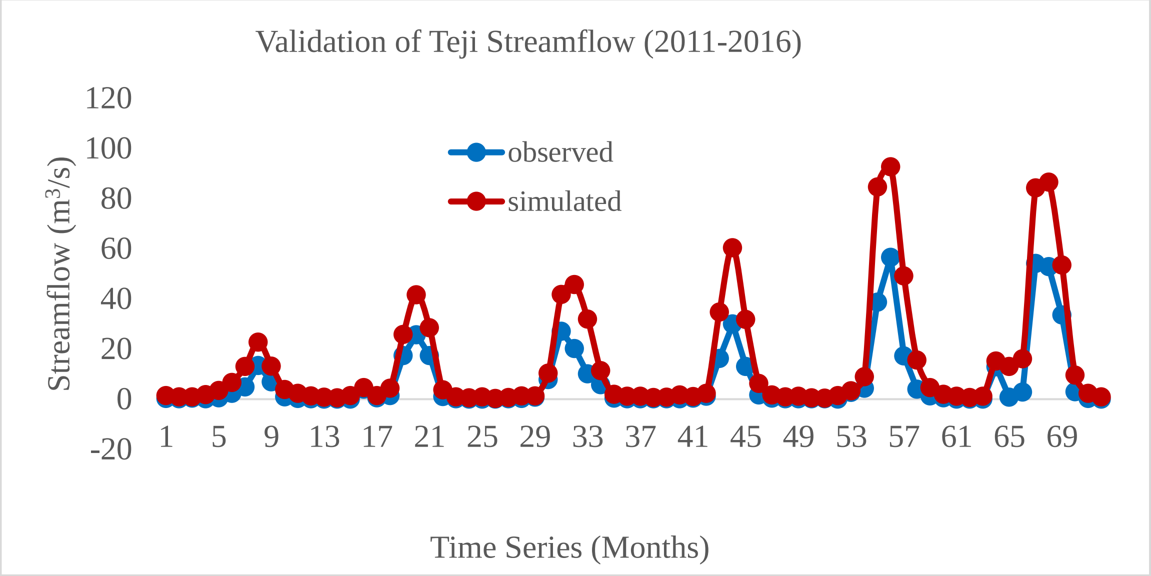


Figure 4.3: Average annual observed and simulated flow validation (2011-2016)

The Nash-Sutcliff efficient (NSE), coefficient of determination (R^2) and percent bias were 0.78, 0.77 and +2.3% respectively. Figure 4.3, above and Figure 4.4, below show that the model performance indicates a best quality of correlation and agreement between the measured data and simulated flow was very good correlation.

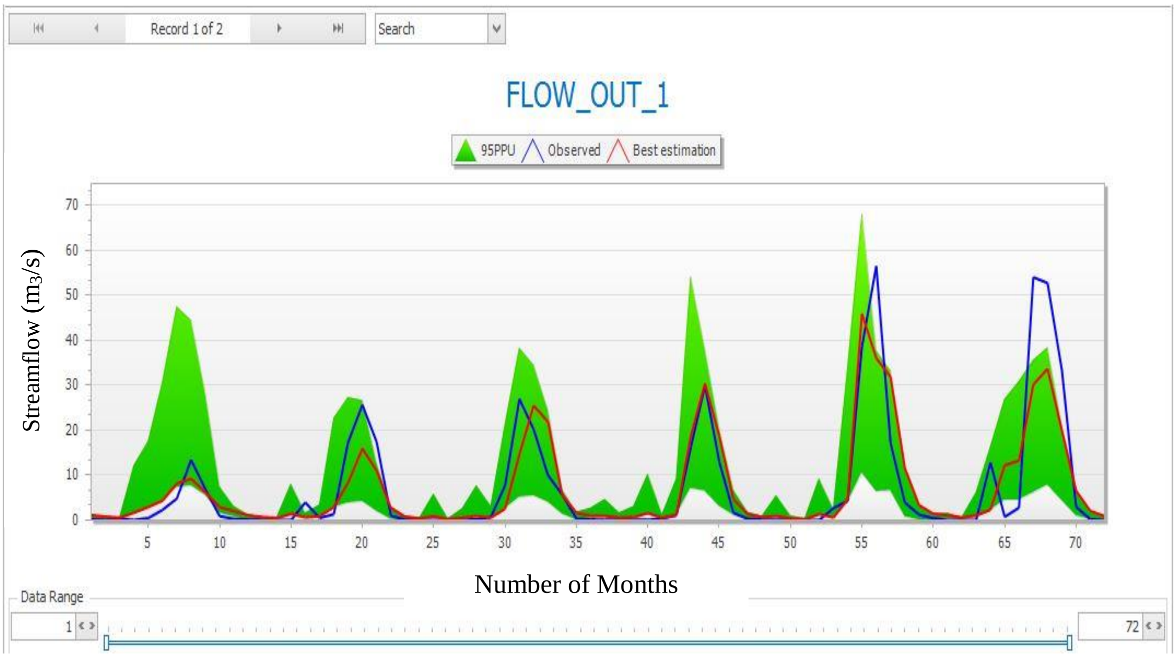


Figure 4.4: Best simulated discharge with 95PPU for validation (2011-2016) in SUFI-2

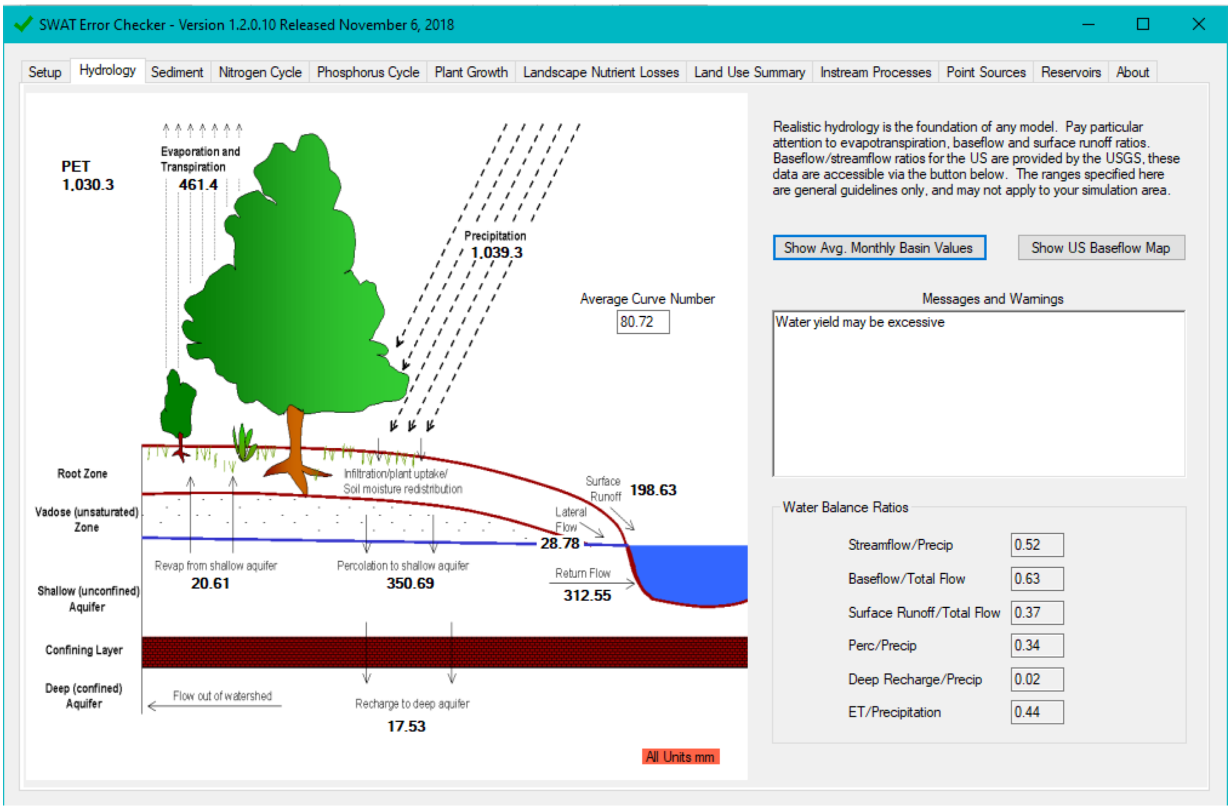
The estimated numerical values during model calibration and validation were summarized in the Table 4.2, below

Table 4.2: Model performance measurement in the calibration and validation

No	Simulation Method and period	P-Factor	R-Factor	Type of Statistical		
				R^2	NSE	PBias
1	Calibration (2000-2010)	0.71	0.77	0.81	0.81	1.6%
2	Validation (2011-2016)	0.77	0.89	0.77	0.78	2.3%

4.2. Water Balance Components in the watershed

The Teji watershed annual and seasonal water balance components were estimated by the SWAT model based on the Soil Conservation Service Curve Number (SCS-CN) method. From the result, the water balance components were surface runoff, evapotranspiration, streamflow, interception storage, and infiltration, shallow and deep aquifers etc.



Realistic hydrology is the foundation of any model. Pay particular attention to evapotranspiration, baseflow and surface runoff ratios. Baseflow/streamflow ratios for the US are provided by the USGS, these data are accessible via the button below. The ranges specified here are general guidelines only, and may not apply to your simulation area.

Messages and Warnings

Water yield may be excessive

Water Balance Ratios

Streamflow/Precip	0.52
Baseflow/Total Flow	0.63
Surface Runoff/Total Flow	0.37
Perc/Precip	0.34
Deep Recharge/Precip	0.02
ET/Precipitation	0.44

Figure 4.5: General SWAT model simulation result of hydrologic cycle

The mean annual distributions of the water balance components were simulated as a mean annual precipitation of 1039.30mm. Surface runoff, lateral flow, and groundwater flow were 198.63 mm, 28.78 mm, and 17.53 mm respectively. Whereas, mean annual evaporation losses were estimated as 461.40 mm which accounting for 44.34% of the mean annual water budget.

The main water budget in the watershed is contributed during Ethiopian summer season or ′Kiremit′ (June, July, August and September) which can produce a total surface runoff of 173 mm (87.54%), rainfall of 766.50 mm, and lateral flow of 23.10 mm. The maximum rainfall was observed during the July and August which corresponding to generate the higher streamflow. In other word, the water budget is low in winter or ′Bega′ season (November, December, January and February) with a total rainfall and surface runoff depth of 24.37 mm and 1.97 mm respectively.

The mean monthly maximum and minimum potential evapotranspiration values, were 96.20 mm and 74.46 mm which were observed during March and August respectively.

Table 4.3: Average monthly water balance values of the watershed

Mon.	Rain (mm)	Surface Runoff (mm)	Lateral flow (mm)	Water Yield (mm)	ETO (mm)	PET (mm)
Jan	13.59	1.49	0.23	4.52	14.26	86.53
Feb	12.12	0.85	0.18	2.15	14.63	86.03
Mar	43.35	2.94	0.60	4.46	57.16	99.32
Apr	64.29	4.57	1.07	6.24	66.38	96.10
Ma	99.53	9.60	1.92	13.15	56.26	96.20
Jun	178.71	35.75	4.00	46.08	43.41	82.71
Jul	234.53	55.17	7.42	103.76	49.71	79.60
Au	246.71	60.46	7.40	140.51	56.36	74.46
Sep	106.59	21.66	4.28	116.32	47.45	82.83
Oct	28.71	5.67	1.22	73.98	30.27	91.68
No	7.47	0.36	0.27	34.24	14.27	79.36
Dec	4.00	0.14	0.18	12.33	11.63	77.54

The mean annual surface runoff was estimated to 198.66 mm, which is generated from the watershed area of 65564 ha. Surface runoff shares near 19% of the mean annual water budget. The mean annual runoff can be expressed in terms of volume, i.e. the runoff depth multiplied by the entire area of the watershed. So, the mean annual surface runoff was estimated to 130.25 MCM. The mean maximum and minimum surface runoff generated in the watershed were 60.46mm and 0.14 mm MCM in August and December, respectively.

Table 4.4: Average annual water balance values of the watershed

S.No	Element of water balance	Depth (mm)
1	Precipitation	1039.30
2	Surface runoff (Q	198.66
3	Potential evapotranspiration (PET)	1030.30
4	Evapotranspiration (ETo)	461.40
5	Lateral flow (Q)	28.78
6	Return flow	312.55
7	Percolation to shallow aquifer	350.69
8	Recharge to deep aquifer	17.53
9	Revap from shallow aquifer	20.61

4.3.Result on Water Demands

4.3.1. The Current water demands

4.2.1.1.Domestic water demands

All the water used for domestic purposes in 2021, in the watershed were included water for preparing food, bathing, washing clothes, drinking, flushing toilets and unaccounted uses as watering gardens and lawns. The current account domestic water demand was estimated using the demand data and current population data. Due to the per capita water demand is different in rural and urban areas, the domestic water demand was the summation of the two demands.

The current account annual domestic water demand was estimated on the basis of 25 l/c/d and 60 l/c/d for rural and urban were 5.58 MCM and 1.44 MCM respectively. So, in the current account for the anticipated population number of 677464 with annual growth rate 3.2%, the total estimated water demand was 7.02 MCM**.** It reveals that, out of the total domestic water demands in the Teji watershed, more than 80 % is needed in the rural areas.

Table 4.5: Monthly Domestic water demand (MCM) in the watershed for the year 2021

Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
Rural	0.5	0.7	0.7	0.5	0.5	0.4	0.3	0.1	0.2	0.3	0.48	0.51	5.58
Urban	0.12	0.14	0.2	0.16	0.11	0.1	0.1	0.1	0.1	0.1	0.1	0.11	1.44
Sum	0.6	0.7	0.8	0.7	0.6	0.5	0.4	0.4	0.4	0.5	0.6	0.6	7.02

4.2.1.2. Livestock water demand

At the current account year the annual water demands was 10.32 MCM for 1129154 TLU living in the watershed. The TLU water demand varies from month to months depend on the air condition of the month which alters the animal water requirements.

Table 4.6: Monthly water demand by TLU in the current account year

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
1.47	1.36	1.37	1.15	0.76	0.41	0.22	0.22	0.39	0.54	1.2	1.24	10.32

4.2.1.3.Irrigation water demand

The output of Cropwat8.0 has shown that the monthly maximum ETO distribution is in February followed by March with the mean values are 6.09 and 5.79 mm/day respectively. The minimum ETO was observed in July and August by 3.10 and 3.20 mm/day respectively. The mean annual reference evapotranspiration was estimated to 4.63 mm/day. The reference evapotranspiration, was fluctuated higher than the mean value during dry months (Appendix Table.8) and lower than the mean value in the rainy months.

The summation of irrigation water requirement (mm/dec) multiplying by the cropping area give the volume of net irrigation water demand in one full growth season (Appendix Table 9-16). Subsequently, the current account net irrigation water requirement was estimated as 12.88 MCM. The irrigation water requirement would likely varied in months, depending up on the access of rainfall. If rainfall is there enough and it can be met the crop water requirement, then the degree of irrigation water requirement is low or totally be zero in case of full effective rainfall.

Table 4.7: Monthly Irrigation water demand (MCM) in the current account (2021)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
1.72	1.71	1.83	1.74	1.21	0.51	0.1	0.0	0.49	0.84	1.11	1.62	12.88

4.2.1.4.Environmental flow requirement

The flow of water which is required for maintaining the stabilities of ecosystem, was estimated based on the assumption of 10% of available streamflow should be leaved in the river. At the current account year the minimum flow left in the Teji River was estimated to

13.0 MCM. The environmental flow requirement was adjusted as constant throughout the year, with the minimum flow rate of 0.41m^3/sec.

Table 4.8: Monthly environmental flow requirements (MCM)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	13.0

4.2.1.5.Commercial and Institutional water demand

The current account, commercial and institutional water demand which is 5 percent of the urban domestic water demand was estimated to be 0.07 MCM. The water to be serve for this demand site is very small than all water demand during current account in the watershed. To be the smallest commercial and institutional water demand is indicating that the most water for domestic demand has been used in the rural water demand, since commercial water depends only on the urban domestic water demand.

The overall water demand in the current account is the summation of domestic, irrigation, livestock water demand, commercial and institutional water demand and environmental flow requirements. But, the commercial and institutional water demand is very small (<1%) which has no significance in the overall water system, so it was ignored. Therefore, the current account total water demand is the summation of domestic, irrigation, livestock and environmental flow requirement which equivalent to 43.22 MCM. The total water demand, excluding commercial and institutional water demand for the current account year is equivalent to 33.2% of available surface water.

Table 4.9: The overall water demand (MCM) for the current account year 2021

S. No.	Water demands Sites	Quantity of water demands	
		(MCM)	(%)
1	Domestic water demand	7.02	16.2
2	Irrigation water demand	12.88	29.8
3	Livestock water demand	10.32	23.9
4	Environmental flow requirement	13.00	30.1
	Total	42.22	100

During current account the environmental flow requirement was the largest water demand site, followed by irrigation and livestock water demand which equivalent to 30.1%, 29.8%

and 23.9% respectively. The domestic water demand is sharing the least water demand, 16.2% of the total.

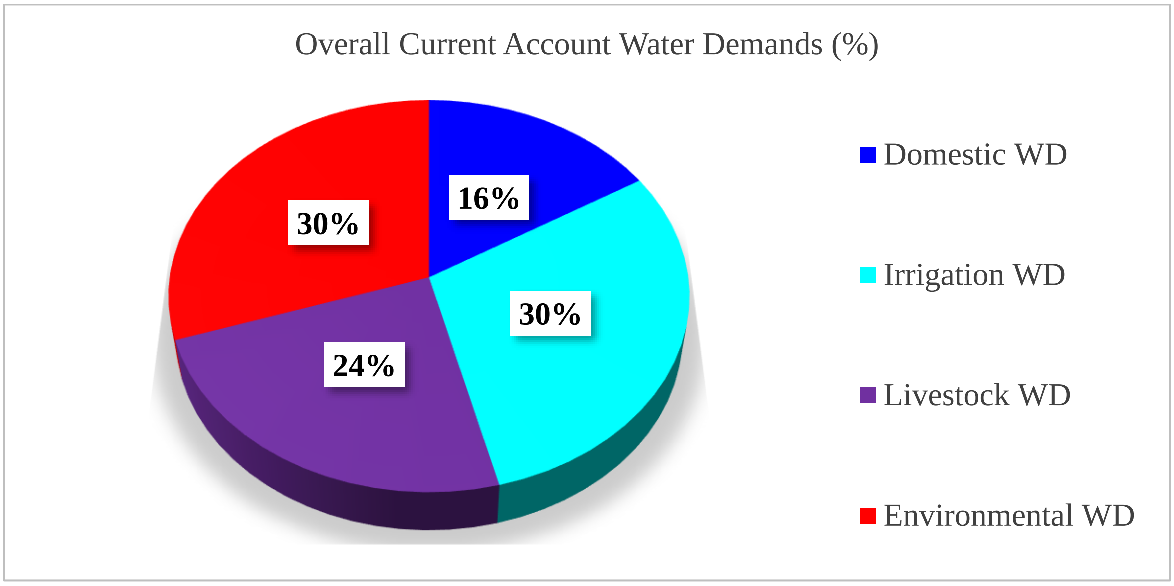


Figure 4.6: Percentage of overall water demand in the current account year (2021)

4.2.2. Reference Scenario

In this scenario, the changes can be likely to occur in the future without intervention new policy measures were considered; it only increases in population and livestock growth intensity throughout the year. The annual population growth rate for domestic users and livestock was found to be 3.2% and 1.2% respectively. The “reference scenario” includes the current accounts data into the entire projected years (2022-2060). At the end of the 2060, the total water demand will be increased to 74.8 MCM which accounting 42% of the current account year water demand.

Table 4.10: Annual Water Demand (MCM) in Reference Scenario

Year	Agriculture	EFR	Livestock	Domestic	Sum
2021	12.88	13.00	10.32	7.02	43.22
2022	12.88	13.00	10.44	7.30	43.69
2025	12.88	13.00	10.82	8.22	44.99
2030	12.88	13.00	11.49	9.99	47.43
2035	12.88	13.00	12.20	12.16	50.31
2040	12.88	13.00	12.95	14.80	53.70
2045	12.88	13.00	13.74	18.01	57.70
2050	12.88	13.00	14.59	21.90	62.44
2055	12.88	13.00	15.48	26.65	68.08
2060	12.88	13.00	16.43	32.42	74.80

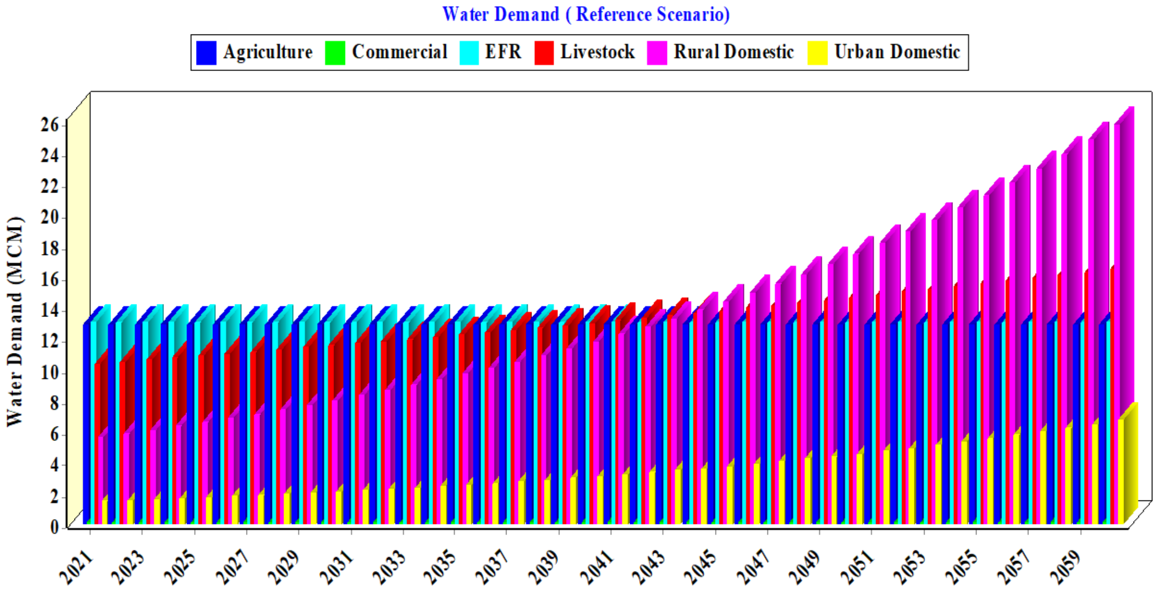


Figure 4.7: Annual water demand in the Reference Scenario (2022-2060)

4.2.3. Scenario One: High Population Growth Rate

Growth in population number have always the drive force which would entail affecting the water demand. Depending up on the increasing population growth rate assumption the projected population in the Teji watershed will be 6.6 million in 2060. The impacts of high population growth rate on the domestic water demand as well as on overall water demands in the watershed was simulated. As a result the overall water demand will be 116 MCM in 2060 which equivalent to 63% of the current account. The result shows that, increase population growth rate by 6% and keeping all other demands as constant, will increase the domestic water demand by 89% and total water demand to 63%. By this assumption the future water demand will grow up to 90% of available surface water.

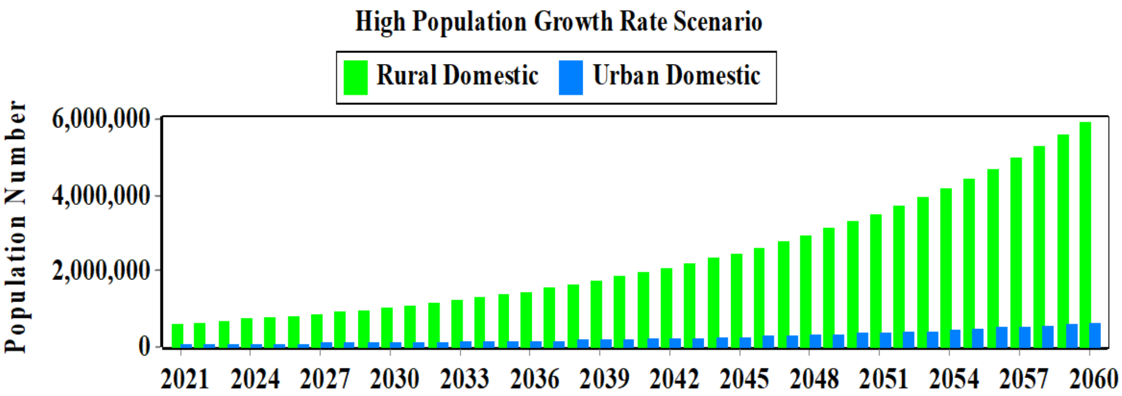


Figure 4.8: Projected human population with annual growth rate in Scenario One

Table 4.11: Annual water demand for Scenario One; High population growth rate

Year	Agriculture	EFR	Livestock	Domestic	Sum
2021	12.88	13.00	10.32	7.02	43.22
2022	12.88	13.00	10.53	7.45	43.85
2025	12.88	13.00	11.17	8.87	45.91
2030	12.88	13.00	12.33	11.87	50.07
2035	12.88	13.00	13.62	15.88	55.37
2040	12.88	13.00	15.03	21.26	62.16
2045	12.88	13.00	16.60	28.44	70.91
2050	12.88	13.00	18.33	38.06	82.26
2055	12.88	13.00	20.24	50.93	97.04
2060	12.88	13.00	22.34	68.15	116.36

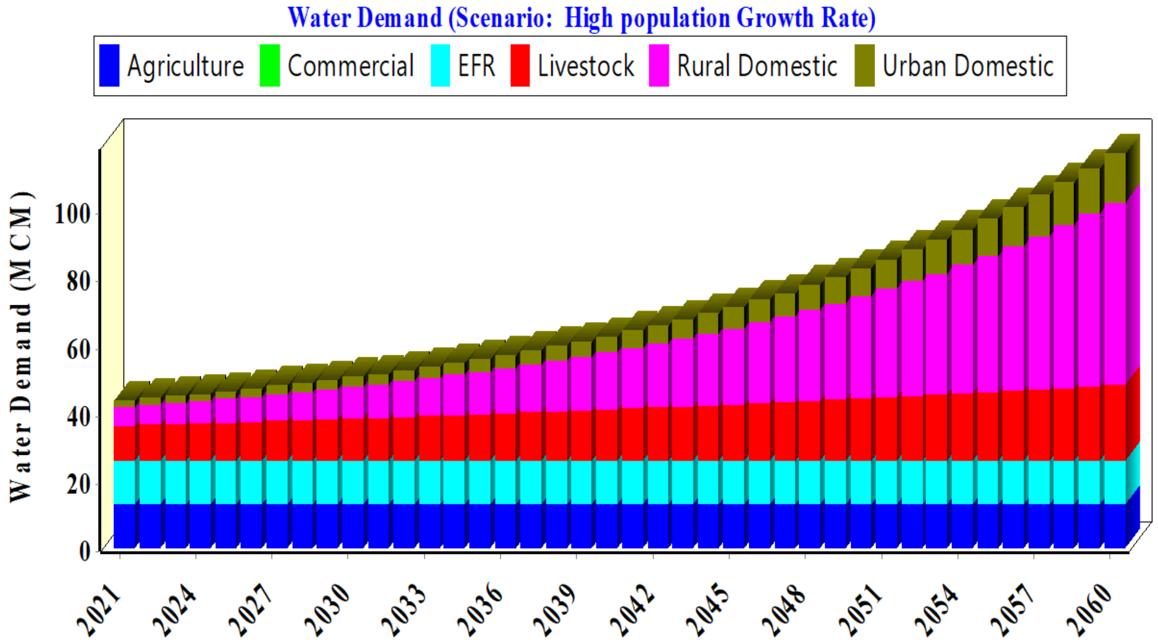


Figure 4.9: Annual water demand for high population growth scenario

4.2.4. Scenario Two: Projections in the Irrigation Area

This scenario has developed to show the effect of enlarging the irrigation area on the water demand. Increase the size of irrigation area by 50% i.e. from 1615 ha to 3250 ha during 2021 to 2060, and keeping other demand sites constant will be increase total water demand from 43.22 MCM to 56.24MCM. As it has shown from the result, even if, increasing the irrigation area increase water demand in the future, the overall water demanded by this scenario is the least than the impacts of other scenarios.

Table 4.12: Annual water demand for Scenario Two: Increase irrigation area

Year	Agriculture	EFR	Livestock	Domestic	Sum
2021	12.88	13.00	10.32	7.02	43.22
2022	13.15	13.00	10.32	7.02	43.49
2025	14.15	13.00	10.32	7.02	44.49
2030	15.54	13.00	10.32	7.02	45.88
2035	16.54	13.00	10.32	7.02	46.88
2040	17.53	13.00	10.32	7.02	47.87
2045	20.32	13.00	10.32	7.02	50.66
2050	22.32	13.00	10.32	7.02	52.66
2055	23.35	13.00	10.32	7.02	53.69
2060	25.90	13.00	10.32	7.02	56.24

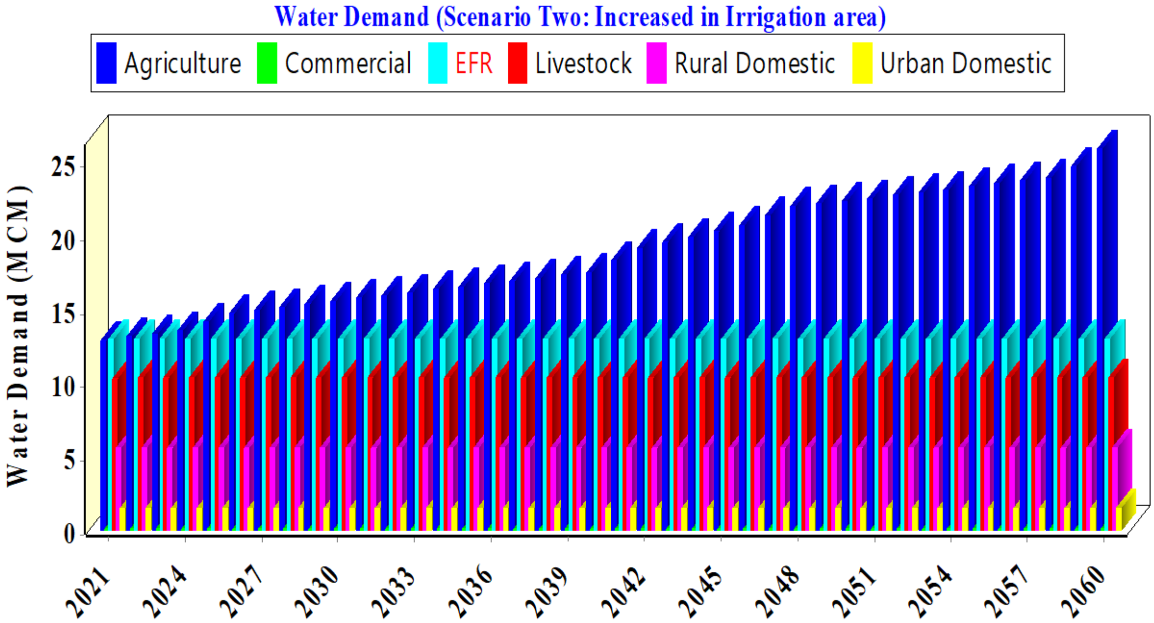


Figure 4.10: Water demand under increase irrigation area

4.2.5. Scenario Three: Increase per Capita Water Demand

The projected change in per capita water usage is based on the assumption that living standard of the people may improve in the future, which governs the domestic water demand. Therefore, the per capita water demand which has used in the current account and reference scenario are changed from 25 l/c/d (9.125m^3) to 50 l/c/d (18.25 m^3) and 60 l/c/d (21.9 m^3) to 100 l/c/d (36.5 m^3) for rural and urban domestic water demand respectively.

Table 4.13: Annual water demand for Increase per capita water demand Scenario

Year	Agriculture	EFR	Livestock	Domestic	Sum
2021	12.88	13.00	10.32	7.02	43.22
2022	12.88	13.00	10.44	14.00	50.32
2025	12.88	13.00	10.82	15.39	52.09
2030	12.88	13.00	11.49	18.01	55.38
2035	12.88	13.00	12.20	21.09	59.17
2040	12.88	13.00	12.95	24.68	63.51
2045	12.88	13.00	13.74	28.89	68.51
2050	12.88	13.00	14.59	33.81	74.28
2055	12.88	13.00	15.48	39.59	80.95
2060	12.88	13.00	16.43	46.34	88.65

By increasing the per capita per day water demand for urban and rural, the total future water demand as well as the domestic water demand will be increased to 88.65 MCM and 46.34 MCM respectively, in 2060.

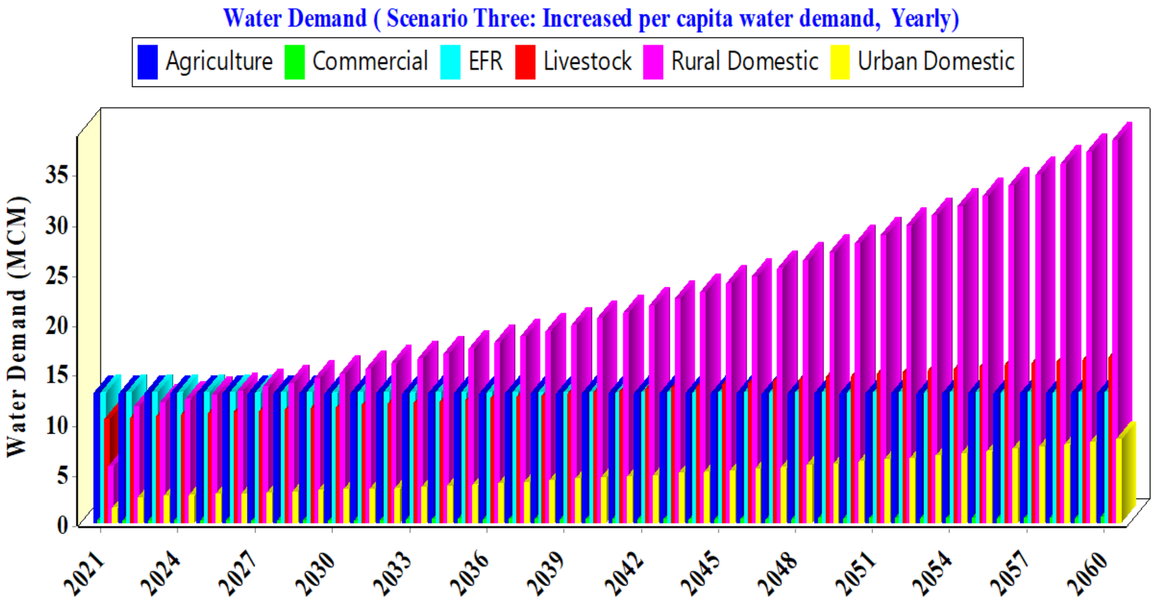


Figure 4.11: Water demand under increased per capita demand

4.2.6. Unmet Demands

The outputs of WEAP show that during the all scenario, the water demand sites have not get full coverage. The highest and lowest unmet demand values were observed in the increase per capita water demand scenario and irrigation area projection scenario respectively. The monthly maximum unmet demand in the increase per capita water demand scenario is 6.94 MCM in March.

The monthly maximum unmet demands in all scenarios were occurred highly during December, January, February and March, while the minimum or non-unmet demands were observed in June, July, August and September. December to March are the dry the months of the year in which demand for water and unmet demand are high while, June to September are the rainy and wet with low or non-unmet demands.

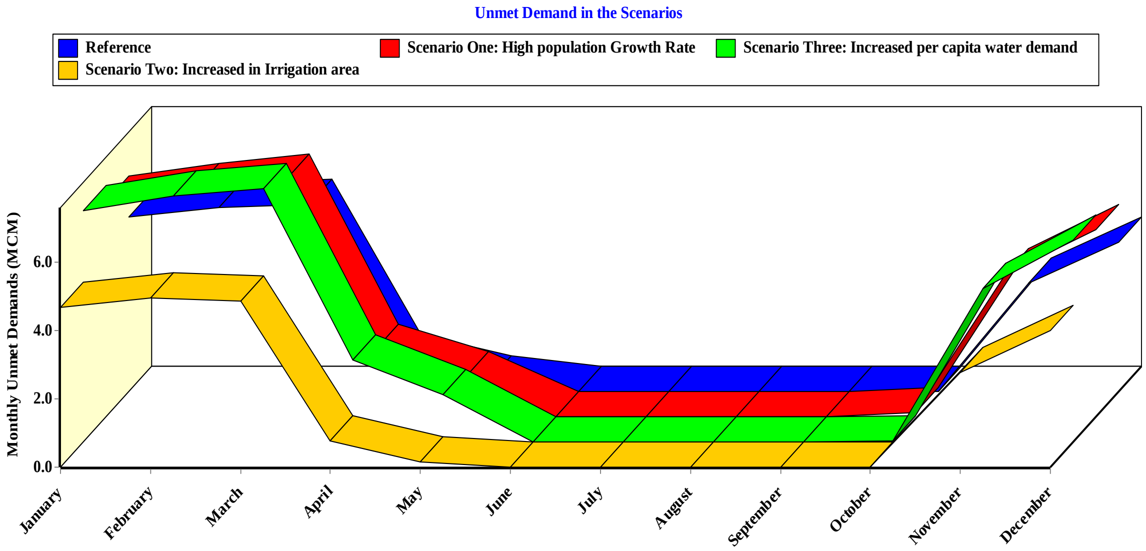


Figure 4.12: Monthly unmet demand in all Scenario

Table 4.14, shows the annual unmet demand for Reference, high population growth rate, increase irrigation area and increases per capita water demand scenarios. The result of the high population growth rate scenario shows that the unmet water demand increased four times of the current account which will be 64.38 MCM in 2060. In other word, the scenario of increase irrigation area will increase unmet demands by least magnitude 27.78MCM in 2060.

Table 4.14: Unmet Demand comparisons with four Scenarios

Scenario	Unmet Water Demand (million m^3/year)							
	2021	2022	2025	2030	2040	2050	2055	2060
Reference	16.7	18.07	18.75	20.03	23.32	28.54	31.96	36.06
Scenario One	16.7	18.19	19.27	21.47	28.45	40.81	50.53	64.38
Scenario Two	16.7	18.06	18.77	19.76	21.17	24.9	25.74	27.78
Scenario Three	16.7	21.73	23.4	26.49	33.1	43.84	48.91	56.35

4.2.7. Comparison between Scenarios

Table 4.15, and Figure 4.13 show that the comparison between all scenarios to identify the most influential scenario on the future water demands. The comparison take place between the reference scenario, scenario one, scenario two and scenario three, and the output of WEAP model show that the most subjective scenario is Scenario one, i.e. the high population growth rate scenario which will increase the water demand from 43.22 MCM to 116.36 MCM from 2021 to 2060. This result shows that the annual unmet demand for high population growth scenario is higher than the annual unmet demand for the reference scenario and scenario two and three.

The second and third influential scenarios are Scenario three and Reference Scenario, in which the future water demands will be 88.65 MCM and 74.80 MCM respectively. But, Scenario two is the least influencing scenario that future water demand increase to 56.24 MCM in 2060. The Reference, high population growth rate, projection irrigation area and increase per capita water demand scenarios are likely brought water demands 57%, 90%, 43% and 68% of streamflow respectively, in 2060.

Table 4.15: Comparison of the annual water demand between the Scenarios

Year	Reference Scenario	Scenario One	Scenario Two	Scenario Three
2021	43.22	43.22	43.22	43.22
2022	43.69	43.92	43.57	50.32
2030	47.43	50.14	45.96	55.38
2040	53.69	62.23	47.95	63.51
2050	62.43	82.33	52.73	74.28
2055	68.08	97.11	53.77	80.95
2060	74.80	116.36	56.32	88.65

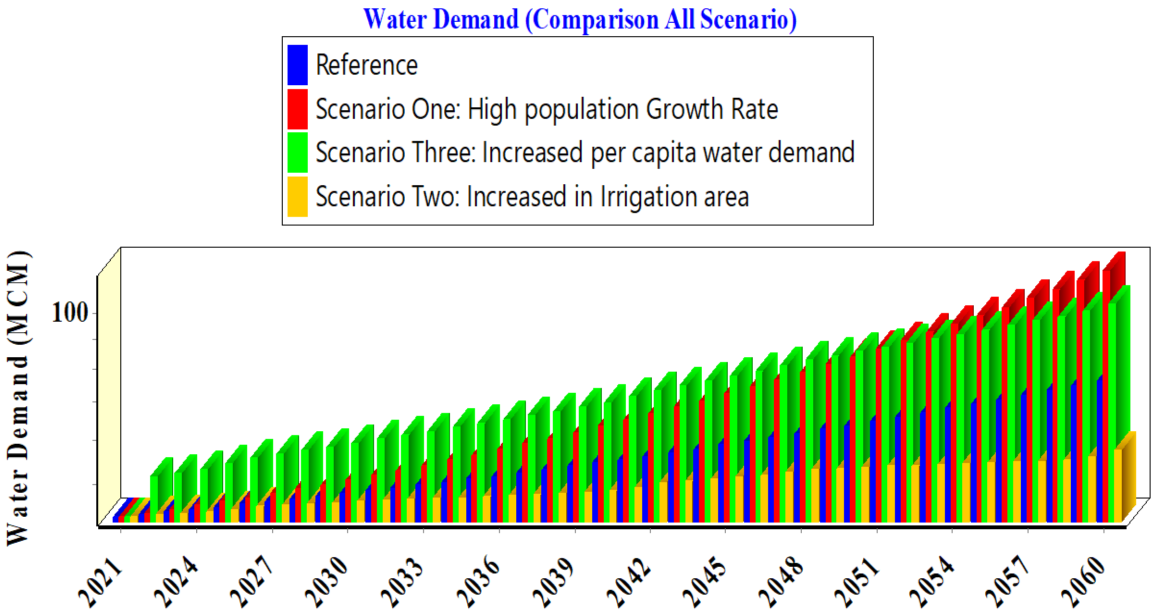


Figure 4.13: Comparison of the annual water demand between Scenarios

The water demand modeling in the above scenarios show that the water deficit will be get worse in the future without intervention. Therefore, an integrated water management should be necessarily done while developing projects in such scenarios.

5. SUMMARY, CONCLUSION AND RECOMMENDATION

5.1.Summary and Conclusions

Water is the most important element for all living things and environment which plays a vital role in supporting the production of human activities such as agricultural, energy and industrial production, sanitation, transportation services, fishing and tourism. However, the availability of water both in quantity and quality have reduced as the result of natural and anthropogenic factors with respecting to time and space. Climate change, land degradation, population growth, economic development and lack of good management in existing water resources are some driving factors which affect water availabilities. In order to meet the limited water resources with unlimited demands the efforts should be invested on the efficient use of all water resources. Knowing the potential available water resources helps to make allocation plans and maximize the resultant economic returns of limited water resources.

This study is aimed to assess surface water availability and evaluation of the current and future demand conditions in Teji River watershed. The study has held by using hydrological models such as Arc SWAT and WEAP models for the purpose of geospatial process and hydrological simulation and the evaluation of water demands respectively. To achieve the objectives of the study, raw data (meteor-hydrological, geographical features, human population and water demand and others) were collected from the associated sources. The daily recorded meteorological data of over 32 years (1987–2018) included precipitation, temperature (maximum and minimum), wind speed, sunshine hours and relative humidity of watershed and nearby were obtained from NMA of Ethiopia. The missing values of climate elements were filled by a weather generator model. Other most important data, the daily streamflow data of six gauging stations were collected from the MoWIE of Ethiopia. The quantity and quality of the data have been checked as desired. The 12.5m x 12.5m resolution DEM was downloaded and used to delineate the watershed via using the Arc GIS 10.4.1, and the 30m x 30m land use/cover and soil data were collected from the MoWIE, are used to determine the Hydrologic response units of the watershed. The minimum thresholds of 10%, 20% and 10% for land use/land cover, soil map and slope classes respectively, were set combined together; and the 9 sub-basins and 123 hydrological response units were identified.

The process sensitivity analysis was executed to limit the number of optimized runoff parameters in order to achieve best fit correlation between the measured and simulated data. The SWAT model sensitivity analysis has done based on twelve runoff parameters using the Global sensitivity analysis method in SWAT-CUP SUFI2. The eleven most sensitive parameters with high to medium ranks were selected and used further in model calibration and validation processes.

The SWAT model was run for simulation period 1/1/1998 to 12/31/2018 by using the daily recorded streamflow data of Teji River near Asgori town. The eleven and six years (2000-2010 and 2011-2016) monthly time step streamflow data were used in model calibration and validation respectively. In both the calibration and validation periods, the model performance were confirmed to obtain very good results.

According to the findings, the watershed receives the mean annual rainfall of 1039.63mm. The annual surface runoff produced from the watershed was estimated to 130.25 MCM and the annual evaporation losses were estimated to 461.40 mm which accounting 44.34% of the mean annual water budget.

At the current account year (2021) about 43.22 MCM of water was required for consumptive and non-consumptive uses. The amount of available water is the summation of flow during high storming as well as low flow in the dry seasons. However, most demand sites have not got full coverage and there were slight to high water shortage in dry seasons which accounted monthly and annual unmet demands.

The future water demand evaluation show that the supply is deficit in all developed scenarios; reference scenario, scenario one, two and three. However, the absolute deficits are varied between scenarios. Under Scenario one the total annual water demand reach up to 116.36 MCM in 2060, which caused by high population growth rate. All scenarios have dialoged that there were unmet demands in monthly as well as annual order to each water demands. The unmet demand was observed highly during the dry seasons (December to May) and the rate is increasing from year to year under all scenarios.

5.2.Recommendations

This study was conducted at the watershed scale to come up with a better understanding and information on the surface water potential and demands of the watershed. The hydrological model used in water resources assessment such as SWAT requires the adequate and accurate input of data to simulate best results and from the conclusion drawn and realistic observation in the watershed the following issues are recommended.

- DEM of the study area has low resolution quality therefore if possible MoWIE should revise and update the DEM, land use and management data is essential for SWAT model.
- The contribution of surface water is skewed to few rainy months (June to September) and other most months of the year are dry which have no enough flow. In order to address water deficits in the watershed the capacities of water conservation and sustainable managements should be judiciously done. Storm water harvesting measures must be adopted during rainy seasons. Water storage structures had better to be constructed in the river to store storm water during rainy seasons which affecting the downstream communities by flooding and use these stored water for the dry months.
- Optionally, misuse and overuse of water in all sectors should be avoided, because water is a finite resource and its future supply is uncertain in the watershed unless water saving measures are taken. So, the equitable and wise use of water is important to guarantee water security and address the challenges and conflict arising among water users.
- An interested party or the stakeholders may use the developed scenarios under this study for discussions, planning and management of the surface water in the watershed.

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APPENDIXIES

Appendix Table 1: Rainfall stations with time of data recorded and percent missed

Stations	Latitude (Degree)	Longitude (Degree)	Elevation (m)	Year of data	% of data Missed
Asgori	8°47’24”	38°19’48”	2078	1987-2018	2.6
Bantu Liben	8°37’12”	38°21’36”	2167	1987-2018	5.3
Herbu Chulule	8°28’12”	38°15’00”	2428	1987-2018	11.4
Teji	8°49’48”	38°22’12”	2067	1987-2018	3.9
Tulu Bolo	8°39’00”	38°12’36”	2169	1987-2018	2.8
Woliso	8°33’00”	37°58’48”	2058	1987-2018	0.3

Appendix Table 2: Mean monthly Rainfall (mm) of the basic stations

Months	Asgori	Bantu Liben	Herbu Chulule	Teji	Tulu Bolo	Woliso
Jan	16.2	14.5	14.1	10.5	10.3	16.5
Feb	29.4	19.5	28.7	28.2	14.2	25.3
Mar	57.6	56.5	57.3	50.0	46.5	57.7
Apr	82.6	90.7	89.7	69.5	62.1	79.6
May	74.5	78.1	91.2	74.3	103.0	105.5
Jun	138.1	180.6	168.0	127.6	213.0	181.4
Jul	234.1	312.2	243.5	210.8	266.8	271.8
Aug	227.7	300.7	242.1	213.9	278.1	260.1
Sep	112.7	150.6	139.6	105.7	109.1	153.5
Oct	22.4	40.0	52.7	25.1	29.8	53.8
Nov	9.3	20.4	14.6	7.4	4.9	15.4
Dec	6.3	7.3	12.4	7.5	5.7	8.8

Appendix Table 3: Monthly Mean Temperature (°C) of the basic stations

Months	Asgori		T/Bolo		Woliso	
	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin
Jan	28.1	6.8	25.3	8.6	26.5	13.1
Feb	29.1	7.9	25.8	9.1	27.6	14
Mar	29.4	9	26.3	10	28.0	14.4
Apr	28.8	10.5	26.4	10.4	27.5	14.4
May	28.8	10.2	26.3	10.2	26.5	13.2
Jun	27.7	10.7	25.1	10.3	23.6	12.8
Jul	25.3	11.2	23.6	10.2	21.4	12.7
Aug	25.2	11.2	23.6	10.1	21.6	12.7
Sep	25.9	10.3	23.9	9.6	23.2	12
Oct	26.5	6.8	24.2	8.8	25.2	12.3
Nov	27.1	5.6	24.2	8.2	25.6	12.7
Dec	27.2	5.8	24.2	7.7	25.8	12.8

Appendix Table 4: Mean Annual Rainfall (mm) of stations the basic stations

Year	Asgori	B/Liben	H/Chulule	Teji	T/Bolo	Woliso
1987	993	1156.8	1414.2	821.4	938	1271.2
1988	991	1578.2	1364.4	1152.8	1128.8	1448.4
1989	926	1494.2	1075	898.2	1169.4	1231.1
1990	1146	1044.9	1170.4	990.8	762.5	1259.6
1991	1074	1307.1	1463.9	961	796.3	1040.6
1992	1225	1336.3	1161.1	962	1665.8	1387.1
1993	1256	2080.2	1209.4	1093.6	2258.2	1553.1
1994	1170	1266.6	1690.9	866.1	1380.3	1082.5
1995	1111	1022.3	1313.8	786.8	668.3	1070.6
1996	1409	2448.9	1582.5	946.1	1217.4	1446.7
1997	849	1033.7	1203.7	794.7	1140.4	1050.5
1998	1198	1653.6	812.2	1135.7	1453.8	1380.6
1999	928	841.6	809.3	833.8	1372.4	1415.5
2000	816	920.2	654.5	866.1	1225.9	1136.1
2001	896	1044	715.7	872.5	819.4	1021.2
2002	933	1019.7	696.7	811.1	1021.5	1114.4
2003	1127	1413.2	1073.8	1082	979.4	1175.4
2004	917	1376.7	1331.4	941.9	1158.6	1229.8
2005	901	1909.2	1217.4	1112.6	1122.3	1209.9
2006	919	1625.6	1033.9	1170.9	1039	1400
2007	1071	1207.9	990.3	969.3	1131.2	1170.2
2008	958	920.2	1286.2	806.5	1139.1	1242.2
2009	864	1034.9	1001.7	809.6	978.7	978.5
2010	1102	441.1	980.8	1216.3	1394.8	1383.7
2011	910	655.5	1226.2	902.5	853.7	1135.8

2012	774	1251.3	945.3	714.2	919.6	955
2013	1292	1277.8	799.8	965.4	1683.6	1418.1
2014	996	1363.8	1363.9	844.8	1022.9	1143.5
2015	783	1049.5	1228	835.1	838.6	1011.5
2016	947	1888.7	1098	1009.8	996.3	1360.6
2017	922	1118.4	1306.8	674.4	1070.7	1250.1
2018	947	889	1708.9	930.1	1240.9	1369.8

Appendix Table 5: Mean monthly streamflow (m^3/s) of Teji gauging station

	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Year	Warmup period (1998-1999)											
1998	0.112	0.014	0.091	0.113	0.192	1.929	7.965	19.416	4.851	0.81	0.046	0.015
1999	0.01	0.002	0.08	0	0.478	1.377	9.28	18.133	1.894	1.995	0.042	0.007
Calibration period (2000-2010)												
2000	0.002	0	0	0.007	0.021	0.286	5.989	8.902	4.439	0.703	0.036	0.007
2001	0.002	0.001	0.042	0.013	0.426	4.453	6.006	6.389	1.745	0.025	0.001	0
2002	0.003	0	0.018	0.057	0.002	0.577	6.086	5.343	0.763	0	0	0
2003	0	0	0	0.004	0	0.445	7.518	8.743	3.683	0.035	0	0
2004	0.002	0	0	0.277	0	1.189	4.902	9.303	6.709	1.444	0.467	0.35
2005	0.451	0.254	0.658	0.655	2.873	4.52	13.15	20.294	8.545	1.298	0.351	0.253
2006	0.198	0.236	0.605	5.345	11.853	5.345	35.683	18.198	11.653	1.211	0.587	0.419
2007	0.323	0.333	0.317	0.387	1.52	4.817	11.925	35.91	18.238	1.913	0.472	0.399
2008	0.302	0.235	0.126	0.246	0.464	2.165	14.1	26.811	8.673	0.853	1.342	0.401
2009	0.39	0.235	0.148	0.29	0.286	0.624	5.105	27.449	6.378	0.706	0.241	0.246
2010	0.189	0.332	0.308	0.809	0.958	4.535	18.668	13.357	14.44	0.606	0.309	0.259
Validation Period (2011-2016)												
2011	0.222	0.058	0.344	0.074	0.517	2.317	4.867	13.499	7.138	0.67	0.272	0.159
2012	0.064	0.009	0.005	3.986	0.533	1.344	17.443	26.064	17.471	0.378	0.108	0.052
2013	0.04	0.003	0.102	0.251	0.711	7.888	27.643	19.939	9.918	5.406	0.314	0.173
2014	0.131	0.099	0.117	0.098	0.402	1.103	16.174	32.165	11.34	1.128	0.286	0.171
2015	0.363	0.33	2.443	0.414	1.343	7.2	18.144	34.11	8.187	0.5	0.429	0.429
2016	0.442	0.38	0.482	0.405	0.448	1.791	12.242	14.215	2.244	0.43	0.37	0.461

Appendix Table 6: Monthly rainfall (mm) used in the CROPWAT8.0 model

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	58	53	56	89	179	157	259	257	175	92	7	0
1999	8	28	49	34	167	150	261	196	128	102	15	6
2000	0	13	41	11	155	185	239	201	134	7	3	23
2001	22	53	21	24	155	201	273	233	153	28	8	0
2002	0	1	5	36	134	164	340	246	171	56	39	50
2003	5	52	28	88	134	229	306	360	122	26	5	28
2004	5	1	36	65	132	162	261	279	159	5	29	1
2005	9	0	29	18	124	206	281	373	171	181	22	0
2006	2	7	54	118	113	157	377	271	169	122	27	0
2007	2	59	91	83	110	214	303	323	154	43	18	0
2008	0	0	4	110	99	118	323	249	175	29	16	13
2009	11	8	83	31	80	152	329	141	139	29	18	0
2010	63	0	75	106	69	189	229	241	173	50	16	0
2011	17	2	43	38	64	78	234	282	99	85	16	22
2012	0	0	33	77	63	167	180	209	209	9	4	6
2013	21	30	82	59	50	238	283	258	64	4	0	27
2014	55	33	50	92	41	225	277	232	176	41	8	0
2015	27	6	83	142	18	189	331	199	106	30	14	32
2016	22	11	62	95	148	131	227	171	103	22	5	0

Appendix Table 7: Rank of precipitation from the highest to the lowest

Rank	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	63	59	91	142	179	238	377	373	209	181	39	50
2	58	53	83	118	167	229	340	360	176	122	29	32
3	55	53	83	110	155	225	331	323	175	102	27	28
4	27	52	82	106	155	214	329	282	175	92	22	27
5	22	33	75	92	134	206	323	279	173	85	18	23
6	21	30	56	89	134	201	306	271	171	56	18	22
7	17	28	54	88	132	189	303	258	171	50	16	13
8	11	13	50	83	124	189	283	257	169	43	16	6
9	9	8	49	77	113	185	281	249	159	41	16	6
10	8	7	43	65	110	167	277	246	154	30	15	1
11	5	6	41	59	99	164	273	241	153	29	14	0
12	5	2	36	38	80	162	261	233	139	29	8	0
13	2	1	33	36	69	157	261	232	134	28	8	0

14	2	1	29	34	64	157	259	209	128	26	7	0
15	**0**	**0**	**28**	**31**	**63**	**152**	**239**	**201**	**122**	**9**	**5**	**0**
16	0	0	21	24	50	150	234	199	106	7	4	0
17	0	0	5	18	41	118	229	196	99	5	3	0
18	0	0	4	11	18	78	180	141	64	4	0	0

The procedures to estimate the probability of exceedance are summarized as follows.

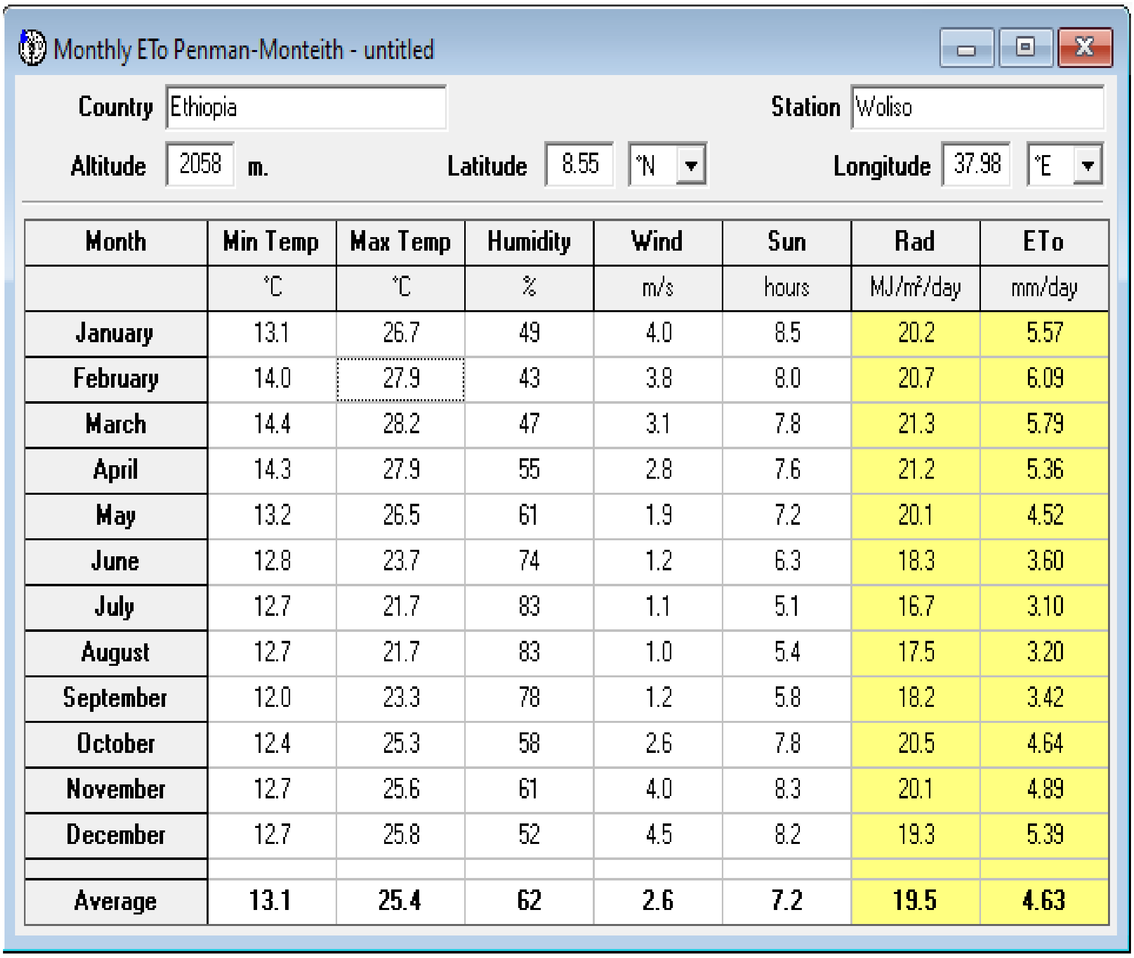
Assuming the probability of exceedance (P) of 80% or 0.8 to calculate the return period (Tr),

$$P = 1/Tr \qquad Tr = 1/P \qquad Tr = 1/0.8 = 1.25$$

The ranks of rainfall with 80% probability of exceedance is calculated and the corresponding monthly values are taken as dependable rainfall.

Tr = (n+1)/m; n= no of events (18 years) m= (n+1)/Tr , m=rank m=(n+1)/Tr m=(18+1)/1.25= 15.2 take 15 as shown above. Therefore the 15th order rainfall was taken to calculate the monthly effective rainfall using the above formula.

Appendix Table 8: ETO of the Teji watershed



Monthly ETo Penman-Monteith - untitled

Country: Ethiopia
Station: Woliso
Altitude: 2058 m.
Latitude: 8.55 °N
Longitude: 37.98 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	m/s	hours	MJ/m²/day	mm/day
January	13.1	26.7	49	4.0	8.5	20.2	5.57
February	14.0	27.9	43	3.8	8.0	20.7	6.09
March	14.4	28.2	47	3.1	7.8	21.3	5.79
April	14.3	27.9	55	2.8	7.6	21.2	5.36
May	13.2	26.5	61	1.9	7.2	20.1	4.52
June	12.8	23.7	74	1.2	6.3	18.3	3.60
July	12.7	21.7	83	1.1	5.1	16.7	3.10
August	12.7	21.7	83	1.0	5.4	17.5	3.20
September	12.0	23.3	78	1.2	5.8	18.2	3.42
October	12.4	25.3	58	2.6	7.8	20.5	4.64
November	12.7	25.6	61	4.0	8.3	20.1	4.89
December	12.7	25.8	52	4.5	8.2	19.3	5.39
Average	**13.1**	**25.4**	**62**	**2.6**	**7.2**	**19.5**	**4.63**

Appendix Table 9: IWR for Wheat computed by CROPWAT 8.0

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jan	1	Init	0.3	1.37	8.2	0	8.2
Jan	2	Init	0.3	1.42	14.2	0	14.2
Jan	3	Init	0.3	1.44	15.8	0	15.8
Feb	1	Dev	0.3	1.46	14.6	0	14.6
Feb	2	Dev	0.5	2.44	24.4	0	24.4
Feb	3	Dev	0.81	4.07	40.7	0	40.7
Mar	1	Mid	1.11	5.79	57.9	0	57.9
Mar	2	Mid	1.22	6.57	65.7	0	65.7
Mar	3	Mid	1.22	6.64	73	0	73
Apr	1	Mid	1.22	6.71	67.1	0	67.1
Apr	2	Late	1.21	6.74	67.4	0	67.4
Apr	3	Late	0.97	5.59	61.5	0	61.5
May	1	Late	0.65	3.86	38.6	0	38.6
May	2	Late	0.39	2.39	16.7	0	16.7
Total					**565.8**	**0**	**565.8**

Planting Date: Jan 5/2021 Harvested Date: May 14/2021 Area:154 ha

Appendix Table 10: IWR for Carrot computed by CROPWAT 8.0

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req.mm/dec
Jan	1	Init	0.7	3.32	19.9	0	19.9
Jan	2	Init	0.7	3.35	36.9	0	36.9
Jan	3	Dev	0.74	3.55	35.5	0	35.5
Feb	1	Dev	0.87	4.24	42.4	0	42.4
Feb	2	Mid	1	5.06	50.6	0	50.6
Feb	3	Mid	1.1	5.73	57.3	0	57.3
Mar	1	Mid	1.1	5.93	59.3	0	59.3
Mar	2	Mid	1.1	6	66	0	66
Mar	3	Lat	1.08	5.92	59.2	0	59.2
Apr	1	Lat	1.02	5.65	39.6	0	39.6
	Total				**466.6**	**0**	**466.6**

Planting Date: Jan 01/2021 Harvested Date: Apr 12/2021 Area :83 ha

Appendix Table 11: IWR for Tomato computed by CROPWAT 8.0

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jan	1	Init	0.6	2.58	18.1	0.1	18
Jan	2	Init	0.6	2.84	28.4	0	28.4
Jan	3	Init	0.6	2.87	31.6	0	31.6
Feb	1	Dev	0.65	3.15	31.5	0	31.5
Feb	2	Dev	0.81	3.94	39.4	0	39.4
Feb	3	Dev	0.96	4.84	48.4	0	48.4
Mar	1	Dev	1.11	5.79	57.9	0	57.9
Mar	2	Mid	1.21	6.5	65	0	65
Mar	3	Mid	1.21	6.58	72.4	0	72.4
Apr	1	Mid	1.21	6.65	66.5	0	66.5
Apr	2	Mid	1.21	6.73	67.3	0	67.3
Apr	3	Lat	1.19	6.84	75.3	0	75.3
May	1	Lat	1.08	6.41	64.1	0	64.1
May	2	Lat	0.96	5.87	58.7	0	58.7
May	3	Lat	0.87	5.24	26.2	0.1	26.1
Total					**750.7**	**0.2**	**750.5**
Planting Date: Jan 01/2021 Harvested Date: May 25/2021 Area: 267 ha							

Appendix Table 12: IWR for Potato computed by CROPWAT 8.0

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jan	1	Init	0.5	2.37	16.6	0	16.6
Jan	2	Init	0.5	2.39	26.3	0	26.3
Jan	3	Dev	0.51	2.47	24.7	0	24.7
Feb	1	Dev	0.7	3.43	34.3	0	34.3
Feb	2	Dev	0.94	4.74	47.4	0	47.4
Feb	3	Mid	1.16	6.05	60.5	0	60.5
Mar	1	Mid	1.21	6.51	65.1	0	65.1
Mar	2	Mid	1.21	6.59	72.4	0	72.4
Mar	3	Mid	1.21	6.66	66.6	0	66.6
Apr	1	Mid	1.21	6.73	67.3	0	67.3
Apr	2	Late	1.14	6.55	72.1	0	72.1
Apr	3	Late	1	5.91	59.1	0	59.1
May	1	Late	0.86	5.25	52.5	0	52.5
Total					**665**	**0**	**665**
Planting Date: Jan 01/2021 Harvested Date: May 10/2021 Area:189 ha							

Appendix Table 13: IWR for Cabbage computed by CROPWAT 8.0

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Nov	1	Init	0.7	2.63	2.6	1.7	2.6
Nov	2	Init	0.7	3.01	30.1	0.1	30
Nov	3	Init	0.7	3.32	33.2	0	33.2
Dec	1	Init	0.7	3.35	36.9	0	36.9
Dec	2	Dev	0.7	3.37	33.7	0	33.7
Dec	3	Dev	0.71	3.45	34.5	0	34.5
Jan	1	Dev	0.71	3.61	36.1	0	36.1
Jan	2	Dev	0.72	3.77	37.7	0	37.7
Jan	3	Dev	0.73	3.93	39.3	0	39.3
Feb	1	Dev	0.74	4.01	44.2	0	44.2
Feb	2	Mid	0.74	4.1	41	0	41
Feb	3	Mid	0.75	4.16	41.6	0	41.6
Mar	1	Mid	0.75	4.28	47.1	0	47.1
Mar	2	Mid	0.75	4.41	44.1	0	44.1
Mar	3	Mid	0.75	4.54	45.4	0	45.4
Apr	1	Late	0.8	4.82	38.5	0.1	38.4
Apr	2	Late	0.98	5.77	57.7	1.7	56.1
Apr	3	Late	0.98	5.68	17	0.7	15.8
Total					**660.7**	**4.3**	**657.5**
Planting Date: Dec 04/2020				Harvested Date: May 18/2021		Area: 209 ha	

Appendix Table 14: IWR for Maize computed by CROPWAT 8.0

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	1	Init	0.3	1.29	3.9	0	3.9
Dec	2	Init	0.3	1.42	14.2	0	14.2
Dec	3	Dev	0.33	1.56	17.2	0	17.2
Jan	1	Dev	0.57	2.73	27.3	0	27.3
Jan	2	Dev	0.85	4.16	41.6	0	41.6
Jan	3	Mid	1.13	5.73	57.3	0	57.3
Feb	1	Mid	1.29	6.72	67.2	0	67.2
Feb	2	Mid	1.29	6.94	69.4	0	69.4
Feb	3	Mid	1.29	7.01	77.2	0	77.2
Mar	1	Late	1.29	7.09	70.9	0	70.9
Mar	2	Late	1.12	6.21	62.1	0	62.1
Mar	3	Late	0.79	4.52	49.7	0	49.7
Apr	1	Late	0.48	2.81	25.3	0	25.3
Total					**583.3**	**0**	**583.3**
Planting Date: Dec 02/2020				Harvested Date: Apr 05/2021		Area:140 ha	

Appendix Table 15: IWR for Pepper computed by CROPWAT 8.0

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	2	Init	0.6	2.58	2.6	0	2.6
Dec	3	Init	0.6	2.84	28.4	0	28.4
Jan	1	Init	0.6	2.87	31.6	0	31.6
Jan	2	Dev	0.6	2.91	29.1	0	29.1
Jan	3	Dev	0.71	3.47	34.7	0	34.7
Feb	1	Dev	0.86	4.33	43.3	0	43.3
Feb	2	Mid	1	5.23	52.3	0	52.3
Feb	3	Mid	1.11	5.96	59.6	0	59.6
Mar	1	Mid	1.11	6.05	66.6	0	66.6
Mar	2	Mid	1.11	6.12	61.2	0	61.2
Mar	3	Late	1.11	6.19	61.9	0	61.9
Apr	1	Late	1.08	6.2	68.1	0	68.1
Apr	2	Late	1	5.9	59	0	59
Apr	3	Late	0.95	5.81	5.8	0	5.8
Total					**604.2**	**0**	**604.2**
Planting Date: Dec 15/2020 Harvested Date: Apr 21/2021 Area:67ha							

Appendix Table 16: IWR for Onion computed by CROPWAT 8.0

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Oct	1	Init	0.7	3.01	30.1	0.1	30
Oct	2	Init	0.7	3.32	33.2	0	33.2
Oct	3	Dev	0.76	3.64	40	0	40
Nov	1	Dev	0.86	4.16	41.6	0	41.6
Nov	2	Dev	0.97	4.72	47.2	0	47.2
Nov	3	Mid	1.04	5.28	52.8	0	52.8
Dec	1	Mid	1.05	5.48	54.8	0	54.8
Dec	2	Mid	1.05	5.65	56.5	0	56.5
Dec	3	Mid	1.05	5.72	62.9	0	62.9
Jan	1	Mid	1.05	5.78	57.8	0	57.8
Jan	2	Mid	1.05	5.85	58.5	0	58.5
Jan	3	Mid	1.05	6.03	66.3	0	66.3
Feb	1	Mid	1.05	6.21	62.1	0	62.1
Feb	2	Mid	1.05	6.39	63.9	0	63.9
Feb	3	Mid	1.05	6.29	50.3	0.1	50.2
Mar	1	Mid	1.05	6.18	61.8	1.7	60.2
Mar	2	Late	1.04	6	60	2.5	57.5
Mar	3	Late	0.97	5.48	60.2	2.6	57.6
Apr	1	Late	0.9	4.95	49.5	2.1	47.4

Apr	2	Late	0.83	4.47	44.7	2.1	42.6
Apr	3	Late	0.77	3.93	31.4	3.5	27
Total					**1085.7**	**14.8**	**1070.1**
Planting Date: Oct 01/2020 Harvested Date: May 21/2021 Area: 380 ha							

Appendix Table 17: Livestock number before converted into TLU

Woreda	Cattle	Sheep	Goat	Donkey	Horse	Mule	Poultry
Becho	688500	337500	303750	62782	33750	3713	1181250
Sed/Sodo	174985	134604	104317	25220	13460	186	370160
Kondaltiti	176825	101042	80834	18598	10104	252	303128
Tole	140942	70471	81042	13108	7048	2339	158560
Ilu	25984	9280	8352	3440	1856	334	55679
Woliso	21019	12611	9668	4183	1681	167	46241
Total	1228255	665508	587964	127331	67900	6990	2115018

Appendix Table 18: SWAT Sensitive Parameters for Streamflow of Watershed

S. N	Parameters Name	Parameters Description	File Ext	Method	Range	
					Min	Max
1	CN2	Initial SCS runoff curve number	.mg	Abs.	35	98
2	ALPHA_BF	Base flow alpha factor (days)	.gw	Rep.	0.2	1
3	GW_DELAY	Groundwater delay (days)	.gw	Rep.	0	22
4	GWQMN	Min. water in shallow aquifer (mm)	.gw	Rep.	0	5000
5	GW_REVAP	Groundwater "revap" coefficient	.gw	Rel.	0.1	0.2
6	ESCO	Soil evaporation compensation factor	.hru	Rep.	0.1	1
7	EPCO	Plant uptake compensation factor	.hru	Rel.	0.1	1
8	RCHRG_DP	Deep aquifer percolation fraction	.gw	Rel.	0.6	1
9	SOL_AWC	Available water capacity in soil layer	.sol	Rep.	0	1
10	SURLAG	Surface runoff lags coefficient	.bs	Rel.	0.05	24
11	OV_N	Manning's "n" value for overland flow	.hru	Rep.	0.1	30
12	SOL_BD	Moist bulk density	.sol	Rel.	0	5000