

**INVESTIGATION OF WATER AVAILABILITY AND WATER
DEMAND SECENARIOS OF MOJO RIVER WATERSHED IN THE
UPPER AWSH RIVER BASIN IN ETHIOPIA.**

By

AHMEDNASIR AMIN



**A Thesis Submitted to the Water Resources Engineering Department,
School of Civil Engineering and Architecture**

**Presented in Partial Fulfillment of the Requirement for the Degree of
Master's in Water Resource Engineering (Specialization in Irrigation
Engineering)**

**Office of Graduate Studies
Adama Science and Technology University**

**Adama, Ethiopia
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ADIVISOR: Dr. ZELALEM BIRU



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Approvals of the Board of Examiners

We, the undersigned, members of the Boards of Examiners of the final open defenses by **Ahmednasir Amin Abdule** have read and evaluated his thesis entitled **“INVESTIGATION OF WATER AVAILABILITY AND WATER DEMAND SECENARIOS OF MOJO RIVER WATERSHED IN THE UPPER AWSH RIVER BASIN IN ETHIOPIA”** and examined the candidate. This is therefore, to certify that the thesis have been accepted in partial fulfillment of the requirement of the Degree of Master in Water Resources Engineering (Specialization in Irrigation Engineering).

Major Advisor:	Signature	Date
Chairperson	Signature	Date
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Date of submission: _____

Advisor Approval Sheet

TO: Water Resources Engineering Department

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Name of Major Advisor

Signature

Date

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LIST OF ACRONYMS AND ABBREVIATIONS

DEM	Digital Elevation Model
FAO	Food and Agriculture Organization
GIS	Geographical Information System
HRU	Hydrological Response Units
LULC	Land Use Land Cover
SWAT	Soil and Water Assessment Tool
MoWIE	Ministry of Water, Irrigation and Energy
SUFI-2	Sequential Uncertainty Fitting_ 2
NMA	National Meteorological Agency
Ha	Hectare
Km	Kilometer
M	Meter
PCP	Precipitation
P _{BIAS}	Percent Bias
AET	Actual Evapo-transpiration
PET	Potential Evapo transpiration
NSE	Nash-Sutcliffe Efficiency
R ²	Coefficient of Determination
RMSE	Root Mean Square Error
CWR	Crop Water Requirement
IWR	Irrigation Water Requirement
SWS	Scheme Water Supply
IN gross	Gross Irrigation Need
CA	Command Area (ha)
RSR	Root Mean Square Error Observation Standard deviation
P	Population
MCM	Million Cubic Meter
Q	Discharge or Annual volume of water
q	Consumptive rate (lit/depth/day)
CN	Consumptive Requirement (m ³)
°C	Degree Celsius

Abstract

This study was conducted to assess availability of Mojo stream flow for irrigation using soil and water assessment tools (SWAT). The assessment of stream flow availability was conducted for Mojo watershed, which is having a total area of 2017.09km. The performance evaluation of the model to obtain the water balances was conducted. The crop and irrigation water demand of Major crops of the area such as: Cabbages, Onion, Maize, Tomato and pepper were analysed using CROPWAT 8 modelling. The other data required to calculate the demand of water like Livestock and human consumptive use were obtained from the four woreda included in the watershed. In this study for stream flow yield simulation the parameters involving surface runoff (CN2.mgt) and ground water (ALPHA_BNK.rte) was found to be the most sensitive parameters. A good agreement between observed and simulated discharge were observed, which was verified using both graphical technique and quantitative statistics. The value of $R^2=0.80$, $NSE=0.75$, $RSR=0.5$ and $PBIAS=-10.6$ obtained during calibration and R^2 value 0.76, NSE value 0.69, RSR value 0.56 and $PBIAS$ -14.4 obtained during validation as well as the uniformly scatter points along the 1:1 line during calibration and validation justify that the model is very good in simulating observed steam flow. From the results the total annual surface water available yields is estimated around 0.401Billion Cubic Meters (BCM), irrigation water requirement, human and livestock water consumption were found to be 0.279, 0.13 and 0.106BCM/year respectively. So, there was shortage of water around 0.114BCM/year occurred. This shows that the demand exceeds the availability by 0.011BCM during the study period. During the dry month (Dec-May) there was highest water deficits occurred, which is about 0.0096BCM/month. During this period there was also conflict between users at diversion and water allocation. Therefore, in order to solve water shortage, alternative source of water supply like ground water and water harvesting technologies should be studied and integrated water management system should be implemented. In addition to this, to improve the efficiency of irrigation water, different irrigation methods like drip irrigation and sprinkler irrigation should be improved in the area.

Key words: water availability, SWAT model, Supply and Demand, CWR and IWR

1. INTRODUCTION

1.1. Background

Irrigation has contributed to the agricultural production increase during the past decades, becoming the largest water consumption sector throughout the world, accounting for about 70 % of the global freshwater withdrawals and 90 % of consumptive water uses (Siebert *et al.*, 2010). The development of irrigation in the Awash River basin has been intimately associated with the settlement and industrial development of the country. Most of the basin suitable for crop production is semiarid, and irrigation is required during the growing season. Irrigation agriculture was practiced by the early settlers to meet the local needs for vegetable and grain crops. Transportation was slow and difficult, requiring each settlement to be practically self-sustaining. As settlement of the country progressed, markets for farm products expanded continually, and irrigation agriculture became an increasing factor in the region's economy.

The adequacies of the water for irrigation need supply for specific area is seldom known for a particular year. Likewise; the determination of net consumptive use, records are inadequate for estimating rates for individual years but are believed to be reliable when taken as an average over a period of years. Consumptive use will be greater during dry, hot summers, and a greater part of the water must be supplied by irrigation during these years (Adeba et al,2015). Improving this sector contributes to improve the productivity of agriculture and thus the generation of higher incomes, promotion food self-sufficiency and improving health condition of the people. It also increases and diversifies production of raw materials for industries and promotion of export item. Irrigation is one means for a good farm husbandry, better land utilization and stable and higher crop production.

Sustained growth and dynamism in agriculture is a fundamental necessity to meet the increasing demand for food and other products in view of the growing population. Irrigated agriculture will play a major role in reaching the broader development vision of the country in achieving food security poverty alleviation and improvement in the quality of life. The main objective of irrigated agriculture is to provide plants with sufficient water to prevent stress that may cause reduced yields or poor quality of harvest (Haise and Hagan, 1987; Tayler, 19 65).

Irrigation water management can bring about physical savings of water by improving the efficiency of water use in agriculture (FAO, 2012). Supply management can be another option to address the problem of water scarcity in the basin. Water pollution in the basin is another basic problem which aggravates water shortage. The industries in the major cities of Ethiopia located in the basin are the sources of water pollution. Urbanization, industrial development of agricultural chemicals and fertilizers overcharged the carrying capacity of water bodies and resulted in deterioration of surface water quality and groundwater aquifer in the basin. This issue requires an urgent attention from the government and stakeholders. Water logging and salinization are putting increasing pressure on land and water quality in the basin in irrigated agriculture. Through collection and analysis of reliable and adequate data on water resource status, sound decisions can be made on how best to develop and manage these resources. Proper assessment of the water resources in time and space is important to plan future water use rationally and on a sustainable basis. The assessment of the availability of water in the basin and priority setting of its use is important before planning for the expansion and development of additional sectors which poses pressure on water availability (Adeba, 2015).

1.2 Statement of the problem

Ethiopia is blessed with ample water resources. The country has 12 river basins with an annual runoff volume of 122 billion m³ of water and an estimated 2.6 to 6.5 billion m³ of ground water potential, which makes an average of 1575 m³ of physically available water per person per year, a relatively large volume (Kassa, 2016). However, distribution and availability of water is erratic both in space and time. Hence, despite the abundance, the country is highly water-scarce (Seleshi, 2006). Of the total water resources available to Ethiopia, only 9% remains in the country; the bulk flows downstream to neighboring countries, and is particularly important for Somalia, Kenya, Sudan and Egypt (World Bank, 2006; Seleshi, 2006).

Current water allocation in Ethiopia is targeted at meeting the increasing water demand from economic, and to some extent social sectors, but does not properly consider possible consequences on water availability and potential competition among uses and users (Mersha, *et.al*, 2016). The goal of the Ethiopian water sector strategy is to expand irrigation to the greatest degree possible, as a major way of achieving the ambitious national food security targets; however, there are no clear strategies to maintain sustainable resource availability and ecological integrity (MoWR, 2001). This has led to ambitious

expansion plans by both large commercial and small subsistence farmers in the Awash Basin.

Awash River originates in the Central Highlands and flows down northeast for a length of 1200 km has longer flooding period and larger dry seasons at downstream. However, due to under development of this natural resource most people are influenced by these extreme events.

The rapid population growth in the region creates high stress on water consumption rate and the interest of users to abstract water for different economic sectors; including irrigation making the issue prone to conflicts.

Mojo River is one of the rivers that face competition among users. The competition for water among the major users of the river is increasing due to socio-economic development and population growth in the catchment. Furthermore, the water demand and management system of the catchment is not fully assessed. Due to all the above reasons, the competing users start to face conflicts when allocating the available water. With growing demands on limited water resources, effective allocation and management of stream flow and reservoir storage have become increasingly important. Water resource development is essential to bring about sustainable growth of agriculture, rural development and overall economic progress. Equitable access and sustainable water resources development in a participatory approach of all stakeholders is important to cope with water scarcity. Therefore, the aim of this research was to investigate the availability of surface water with SWAT model and to investigate water supply and demand of Mojo River as well as crop and irrigation water demand with CROPWAT model.

1.3 Objectives of the study

1.3.1 General Objective

The major objective of this study is the investigation of water availability and water demand scenarios of mojo river watershed: in the upper Awash River basin, in Ethiopia with the following specific objectives.

1.3.2 Specific Objectives

- i. To evaluate the performance of SWAT model to simulate stream flow.
- ii. To estimate the irrigation water requirements of major crops.
- iii. To evaluate supply and demand of water to determine critical command area.

1.4 Research Questions

1. What are the parameters to evaluate performance of SWAT model to simulate available mojo streamflow for irrigation?
2. What are the irrigation water requirements for Major crops of Mojo watershed?
3. What are the gaps between supply and demand of mojo watershed water resources and critical command area?

1.5 Significance of the study

This study is used to know the stream flow availability for irrigation and water consumption. It is beneficial for small vegetable farmers and large commercial vegetable farms give information on irrigation water management strategy, crop water requirement of the crop and irrigation requirement method that increase the yield and water use efficiency. It also deals with the accessibility of stream flow for irrigation by using SWAT modeling and to know the demand and supply relationship in the watershed area.

1.6 Scope of the Study

The study focus on identifying and evaluation of stream flow for irrigation using SWAT model, to increase crop production based on water efficiency, crop water requirement and irrigation requirement components under irrigated agriculture. The study doesn't include economic analysis. The study focuses on the evaluation of stream flow for irrigation under passed and current data condition of Mojo River. Observed hydro-meteorological data of the study area were tested the quality and homogeneities of hydro-meteorological data were tested by using statistical tools. Finally, application of cropwat8 for total irrigation water requirement and SWAT model for determination of water availability was conducted.

2. LITRATURE REVIEW

In this section review of SWAT and CROPWAT model, irrigation water requirement, crop water requirement, supply and demand of water as well as critical command area are discussed.

2.1 Global Water Management and Allocation Issues

Integrated Water Resource Management is a way of analyzing the change in demand and operation of water institutions that evaluates a variety of supply side and demand side management measures to determine the optimal way of providing water services. Demand side management includes any measure or initiative that will result in the reduction in the expected water usage or water demand. Supply side management includes any measure or initiative that will increase the capacity of a water resource or water supply system to supply water (Buyelwa, 2004). The growing pressure on the world's fresh water resources is enforced by population growth that leads to conflicts between demands for different purposes. The main concern on water use is the conflict between the environment and other purposes like hydropower, irrigation for agriculture and domestic, and industry water supply, where total flows diverted without releasing water for ecological conservation. Consequently, some of the common problems related to water faced by many countries are shortage, quality deterioration and flood impacts. Hence, utilization of integrated water resources management in a single system, which built up by river basin, is an optimum way to handle the question of water (Tessema, 2011).

2.2 Description of CROPWAT Model

CropWat is a decision support system developed by the Land and Water Development Division of Food and Agriculture Organization (FAO) for planning and management of irrigation (FAO, 1992).CropWat is a practical tool to carry out standard calculations for reference evapotranspiration, crop water requirements, and crop irrigation requirements, and more specifically the design and management of irrigation schemes. For this study, CropWat 8.0 was used. CropWat 8.0 is a computer programme for the calculation of crop water requirements and irrigation requirements from existing or new climatic and crop data. Furthermore, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns. In CropWat8.0, the calculation of crop water requirements is carried out per decade.

2.2.1 Effective Rainfall

For agricultural production, effective rainfall refers to the portion of rainfall that can effectively be used by plants. This shows not all rain is available to the crops as some is lost through runoff and deep percolation. How much water actually infiltrates the soil depends on soil type, slope, crop canopy, storm intensity, and the initial soils water content. During the rainy season in tropical and some sub-tropical regions, a great part of the crop's water needs are covered by rainfall, while during the dry season, the major supply of water should come from irrigation. How much water is coming from rainfall and how much water should be covered by irrigation is unfortunately, difficult to predict as rainfall varies greatly from season to season. In order to estimate the rainfall deficit for irrigation water requirements, a statistical analysis needs to be made from long-term rainfall records (FAO, 1998).

Effective rainfall was calculated according to equation (1 and 2) on monthly basis:

Monthly step:

$$P_{eff} = P_{month} * (125 - 0.2P_{month}) / 125 \text{ for } P_{month} \leq 250 \text{ mm} \dots\dots\dots (2.1)$$

$$P_{eff} = 125 + 0.1P_{month} \text{ for } P_{month} > 250 \text{ mm} \dots\dots\dots (2.2)$$

Where,

P_{eff} is effective rainfall (mm)

P_{month} monthly rainfall amount (mm)

2.2.2. Crop Water Requirements

The amount of water required to compensate the evapotranspiration loss from the cropped field is defined as crop water requirement. Although the values for crop evapotranspiration and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration. The irrigation water requirement represents the difference between the crop water requirement and effective precipitation. The irrigation water requirement also includes additional water for leaching of salts and water to compensate for no uniformity of water application. For the calculations of the Crop Water Requirements (CWR), the crop coefficient approach is used (FAO, 1998).

2.2.3 Crop Coefficient Approach

Crop evapotranspiration can be calculated from climatic data and by integrating directly the crop resistance, albedo and air resistance factors in the FAO Penman-Monteith approach. As there is still a considerable lack of information for different crops, the Penman-Monteith method is used for the estimation of the standard reference crop to determine its evapotranspiration rate, i.e., reference evapotranspiration (E_{To}). Experimentally determined ratios of E_{Tc}/E_{To} , called Crop coefficient (K_c), are used to relate crop evapotranspiration under standard conditions (E_{Tc}) to E_{To} . This is known as the crop coefficient approach.

$$E_{Tc} = K_c * E_{To} \quad \dots 2.3$$

Radiation, air temperature, humidity and wind speed are all incorporated into the E_{To} estimate. Therefore, E_{To} represents an index of climatic demand, while K_c varies predominately with the specific crop characteristics and only to a limited extent with climate and soil evaporation. This enables the transfer of standard values for K_c between locations and between climates. This has been a primary reason for the global acceptance and usefulness of the crop coefficient approach and the K_c factors developed in past studies. The reference E_{To} is defined and calculated using the FAO Penman-Monteith equation (FAO, 1998). The crop coefficient, K_c represents an integration of the effects of four primary characteristics that distinguish the crop from reference grass. These characteristics are crop height, Albedo of the crop soil surface, canopy resistance, and evaporation from soil, especially exposed soil (FAO, 1998).

2.3 Water Demand

The water use types of the basin can be categorized as domestic, livestock, irrigated agriculture, and industrial. Although, its significance have been reduced from time to time since other large hydropower production developed in the country, Koka hydropower system also one of the use category in the basin. The other dams (Kessem and Tendaho) also have micro level potential to generate power. In other perspective since hydropower is a non-consumptive water user, its water needs not counted as user groups. Therefore, the major water users in the basin are 18.6 million human populations, 34.4 million livestock population, 199,234 ha irrigated land and different commercial and industrial activities. They demand annual water 3.411BCM, 0.298BCM, 0.121BCM and 0.283BCM for irrigation, domestic, livestock and industrial uses respectively. If we aggregated the total water use demand in the basin it accounted as 4.114BCM (AwBA, 2016). If we compare

differ water users the irrigation water use accounts 83% of the total water use of the basin. Spatially the water demand system distributed per six planning areas. The irrigation development of Awash Terminal and Awash-Awash take the largest share 23.98% and 23.44% of the irrigation development of the basin and take 1057 MCM and 1260MCM basin water respectively. The middle intensive irrigated areas exist in the Awash-halidibe and Awash-Aditu planning areas with 16.71% and 16.46% irrigated area share with 643.7 MCM and 393.3 MCM annual water demand respectively. Less irrigated planning areas are Eastern Catchment and Awash Upstream of Koka take 10.36% and 9.05% share of irrigated area with 358.8 MCM and 400.7(MCM) annual water demand. Actually, the annual water demand of upstream Koka planning area increase above the its share of irrigation development is accounted with high urban and industrial uses, particularly in Addis Ababa, which currently accounted as 38% of the water demand of the planning area. In general the basin has4113MCM annual water demand, which exceeded the current annual collected capacity by 551MCM (AwBA, 2016). It is compensated with different uncontrolled sources of water in the basin (table 1)

Table 2.1 Water demand per planning Area

Planning Area	Irrigated Area (ha)	Total Population (2016 G.C)	Current Water demand (MCM)
Awash US_Koka	18031.23	6499963	400.7
Awash-Awash	46694.63	2661243	1260.2
Awash_Halidebe	33295.75	1669620	643.7
Awash-Aditu	32785.41	2903242	393.3
Awash_Terminal	47781.00	553921	1057
Eastern Catchment	20645.60	4053029	358.8
Total	199233.62	18341018	4113.7

(Source AWBA, 2016).

As future situation there is a possibility of human and livestock population growth and irrigation expansion based on the Growth and Transformation Plan (GTP). The demand assessment study of the basin confirmed that the irrigation expansion of the basin covers about 338259 ha (MoWE and FAO, 2013) for the next eight year. And the total water requirement of irrigation, human, livestock and industrial development estimated as 6.56 BCM (AWBA, 2016).

2.4 Water Demand Assessment

Water demand forecasting is component based and the demand is broken down into different components and a baseline demand in every component is assessed from a base year to a particular date in the future (Sutherland and Fenn, 2000). Water demand assessment is the amount of water needed to supply population, i.e. the assessment requires data collection on existing water consumption patterns, number and types of facilities and levels of service in use, potential demand for future upgrading, operation and maintenance arrangements (Parry and Morris, 1999; Van Rooijen et al., 2005; Allan et al., 2001). This approach depends on current water consumption, projected population growth, service delivery mode or customer types and demand types. Water demand assessment needs planning the changes with respect to levels and trends in the past and current water consumption.

2.4.1 Irrigation Water Demand

Despite the fact that the physical determination of crop-water requirements (CWR), irrigation schedules and depths, is complicated and time-consuming, they remain vital to irrigation water management and planning (Abdelhadi et al., 1999). The introduction of computer models has made it easier and possible to schedule irrigation and supply the exact amounts of water required by crops at every physiological stage in their growth cycle. CROPWat (Crosby and Crosby 1999, 2010) and more recently Aqua Crop (FAO 2010). The models are based on work done by Doorenbos and Pruitt (1977), Doorenbos and Kassam (1979) and Allen et al., (1998) and they require information on crop environment (climate and soil) and physiological behavior of the crops to estimate reliable CWR (Smajstrla and Zazueta, 1995). Their estimation is based on statistical methods or physical laws that govern water uptake and use. The main advantage of the models is that they produce very accurate estimates once they have been calibrated for a specific area.

The crop water need (ET crop) is the depth or the amount of water needed to meet the water loss through evapotranspiration. It depends on climate (sunshine, temperature, humidity, and wind speed), crop type and the growth stage of the crop. The influence of the climate on crop water needs is given by the reference crop evapo-transpiration, ETO (FAO Water 2012). Due to time constraint to collect all relevant data required to estimate water requirement for irrigation, previous study results were adapted. Yibeltal et al. (2013) made a comprehensive irrigation assessment in the awash basin and found out that the

agricultural water requirement of the basin is estimated at 2.52 BCM for 2012 cropping pattern.

2.4.2 Industrial Water Demand

Adeba, (et.al.2015) Industries that produce metals, paper, pharmaceuticals, chemicals, liquor, textiles and others all use water in their production process. It depends on water for all levels of production. Data on industrial water use are difficult to get because most of them use their own water sources. Water for industry use is not registered by municipality. For Addis Ababa alone, the estimate of these data is obtained from the Addis Ababa water supply and sewerage agency. The estimate of water use for industries in and around Addis Ababa is about 8 % of the total daily domestic water requirement of the city. This is equivalent to approx. 16,800 m³/day and 0.00613 BCM/year for Addis Ababa and its surrounding. For industries outside Addis Ababa but located in the basin, it is assumed that their water requirement is about 0.001 % of the basin yield which is equivalent to 0.00464 BCM. Therefore, the total industrial water requirement in the basin is estimated at 0.01084 BCM.

2.4.3 Commercial and institutional Water Demand

The water demand of towns include the needs of such commercial and institutional consumers as public schools, clinics, hospitals, offices, shops, bars, restaurants, and hotels. This type of water demand is usually linked directly to population size. For small- and medium-sized towns, population of 30,000 to 80,000, it was estimated at 5% of the domestic water demand, and for larger towns, the estimate was 10% (MoWR, 2002). Since the study Town has a small-sized population, commercial and institutional demand was estimated as 5% of the domestic water demand.

2.4.4 Livestock Water Demand

The production of livestock is an integral part of a community because livestock are valued assets. Livestock production places demand on water. It is estimated that livestock industries consume 8% of the global water supply, with most of that water being used for intensive, feed-based production (Schlink *et al.*, 2010). Water intake of a livestock depends upon the size, feed, location; and one tropical livestock unit which weighs 250 Kg (live weigh) requires less than 50litres/ day derived from drinking water and moisture in animal feeds (Pedin *et al.*, 2002). Dairy cows and beef cattle daily water consumption is in the range of 45-55 liters per day per animal (Waterhouse, 1982). In this study livestock water demand was adopted to be 45 liters per livestock per day (Hailu,*et al.*, 2016).

Providing good quality water is essential for healthy livestock husbandry. The daily water requirement of livestock varies significantly among animal species. The animal's size and growth stage will have a strong influence on daily water intake. Consumption rates can also be affected by environmental and management factors. Feed with relatively high moisture content decreases the quantity of drinking water required (Taddese *et al.* 2001).

2.5 Average Daily Demand

The Urban average daily demand is considered to be the combined total of demand from domestic, commercial and institutional, industrial, livestock and system losses per day (MoWR, 2002).

2.6 Management Measure for Irrigation Water

The goal of this management measure is to reduce movement of pollutants from land into ground or surface water from the practice of irrigation. This goal is accomplished through consideration of the following aspects of an irrigation system, which will be discussed in this chapter:

1. Irrigation scheduling
2. Efficient application of irrigation water
3. Efficient transport of irrigation water
4. Use of runoff or tail water
5. Management of drainage water

A well designed and managed irrigation system reduces water loss to evaporation, deep percolation, and runoff and minimizes erosion from applied water. Application of this management measure will reduce the waste of irrigation water, improve water use efficiency, and reduce the total pollutant discharge from an irrigation system. It focuses on components to manage the timing, amount and location of water applied to match crop water needs, and special precautions (i.e., backflow preventers, prevent runoff, and control deep percolation) when chemigation is used.

2.7 SWAT Model

SWAT model is a physically based watershed-scale continuous time-scale model, which operates on a daily time step developed by Dr. Jeff Arnold for the United States Department of Agriculture (USDA) Agricultural Research Service (ARS) (Arnold *et al.*, 1995). The model is comprehensive and was developed to assess the impact of land management practices on water, sediment and agricultural chemical yields in large

complex basins with varying soil types, Land use and management conditions (Arnold et al., 1998).

SWAT is capable of modeling watershed hydrology, irrigation and water transfer, lateral flow, ground water and detailed lake water quality components (Neitsch *et al.*, 2011). SWAT requires specific information like weather data, soil data, topography etc, in the balance equations to simulate stream flow and other hydrological components of the shallow sub-surface and applied in most of the world (Neitsch *et al.*, 2011). It has the advantage of integrating both a crop growth model component into a hydrologic model (Neitsch *et al.*, 2005). Furthermore, extensive crop and soil databases have been developed for the model, which makes it easier to handle.

2.8 Application of SWAT model

The Application areas of SWAT has been growing wider beyond hydrology, such as climate change, sediment and pollutant transport, nutrient loss, pesticides and agricultural management practices over the past decades (Gassman *et al.*, 2007). Numerous studies have been conducted at different scales ranging from small watersheds to the entire globe to assess the assessment of stream flow change in hydrologic system (Jha *et al.*, 2006). However, most studies are carried out in USA, Europe, China, South Asia, Africa and other parts of the world (Neitsch *et al.*, 2011). For instance different researchers inside and abroad of the country apply SWAT hydrological model for hydrological impact studies. The following discussion focused on the wide range of specific SWAT model performance evaluation and application that have been reported in different literature.

Abbaspour et al. (2007) linked SWAT-CUP (SWAT Calibration and Uncertainty Procedures) to the hydrologic simulator SWAT mainly to integrate various calibration/uncertainty analysis procedures for SWAT in one user interface, to make the calibrating easy to use for students and professional users, to make the learning of the programs easier for the beginners, to provide a faster way to do the time consuming calibration operations and standardize calibration steps, and to add extra functionalities to calibration operations such as creating graphs of Calibrated results, data comparison, etc.

Santosh et al. (2010) applied SWAT to the 2,530 km² Chaliyar river basin in Kerala, India to investigate the influence of scale on the model parameters. The model was initially Calibrated for stream flow and then validated. Critical parameters were the curve number,

soil evaporation compensation factor, available water holding capacity, average slope length, and base flow alpha factor. Using the optimized value of various parameters, stream flow was estimated from parts of the basin at two different scales—an area of 2,361.58 km² and an area of 1,013.15 km². Results indicate that the SWAT model could simulate stream flow at both scales reasonably well with very little difference between the observed and computed values.

Misgana and Nicklow (2004) described an automatic approach for calibrating daily stream flow and daily sediment concentration values estimated by SWAT. Their study applies a hierarchy of three techniques, namely screening, parameterization, and parameter sensitivity analysis, at the parameter identification stage of model calibration. The global parameter sensitivity analysis is conducted using a stepwise regression analysis on rank-transformed input–output data pairs. Latin hypercube sampling is used to generate input data from the assigned distributions and ranges, and parameter estimation is performed using genetic algorithm. The Generalized Likelihood Uncertainty Estimation methodology is subsequently implemented to investigate uncertainty of model estimates, accounting for errors due to model structure, input data and model parameters. Finally, to demonstrate their effectiveness, the parameter identification, parameter estimation, model verification, and uncertainty analysis techniques are applied to a watershed located in southern Illinois.

Krause et al. (2005) investigated the utility of several efficiency criteria using a simple observed stream flow hydrograph. Overall, it can be stated that none of the efficiency criteria described and tested performed ideally. Each of the criteria has specific pros and cons which have to be taken into account during model calibration and evaluation. The most frequently used Nash-Sutcliffe efficiency and the coefficient of determination (R^2) are very sensitive to peak flows, at the expense of better performance during low flow conditions. This is also true for the 0 index of agreement because all three measures are based on squared differences between observation and prediction. Additionally, it was shown that R^2 alone should not be used for model quantification, because it can produce high values for very bad model results, because it is based on correlation only. To counteract this gradient ‘b’ should always be discussed together with R^2 . Thus, the form wR^2 was proposed which integrates the gradient ‘b’ in the evaluation. For scientific sound model calibration and validation a combination of different efficiency criteria complemented by the assessment of the absolute or relative volume error is recommended.

Romanowicz et al. (2005) tested the sensitivity of SWAT model to the preprocessing of soil and Land use data for modeling rainfall-runoff processes in the Thyle catchment in Belgium. The results suggest that the SWAT model is extremely sensitive to the quality of the soil and Land use data and the adopted pre-processing procedures of the geographically distributed data. The resolution and fragmentation of the original map objects are significantly affected by the internal aggregation procedures of the SWAT model. The catchment size threshold value (CSTV) is thereby a key parameter controlling the internal aggregation procedure in the model.

Optimal Calibrated modeling results are not obtained when the CSTV is minimized. The hydrological response of the SWAT model to the calculated soil properties is significant. Therefore preference should be given to the calculation of the derived hydrologic soil properties prior to averaging of the profile data.

Harmel et al. (2006) compiled selected published information on uncertainty related to measured stream flow and water quality data for small watersheds, used a root mean square error propagation method to compare the uncertainty introduced by each procedural category, and used the error propagation method to determine the cumulative probable uncertainty in measured stream flow, sediment, and nutrient data. Best case, typical, and worst case “data quality” scenarios were examined. Averaged across all constituents, the calculated cumulative probable uncertainty (\pm %) contributed under typical scenarios ranged from 6% to 19% for stream flow measurement, from 4% to 48% for sample collection, from 2% to 16% for sample preservation/storage, and from 5% to 21% for laboratory analysis. Under typical conditions, errors in storm loads ranged from 8% to 104% for dissolved nutrients, from 8% to 110% for total N and P, and from 7% to 53% for total suspended sediment. Results indicated that uncertainty can increase substantially under poor measurement conditions and limited quality control effort.

Abbaspour (2007) described a procedure for a combined parameter estimation and uncertainty analysis algorithm referred to as SUFI-2 (Sequential uncertainty fitting, ver. 2). SUFI-2 identifies a range for each parameter in such a way that upon propagation: 1) the 95% prediction uncertainty (95PPU) between the 2.5th and 97.5th percentiles contains (brackets) a predefined percentage of the measured data, and 2) the average distance between the 2.5th and 97.5th prediction percentiles is less than the standard deviation of the measured data. If, the above two criteria are reached and a significant R^2 exists between

the best simulation and the measured data for a calibration and validation data set, then the model can be considered Calibrated, and the parameter range is defined as the parameter uncertainty.

Moriasi et al. (2007) recommended three quantitative statistics, Nash-Sutcliffe efficiency (NSE), percent bias (PBIAS), and ratio of the root mean square error to the standard deviation of measured data (RSR), in addition to the graphical techniques, be used in model evaluation. The following model evaluation performance ratings were established for each recommended statistic. In general, model simulation can be judged as satisfactory if $NSE > 0.50$ and $RSR \leq 0.70$, and if $PBIAS \pm 25\%$ for stream flow, $PBIAS \pm 55\%$ for sediment, and $PBIAS \pm 70\%$ for N and P.

Mengistu and Sorteberg (2012) tested the applicability SWAT model over the three major sub basins in Eastern Nile at larger watershed scale. Sensitivity studies to assess the potential impacts of climate change on the annual stream flow are performed using twenty hypothetical climate change scenarios. The result revealed that the annual stream flow sensitivity to changes in precipitation and temperature differed among the basins and the dependence of the response on the strength of the changes was not linear. On average the annual stream flow responses to a change in precipitation with no temperature change were 19%, 17%, and 26% per 10% change in precipitation while the average annual stream flow responses to a change in temperature and no precipitation change were $-4.4\% K^{-1}$, $-6.4\% K^{-1}$, and $-1.3\% K^{-1}$ for Abbay, Baro Akobo and Tekeze river basins, respectively.

Behera and Panda (2006) identified the critical areas of an agricultural watershed and recommend the best management practices using SWAT. Several simulations were performed to determine the best out of the 48 different combinations of treatments for the management of the critical sub-watersheds. The study revealed that no other crop could replace the rice crop during the rainy season and the existing conventional tillage practice needs to be replaced by conservation tillage in order to minimize the sediment yield and nutrient losses. Fertilizer application rate of 80:60 kg ha⁻¹ of N:P is also recommended to minimize the surface water pollution in the watershed due to NO₃-N and P.

Michael et al. (2007) to better understand SWAT's strengths and weaknesses in simulating stream flow conducted a study to evaluate the model's performance under a range of climatic, topographic, soils, and Land use conditions. Hydrologic responses were simulated

on five USDA Agricultural Research Service watersheds. Model simulations were performed on a total of 30 calibration and validation data sets on each of the watersheds. A newly developed auto-calibration tool for the SWAT model was employed to Calibrated eleven parameters that govern surface and subsurface response for the three southern watersheds, and an additional five parameters that govern the accumulation of snow and snowmelt runoff processes for the two northern watersheds. Based on a comparison of measured versus simulated average annual stream flow, SWAT exhibits an element of robustness in estimating hydrologic responses across a range in topographic, soils, and Land use conditions. Differences in model performance, however, are noticeable on a climatic basis in that SWAT will generally perform better on watersheds in more humid climates than in desert or semi-desert climates.

Misgana (2012) demonstrates performance improvement that would be achieved when a season-based model evaluation approach is pursued. A global sensitivity analysis (SA) model has been used to investigate seasonal sensitivity of stream flow parameters of a watershed simulation model on the headwaters of the Little River Watershed, one of the United States Department of Agriculture's experimental watersheds. Two separate analyses have been performed: the conventional approach in which model parameters are assumed to be season insensitive; and a season-based evaluation in which the influential parameters may vary for months with a low runoff coefficient and months with a high runoff coefficient. The sensitivity analysis helped to identify dominant model and watershed behaviors for the conventional annual approach and for the wet and dry seasons. The SA results show that the influential parameters exhibited modest seasonal sensitivity for the experimental watershed. Model calibration was then performed by using the dynamically dimensioned search algorithm for the conventional and seasonbased approaches using the principal parameters identified by the global SA model.

Cotter et al. (2003) evaluated the impact of varying spatial resolutions of DEM, Land use, and soil data (30 x 30 m, 100 x 100 m, 150 x 150 m, 200 x 200 m, 300 x 300 m, 500 x 500 m, and 1,000 x 1,000 m) on the uncertainty of SWAT predicted flow, sediment, NO₃-N, and total-P transport in Moores Creek watershed of Washington County, Arkansas. The SWAT model output was most affected by input DEM data resolution. A coarser DEM data resolution resulted in decreased representation of watershed area and slope and increased slope length. Distribution of pasture, forest, and urban areas within the watershed was significantly affected at coarser resolution of Land use and resulted in significant

uncertainty in predicted sediment, NO₃-N, and total-P output. Soils data resolution had no significant effect on flow and NO₃-N predictions; however, sediment was over predicted by 26 percent, and total-P was under predicted by 26 percent at 1,000 m resolution. Generally, they concluded that for flow, sediment, NO₃-N, and total-P predictions, minimum DEM data resolution should range from 30 to 300 m, whereas minimum Land use and soils data resolution should range from 300 to 500 m.

Gong et al. (2010) studied the Effect of Watershed Subdivision on SWAT Modeling with Consideration of Parameter Uncertainty by delineating the Upper Daning River Watershed into different numbers of sub watersheds under various delineation schemes by changing the threshold drainage area. All schemes were then parameterized and SWAT was run to determine which scheme had the highest modeling efficiency. Results indicate that the simulation under the finest delineation scheme was not the most accurate but moderate level delineation scheme with TDA of 5,000 ha was found to be more accurate.

Gitau and Chaubery (2010) explored the possibility of developing regionalized model parameter sets for used in ungauged watersheds. The study evaluated two regionalization methods: global averaging, and regression-based parameters, on the SWAT model using data from priority watersheds in Arkansas. Resulting parameters were tested and model performance determined on three gauged watersheds. Nash Sutcliffe efficiencies (NS) for stream flow obtained using regression-based parameters (0.53–0.83) compared well with corresponding values obtained through model calibration (0.45–0.90). Model performance obtained using global averaged parameter values was also generally acceptable ($0.4 \leq NS \leq 0.75$). Results from this study indicate that regionalized parameter sets for the SWAT model can be obtained and used for making satisfactory hydrologic response predictions in ungauged watersheds.

3. MATERIALS AND METHODS

3.1 Description of Study Area

This study was conducted at Modjo River, which is located in the upper part of Awash River basin, Ethiopia. Mojo watershed having a total area of 2017.09 km² is situated in central Oromia Regional state, Ethiopia, Fig. 3.1. Geographically it is located between latitudes of 8° 16' N and 9° 18' N and longitude of 37° 57' E and 39° 17' E. The Modjo watershed drains finally into Awash River. The mean annual rainfall of the area ranges from 918.50 to 1226 mm with more than 83 % of annual rainfall falling during June to September. The mean maximum temperature of the watershed is ranging from 21⁰C to 27⁰C the highest being recorded in the month of May and the lowest in July. The mean minimum temperature ranges from 8⁰C to 12⁰ C where the minimum and maximum are occurring in the month of December and April respectively. The altitude of the watershed ranges from 1592.15 msl at the river bed to 3065.49 msl at the upper part of the watershed.

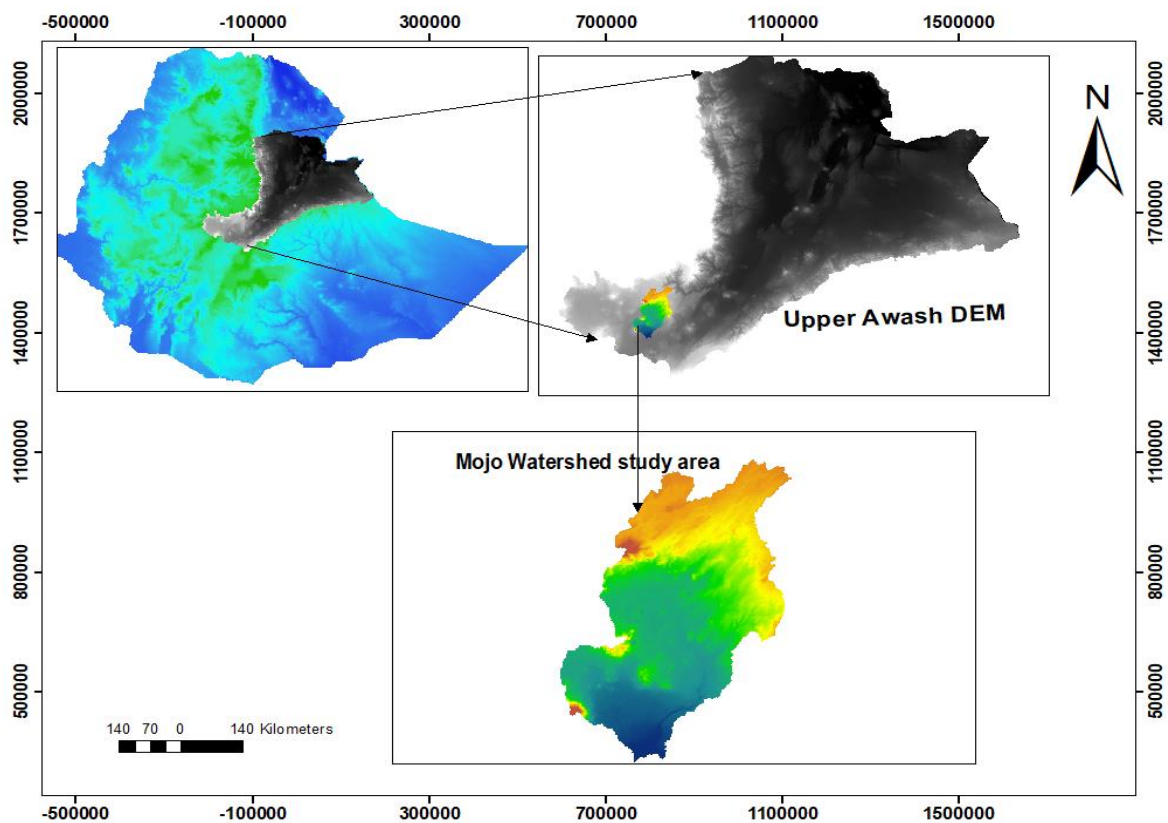


Figure 3.1 Location map of study area.

3.1.1 Rainfall Data

Effective rainfall was calculated based on 31 years monthly rainfall data collected from four stations. The annual rainfall in the catchment or mojo watershed during (1987-2017)

ranges 918 -1226 mm. The average maximum monthly rainfall is 843mm, which occurred in July, and the minimum is zero occurred in December. More than 83% of the annual rainfall occurs during the month June to September with peak in July to August, hence June to September is the moist months for crop production and the rest of the months November to March relatively considered as a dry months. During the month of high rainfall there was also high contribution of lateral flow to the stream flow and in dry month there were high consumption of water demand. However, for the purpose of Cropwat8 modeling only mojo gauge station mean rainfall was used.

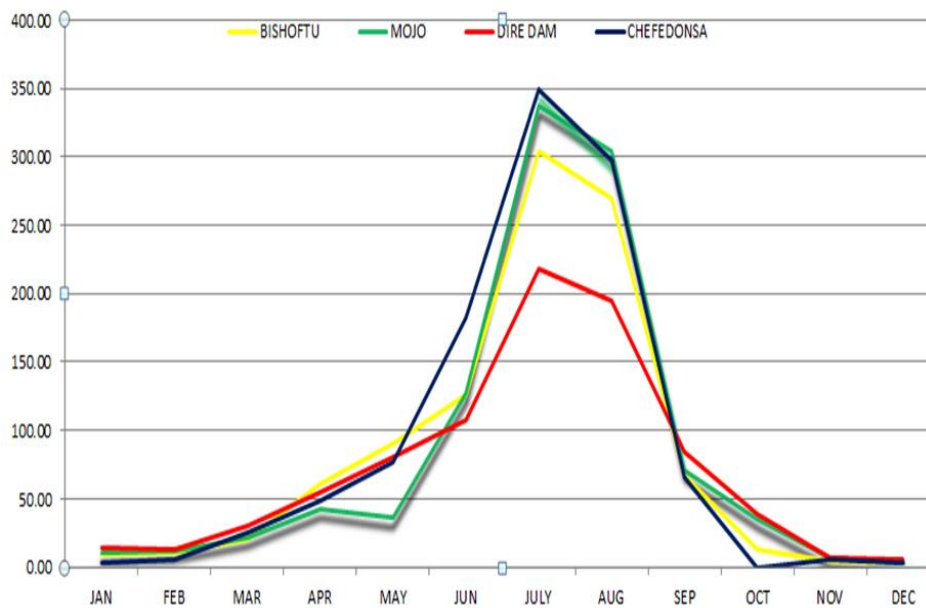


Figure 3.2 Rainfall pattern of Mojo Watershed

3.1.2 Land use Land Cover

The land use is one of the main factors affecting surface runoff and evapotranspiration in the watershed area. The major land use and land cover types of the catchment are irrigated agricultural land, plantation forest, pastureland, degraded (barren) land, settlement (rural and urban), and water bodies. According to SWAT land use and land cover classification, Agriculture (Cultivation) is the dominant land use in the study area (figure 3.3). Around 63.7% of the watershed area is covered by agricultural land (cultivated land).

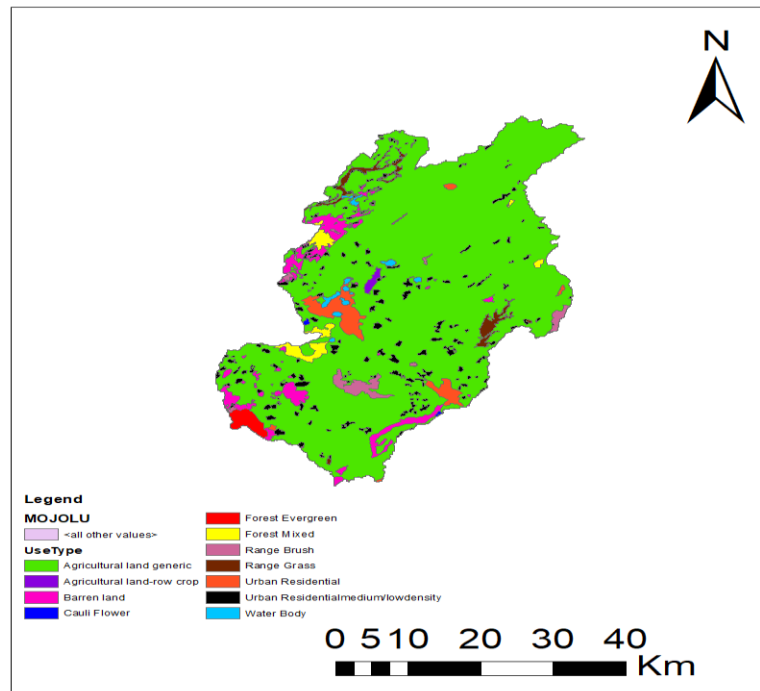


Figure 3.3 Land use Land cover of Mojo watershed

3.1.3 Soil Types

According to the FAO/UNESCO soil classification system, the mojo watershed area comprises five major soil types Such as Pellic Vertisols, Chromic cambisols, Umic Leptsol, Vetric Andsols and Chromic Luvisols (Figure 3.4). However, the dominant are Andisols and Luvisols. Andisols occur on smooth plains and on rolling topography of the plateau (Zelalem, 2016). They are characterized by their high clay content and have in general a good natural fertility. Due to clay mineralogy they are very hard and crack when dries; sticky and plastic when wet. Luvisols generally, occur on steeper hill slopes of the plateau and in the upper parts of the Holetta catchment (Zelalem, 2016). These soils contain more than 35% clay. The high clay content of Andosols result in somewhat better chemical and physical properties than other tropical soils related to the soil depth, stable structure and high water holding capacity permeability (Zelalem, 2016). The andsols are cover around 121261.68ha and 60.11% which was the dominant soil in the area followed by Luvisols which cover 29.73ha.

Table 3.1 Major soil of Mojo watershed and there area distribution.

Nos.	Identified soil types	Major soils	Textures	Area(Ha)	Area (%)
1	Vitric andosols	Andosols	Loam	121261.68	60.11
2	Pellic Vertisols	Vertisols	Clay	2569.53	1.25
3	Chromic Luvisols	Luvisols	Clay loam	59966.77	29.73
4	Umric Leptosols	Leptosols	Loam	2612.73	1.30
5	Chromic Cambisols	Cambisols	Sand Clay Loam	15301.69	7.57

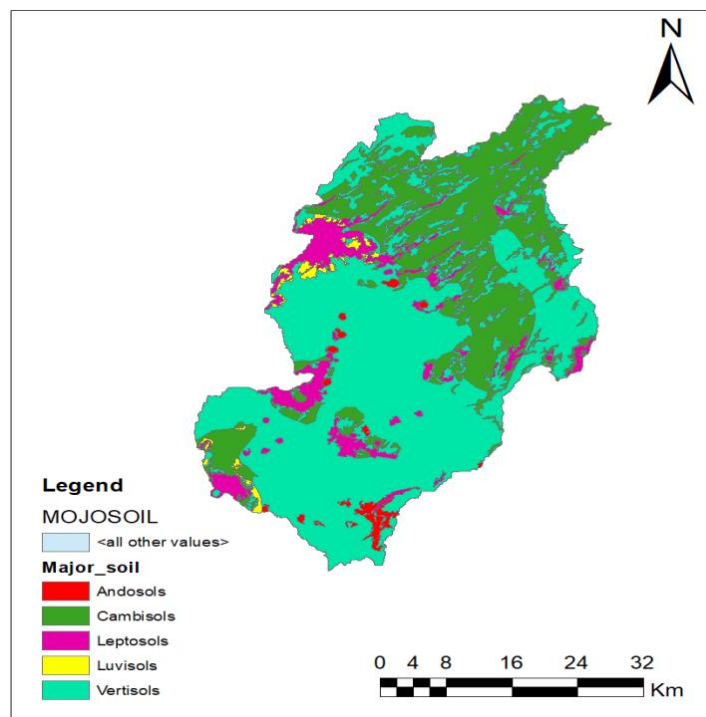


Figure 3.4 Major soil classes of Mojo Watershed.

3.1.4 Slope of watershed area

Majority of the watershed area was under flat and gentle slope; about 58.22% of area is within 0-10 % of slope class range followed by 10-15% which was about 38.5%.

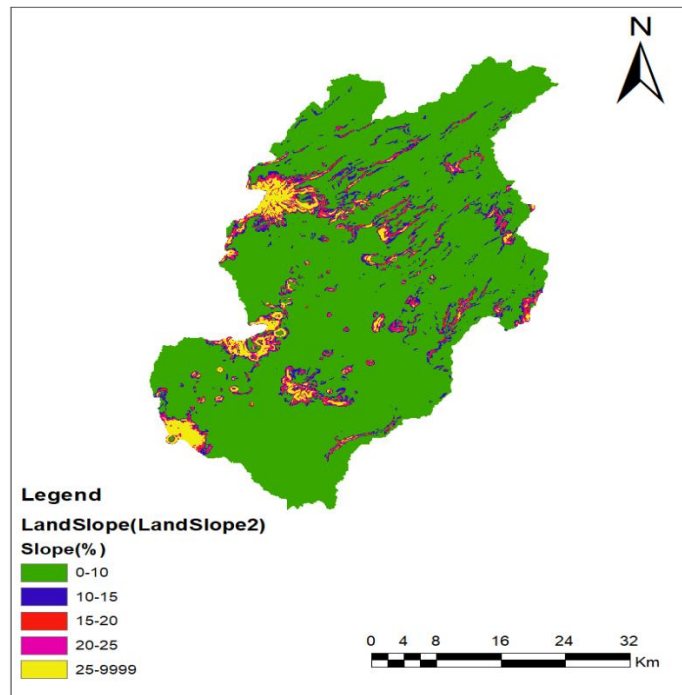


Figure 3.5 Slope classifications of Mojo watershed classes.

3.2 Data Collection

3.2.1 Secondary data

All daily observed meteorological dataset such as rainfall, maximum and minimum temperature, relative humidity, wind speed, and sunshine hour of four representative stations within and around watersheds (Mojo, Bishoftu, Diredam and Chefedonsa) for a period of 31 years (1987-2017) were collected from National Meteorology Agency (NMA). For Hydrological modelling of Mojo watershed, stream flow datasets of Mojo River station recorded from (1987-2016), Spatial data (topographic, land use/cover data and map, soil map) and digital elevation model (DEM) data with a resolution of 30x30 was collected from Ethiopian Ministry of water, Irrigation and Energy (MOWIE). All water consumption like, the numbers of population (householder) requires water for domestic and irrigation, Livestock population, Major crops and areas were obtained from East Showa Agricultural Offices and the four woreda covered by watershed (Liban Cukala, Ada'a, Gimbichu and Lume).

3.2.2 Estimating the missing data

While working with hydrological model, it is common to encounter missing weather data values from observed records for so many reasons. It is very essential to fill in the missing data when a hydrological basin analysis needs a continuous data. Also in availability of stream flow studies it is common to check the gaps in the time series of precipitation and

temperature before filling the missing data. Simple mathematical equation was applied to quantify the total percentage of the missing value from the total data series as follows.

$$\% \text{ of missed data } a = \left[\frac{X_1}{X_2} \right] * 100 \quad \dots (3.1)$$

Where, X_1 is count of missed data; X_2 is whole data set

The filling of missing data is very essential to perform metrological data analysis and stream flow simulation using data of long time series. In this study two methods were applied to fill the missing values; Arithmetic mean method (for the normal annual precipitations at surrounding gauges are within the range of 10% of the normal annual precipitation of station with missed data)

$$P_X = \frac{1}{n} (P_1 + P_2 + \dots + P_n) \quad \dots (3.2)$$

Where, $P_1, P_2 \dots P_n$ are the precipitation of index stations

P_X is that of the missing station and n , is the number of index stations.

And the normal ratio (for the surrounding gauges have the normal annual precipitation exceeding 10% of the gauge with missed data) for rainfall.

$$P_X = \frac{N_X}{n} \left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + \dots + \frac{P_n}{N_n} \right] \quad \dots (3.3)$$

Where, $P_1, P_2 \dots P_n$ are the rainfall data of index stations, $N_1, N_2, \dots N_n$ the normal annual rainfall of index stations and P_X, N_X the values for the missing station "X" in question and n , is the number of stations surrounding station "X".

3.2.3 Data Consistency test

Double mass curve method was used to check the consistency of the data (Fig.3.5) by comparing data of a single station with that of a pattern composed of the data from other station. The data of the annual rainfall of the doubtful station and the average rainfall of the group of base stations covering a long period was arranged in the reverse chronological order. The cumulative values of the doubtful stations were plotted against the cumulative average groups. From Fig.3.5 the annual cumulative rainfall (mm) for each stations were put in "y- axis and the average annual cumulative (mm) in "x-axis.

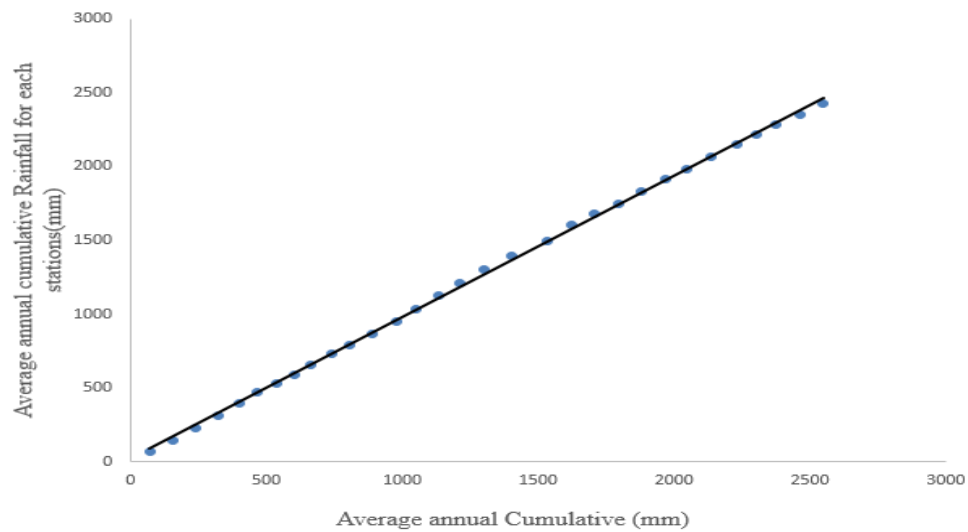


Figure 3.6 Double mass curves for four representative meteorological station of Mojo

3.3 Assessment of Water Resources Availability

The assessing surface water availability was estimated using soil and water assessment tool (SWAT) model. SWAT is a physically based watershed scale continuous time-scale model, which operate on a daily time step developed by Jeff Arnold for the United states Department of Agriculture (USDA) Agricultural Research Service (ARS) (Arnold *et al.*1995). The model is compressive and was developed to assess the impact of land management practices on water, sediment and agricultural chemical yields in large complex basin varying soil types, land use and management conditions (Arnod *et al*, .1998).

3.3.1 SWAT Model Input

The SWAT model works with spatial and temporal data. Spatial data include elevation, soil type, slope and land use/cover. To delineate the watershed Digital Elevation Model (DEM) grid, digitized stream network files were loaded using the watershed delineation tool. Land use and land cover was also one of the most important spatial input data in SWAT Model. The land use/cover data was reclassified according to requirement of the SWAT model. Soil data are another spatial input required by SWAT model. SWAT model requires different soil textural and physicochemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type. Basic physical and chemical property of major soil types in watershed were collected from the Ministry of Water and Electricity (MOWIE).

The temporal input data for the model are meteorological datasets and stream flow data. For this study, the meteorological data element such as daily precipitation, minimum and maximum air temperature, Relative humidity, wind speed and sunshine hours for thirty one years (1987-2017) of four representatives' weather station were obtained from national meteorological agency. Station those have missing meteorological data values were filled using weather generator model (WXGEN). Other parameters required in User weather generator were calculated using pcpSTAT.exe and dew02.exe computer program. PcpSTAT.exe is a computer program used to calculate statistical parameters of daily parameters of daily precipitation data used by weather generator of the SWAT model and the other weather parameters such as average daily dew-point temperature and humidity was calculated using dew02.exe computer program.

Stream flows are another temporal input data required by SWAT model for calibration and validation. For calibration purpose, Arc SWAT requires stream flow data as an input. Stream flow data of the Mojo sub-basin is collected from Ministry of Water, Irrigation and Electricity and is used for calibration and validation of the model. The daily discharge of hydrological gaging station of the Mojo sub-basin for about 30 years continues data (1987-2016) where used for performing sensitivity analysis, calibration (1987-2001) and validation (2002-2016) of the model.

3.4 SWAT Model Setup

3.4.1 Watershed Delineation

The first step in creating SWAT model input was delineation of watershed from a DEM. Inputs entered into the SWAT model were organized to have spatial characteristics. The SWAT model provides three spatial levels: the watershed, the sub basins, and the hydrologic response units (HRUs). Each level characterized by a parameter set and input data. The largest spatial level, the watershed, refers to the entire area being represented by the model. The watershed and sub watershed delineation was done using DEM data. The watershed delineation process includes five major steps, stream definition, outlet and inlet definition, Watershed outlet selection and definition and calculation of sub basin parameters. For the stream definition the threshold based stream definition option was define the minimum size of the sub basin. The Arc SWAT interface allows the user to fix the number of sub basin by deciding the initial threshold area which was used to obtain detail watershed sub-basin. The SWAT model development for particular area was

defining watershed boundary. These boundaries normally fall along the ridges in a watershed. Cotter et al. (2003) and Santosh et al. (2010) indicated that GIS data resolution has significant impact on model output uncertainty. So, in order to minimize model uncertainty associated with input data Mojo watersheds covering a total drainage area of 2017.09 km² is delineated and subdivided into 25 sub-basins based on the minimum threshold area of 5000 ha (Gong et al. 2010). Because, the SWAT model with greater resolution of soil property and a greater number of HRUs produce the best calibration statistics (Sheshukov et al., 2011). Moreover, Veith et al. (2010) suggest that the HRU threshold value has to be based on a Land use and soil type covering an area of at least 10% and 15%, respectively, within any given sub basin. Accordingly, multiple HRUs were defined based on the minimum threshold level that accounts for 10 % Land use, 15 % soil and 10 % slope threshold combination to have a better estimation of stream flow of Mojo watershed. As Fig. 3.6 shows delineated Mojo Watershed and sub-basin from awash basin with the geographic location of the meteorology and river gauging station.

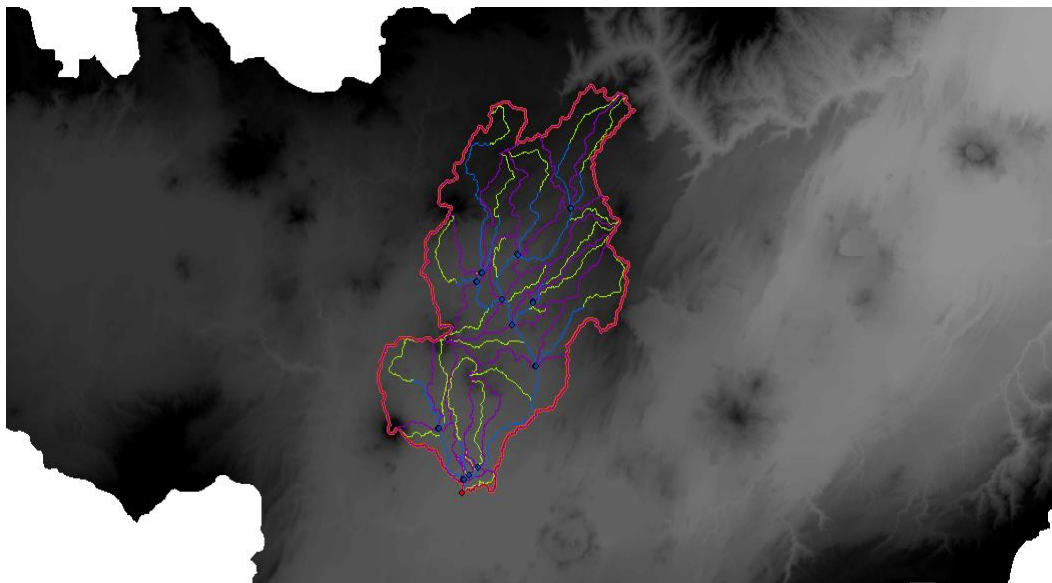


Figure 3.8 Delineated Mojo Watershed from Awash Basin DEM.

3.4.2 Hydrological Response Unit

After watershed delineation, sub-basin was subdivided into areas having unique land use, soil and slope so called hydrologic response units (HRUs). The HRU Analysis tool in Arc SWAT helped to load land use, soil layers and slope map to the project. HRU analysis in SWAT includes divisions of HRUs by slope classes in addition to land use and soils by considering multiple slope option. The spatial inputs like LULC, soil and slope map was reclassified in order to correspond with the parameters in the SWAT database. After

reclassifying the land use, soil and slope in SWAT database, all these physical properties were made to be overlaid for HRU definition. Different researchers set default threshold level in SWAT for land cover, soil and topography depend on project goal and detail required by the modeler (Winchell *et al.*, 2010). Zelalem (2016) recommend the default threshold level as 5%, 20% and 10% for land, soil and slope respectively. For this study, the threshold levels were set to 10% for land use, 15% for soil and 10% for slope. The land use threshold level is used to eliminate minor land uses in each sub-basin and covered land use area below the threshold is eliminated. The remaining area after elimination process is reapportioned so that 99.9% of the land area in the sub-basin is modeled. The same is true for soil classes and slope ranges distribution in all sub-basins.

3.4.3 Sensitivity analysis

The determination of the most sensitive parameters was the key and first step, for model calibration and validation at the watershed scale. Sensitivity analysis was the process of identifying the model parameters that exert the highest influence on model calibration or on model predictions. Sensitivity analysis was done using SWAT CUP which is a computer program for calibration of SWAT models using a SUFI2 global sensitivity method, for the whole catchment area as applied by Zelalem (2016). Generally, twenty three hydrological parameters related to stream flow (appendix 21) were considered for sensitivity analysis. These parameters were selected from previous studies done in Mojo watershed (Zelalem, 2016, Daba, 2014). Sensitive parameters were selected based on the calculated value of t-stat and P-value in SWAT_CUP software. In this analysis, the larger in absolute value of t-stat and the smaller the p-value, considered and most sensitive the parameter. Accordingly, the sensitivity analysis was made for selected parameters (Table 3.1) to rank their potential influence based on t-stat and P-value. The analysis was made with observed flow data measured at Mojo station found near the outlet of the sub-basin delineated.

In the process of parameter identification an important consideration for applying parameter identifiers is that the changes made to the parameters should have physical meanings and should reflect physical factors such as soil, Land use, elevation, etc. (Abbaspour *et al.*, 2012). Therefore the following notation where used; X_Code to indicate the type of change to be applied to the parameter, V_ means the existing parameter value is to be replaced by the given value, a_ means the given value is added to the existing parameter value, and r_ means the existing parameter value is multiplied by (1+a given

value). The presented encoding scheme allows us to make distributed parameters dependent on important influential factors depending on the nature of the parameter.

3.5 Calibration and Validation of SWAT Model

Model calibration and validation are necessary and critical steps in any model application. For most watershed models, while calibration is an iterative procedure of parameter evaluation and refinement and validation assures that the calibrated model properly assesses all the variables and conditions which can affect model results (Donigian *et al.*, 2002).

Automatic calibration and uncertainty analysis incorporated in SWAT 12 via the SWAT-CUP (SWAT Calibration and Uncertainty Procedures) software developed and tested by Abbaspour (2012) with the semi-automated program SUFI2 (Sequential Uncertainty Fitting ver. 2) was used for this study. SUFI-2 is widely used (example Zelalem 2016; Abbas pour *et al.* 2007; Gong *et al.* 2011) mainly due to the relatively fewer required number of runs to reach an acceptable calibration results (Teshager *et al.*, 2015). Additionally, Yang *et al.*, (2008) concluded that SUFI-2 requires 2–30 times fewer runs than the other programs of the SWAT-CUP. Therefore, based on these two reasons SUFI-2 was selected for calibration and validation of the SWAT models.

The relevant model parameter selected based on their sensitivity, t-stat and p-value, were Calibrated on monthly bases for stream flow using SWAT-CUP, SUFI2 interface by changing the parameter value within the range until the predicted value was reasonably in line with that of observed value and its accuracy was evaluated with Nash-Sutcliffe coefficient (NSE) and Coefficient of determination (R^2).

The stream flow data of the period (1987-2016) having continuous data was used for calibration and validation of the model. The data of (1987-2001) for calibration and (2002-2016) year data were used for validation. So, based on sensitivity analysis ranks the top thirteen relevant model parameters selected were used as starting points for model calibration on monthly bases for the stream flow. Then, calibration of the model was done by changing the parameter value within the range until the simulated value is reasonably fit with that of observed value. After the model is calibrated, the accuracy of the model was evaluated during the validation process with the help of the data (2002-2016), which are not used during the calibration process without any adjustment to the calibrated value.

3.6 Model performance evaluation

The accuracy of SWAT simulation results was determined by examination of the coefficient of determination (R^2), the Nash and Sutcliffe (1970) model efficiency coefficient (NSE), the root mean square error (RMSE), percentage bias (PBAIS) and observation standard deviation ratio (RSR).

3.6.1 Coefficient of determination

The R^2 value is an indicator of the strength of the linear relationship between the observed and simulated values, while the (NSE) simulation coefficient indicates how well the plot of observed versus simulated values fits the 1:1 line. It measures how well the simulated versus observed regression line approaches an ideal match and ranges from 0 to 1, with a value of 0 indicating no correlation and the closer the value to unity representing higher agreement between measured and simulated stream (Alemayehu *et al.*, 2013). The R^2 statistic is calculated as:

$$R^2 = \left[\frac{\sum_{i=1}^n (O_i - O_{avr})(P_i - P_{avr})}{\sum_{i=1}^n (O_i - O_{avr})^2 \sum_{i=1}^n (P_i - P_{avr})^2} \right]^2 \quad \dots (3.2)$$

Where R^2 = Coefficient of determination, n is the total number of observation O_{avr} , P_{avr} , are mean observed and predicted value respectively, O_i = Observed (measured) value and P_i = Modelled (predicted) value.

3.6.2 Nash-Sutcliffe efficiency (NSE)

The Nash-Sutcliffe efficiency (NSE) indicates how well the plot of observed versus simulated data fits the 1:1 line. It generally ranges from $-\infty$ to 1. Higher value of NSE indicates better accuracy of model prediction whereas lower NSE indicates poor model prediction. If the NSE is between 0 and 1, it indicates deviations between measured and simulated values. If ENS is negative, predictions are very poor, and the average value of output is a better estimate than the model prediction (Nash and Sutcliffe, 1970). In general, model simulation can be judged as satisfactory if $NSE > 0.50$, Moriasi *et al.* (2007). NSE is computed as shown below:

$$E_{NS} = \frac{\left[\sum_{i=1}^n (Q_{sim} - Q_{obs}) \right]^2}{\left[\sum_{i=1}^n (Q_{obs} - Q_{obs,m}) \right]^2} \quad \dots (3.3)$$

Where: Q_{obs} is observed flow (m^3/s), Q_{sim} is the simulated flow (m^3/s), $Q_{obs, m}$ is the observed measured flow (m^3/s) and $Q_{sim, m}$ is average simulated flow (m^3/s).

3.6.3 Percent bias (PBIAS)

Percent bias measures the average tendency of the simulated data to be larger or smaller than their observed counterparts. The optimal value of PBIAS is 0.0, with low magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias (Gupta et al., 1999) as cited in Moriasi et al., (2007). PBIAS is computed as shown below.

$$PBIAS = \frac{\sum_{i=1}^n (O_i - S_i)}{\sum_{i=1}^n (O_i)} * 100 \quad \dots\dots (3.4)$$

Where, PBIAS is the deviation of data being evaluated, expressed as a percentage. If $PBIAS \pm 25\%$ for stream flow and $PBIAS \pm 55\%$ for sediment, the model simulation can be judged as satisfactory.

3.6.4 Root mean square error observation standard deviation ratio (RSR)

RSR incorporates the benefits of error index statistics and includes a scaling/normalization factor, so that the resulting statistic and reported values can apply to various constituents. RSR varies from the optimal value of “0”, which indicate zero root mean square error (RMSE) or residual variation and therefore Perfect model simulation, to a large positive value. Generally, if the value of $RSR \leq 0.70$ the model simulation can be considered as satisfactory (Moriasi et al. 2007).

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\sqrt{\sum_{i=1}^N (O_i - S_i)^2}}{\sqrt{\sum_{i=1}^n (O_i - S_{avr})^2}} \quad \dots\dots (3.5)$$

Table 3.2 Classification of statistical indices (Moriasi et al., 2007).

Performance Rating	RSR	NSE	R ²	P _{BIAS}
V.good	0.00≤RSR≤0.50	0.75≤NSE≤1.00	0.75<R ² ≤1.00	P _{BIAS} ≤ ±10
Good	0.50≤RSR≤0.60	0.65<NSE≤0.75	0.6 <R ² ≤0.75	±10≤P _{BIAS} ≤±15
Satisfactory	0.60≤RSR≤0.70	0.50<NSE≤0.65	0.5<R ² ≤0.6	±≤P _{BIAS} ≤±25
Unsatisfactory	RSR>0.7	NSE≤0.50	R ² ≤0.25	P _{BIAS} ≥ ±25

3.6.5 P-Factor and r-Factor

The above statistical indices only apply to the comparison of two signals and are not adequate when outputs are expressed as uncertainty bands. In this case, as the simulation results are usually expressed by the 95% prediction uncertainties (95PPU), they cannot be compared with the observation signals using the traditional R^2 and NSE statistics. For this reason, Abbaspour et al. (2004, 2007) suggest using two measures, referred to as the p-factor and the r-factor. The p-factor is the percentage of the measured data bracketed by the 95PPU. This index provides a measure of the model's ability to capture uncertainties. As all the "true" processes are reflected in the measurements, the degree to which the 95PPU does not bracket the measured data indicates the prediction error. Ideally, the p-factor should have a value of 1, indicating 100% bracketing of the measured data, hence capturing or accounting for all the correct processes. The r-factor, on the other hand, is a measure of the quality of the calibration and indicates the thickness of the 95PPU. Its value should ideally be near zero, hence coinciding with the measured data. The combination of p-factor and r-factor together indicate the strength of the model calibration and uncertainty assessment, as these are intimately linked.

The detail explanations of SWAT model was described as follow.

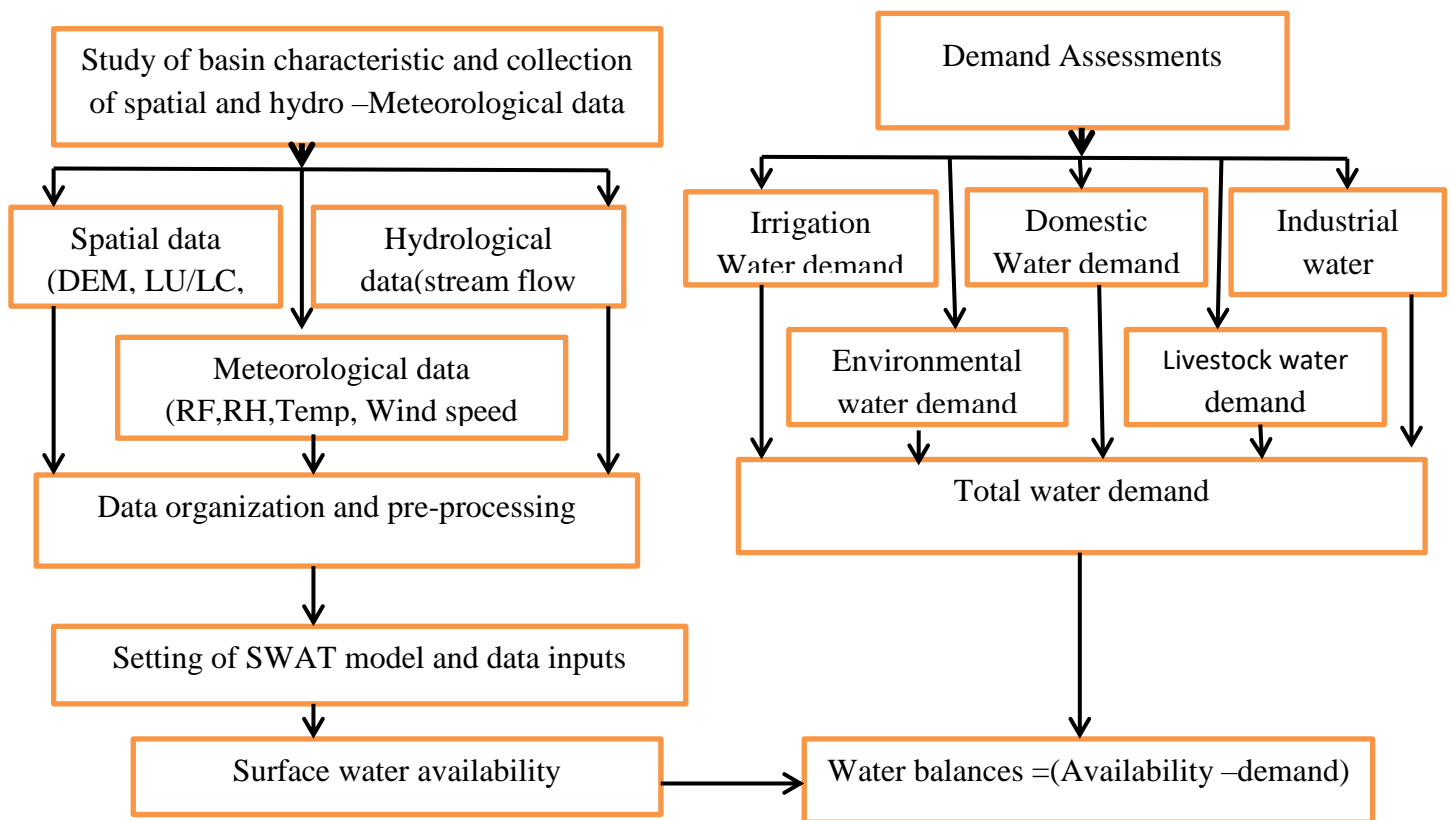


Figure 3.7 Conceptual frame work of Arc SWAT for stream flow simulation yield.

3.7 Model Inputs for CWR and IWR

3.7.1 CropWat8 Model input

To calculate the crop water requirements and irrigation water requirements were carried out with inputs of climatic, major crops and soil data. The model required the following data for estimating crop water requirements (CWR).

3.7.2 Climatic Data

In order to calculate the reference evapotranspiration, CropWat8 model was used monthly maximum and minimum temperature, relative humidity, sunshine hour, and wind speed data that was collected from Mojo station and National meteorological agency. Appendix (A1) below shows all climatic data required for CropWat8 modelling.

3.7.2 Cropping Pattern Data

A Cropping pattern data includes (i) Crop type and crop variety, (ii) Planting date, (iii) Crop coefficient (Kc), (iv) Field irrigation methods, (v) Rooting depth, (vi) Allowable depletion levels, (vii) Critical depletion fraction (p), (viii) Length of individual growth stages (initial, development, mid and late stages), Major crops and the area planted (0-100% of the total area) were obtained from east Shewa agricultural offices, all Woreda Agricultural office, kebele Administration and FAO Irrigation and Drainage paper 33 (FAO, 1986).

3.7.3 Soil Data

The soil data needed for Cropwat8 modelling in study area includes total available soil moisture, maximum rooting depth, initial soil moisture depletion (percentage of total available moisture), and maximum infiltration rate. The above data of soil collected or obtained by SWAT clipping from soil map were also represent the watershed area used for the CropWat8 modeling. So, the textural class of dominant Major Andosols was Loam soil and that of Luvisols was clay loam. However, in this study the soil for CropWat8 was obtained from Mojo and east shewa agricultural offices and FAO Irrigation and Drainage paper 56 (FAO, 1986).

Soil name		Sandy loam
General soil data		
Total available soil moisture (FC - WP)	52.0	mm/meter
Maximum rain infiltration rate	32	mm/day
Maximum rooting depth	45	centimeters
Initial soil moisture depletion (as % TAM)	68	%
Initial available soil moisture	16.6	mm/meter

Figure 3.8 Soil data for CROPWAT8 Model of Mojo Watershed

3.7.4 Crop Data

Crop water requirement and irrigation water requirements were calculated only for the major crops in the study area. The major crops considered were Tomato, Cabbage, Maize, Onion and Pepper. The development stages, Kc factor and root depth of each crop was taken from FAO Irrigation and Drainage paper 24 (FAO, 1992) and FAO Irrigation and Drainage paper 33 (FAO, 1986). The appendix (A-3-A13) showed the summary of growing period, soil water depletion level, Kc value, and root depth for major crops grown in the area. The soil data required by the CropWat model includes, total available soil moisture, maximum rain infiltration rate, maximum root depth, initial soil moisture depletion and initial available soil moisture. The soil data used in the model was the same for all crops except the maximum root depth.

3.7.5 Crop Water Requirement and Irrigation Water Requirements

In order to estimate the water demand for agricultural use/ irrigation for each crop, Evapo-transpiration, effective rainfall, data of crop type, area coverage and soil data were fitted in CropWat8 model. The water demand of irrigation is assumed to occur during the growing season. All calculation procedures as used in CropWat 8.0 are based on the FAO Irrigation and Drainage paper 56 (FAO, 1998). The crop water requirement and Irrigation water requirement of the major crops grown in the watershed area were determined in this study by using CROPWAT 8 model. Where ETo is determined by using Penman-Monteith method calculated from climatic data and effective rainfall is calculated by using USDA soil conservation service method equation (2.2).

Crop evapotranspiration (ET_c) is the evapotranspiration from disease-free, well fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions (Allen et al., 1998). Crop water requirement may simply be defined as the amount of water required by a crop for its development and maturity. Although crop evapotranspiration can be calculated from climatic data and by integrating directly the crop resistance, albedo and air resistance factors, better the Penman-Monteith method is used for the estimation of the standard reference ET_{crop} and used to determine crop evapotranspiration.

$$ET_c = K_c ET_o \quad \dots (3.6)$$

Where K_c is crop coefficient and ET_o is reference evapotranspiration (mm or mm/day). Reference evapotranspiration (ET_o) is the rate of evapotranspiration from a reference crop (green grass) with a height of 8-15 cm, actively growing, completely shading the ground, and no short of water (Allen et al., 1998). The FAO Penman-Monteith method was selected for this study as the method by which the ET_o can be unambiguously determined, and the method which provides consistent ET_o values in all regions and climates. The modified Penman-Monteith equation reads as:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad \dots (3.7)$$

Where:

ET_o = Reference evapotranspiration [mm/day]

R_n = net radiation at the crop surface [MJ/m²day]

G = Soil heat flux density [MJ/m²day]

T = Mean daily air temperature at 2m height [°C]

γ = Psychrometric constant [kpa/°C]

U₂ = Wind speed at 2m height [m/s]

e_s = Saturation vapour pressure [kpa]

e_a = actual vapour pressure [kpa]

e_s – e_a Saturation vapour pressure deficit [kpa]

Δ = Slope vapour pressure curve [kpa/°C]

FAO CROPWAT model, which were used for determination of crop water requirements, irrigation scheduling and irrigation water requirement of the irrigated crops at field levels and the irrigation project as a whole and uses the Modified Penman-Monteith equation. ET_o is only dependent on climatic parameters. Meteorological data required for calculation

of ETo include solar radiation, temperature, relative humidity and wind speed. The irrigation requirements of major crop of irrigation schemes were calculated by using the climatic data, cropping pattern, planting dates, and area of each crops. The net crop water requirement and net irrigation water requirement of the watershed seasons in the year of study (2011E.C) were calculated by using equation (3.8).

$$CWR_{crop-1} \times \left(\frac{Area_{crop-1}}{Total_{area}} \right) + CWR_{crop-2} \times \left(\frac{Area_{crop-2}}{Total_{area}} \right) + \dots + CWR_{crop-n} \times \left(\frac{Area_{crop-n}}{Total_{area}} \right) \quad (3.8)$$

Where: CWR_{CROP-1} is crop water requirement of crop one, $Area_{crop-1}$ is area of crop one cover, $Total_{area}$ is a total area of cultivated $\dots + CWR_{crop-n}$, $Area_{crop-n}$ and $Total_{area}$ are numbers of crop water requirement of each crops.

3.8 Compares the Water Supply and Demand of Watershed Area

The main water supply of Mojo watershed was obtained from the addition of sub basin in the area during the period of simulation. The water availability was computed for both average monthly and average annually. It would be the yield from contribution of surface runoff during high rainfall, lateral flow and ground water contribution to the base flow. There are also minor contributions of base flow like: shallow aquifer recharges and deep aquifer recharges flow in water yield. In other way the total volumes of water in the basin can be calculated as follow. Total water yield (volume) = surface runoff + lateral flow + ground water contribution to base flow – transmission loss during simulation period multiply with total area of basin.

$$W_{YLD} = SURQ + GWQ + LATQ - T_{LOSS} \quad \dots (3.8)$$

Where: $Wyld$, was total amount of water having HRU and linking mean channel (mm), $SURQ$, GWQ , $LATQ$ and T_{Loss} were surface runoff, lateral flow, ground water contribution to base flow and transmission loss in (mm) respectively.

The total water yield (m^3) in the basin could be obtained by total water yield in depth (mm) with multiply area of the basin.

$$Volume(m^3) = Twyld(mm) * basin\ area(m^2) \quad \dots (3.9)$$

3.8.1 Water Demand Estimation

Once, the water availability over the study area was analyzed using SWAT model, the estimation of water distribution for domestic, crops and livestock sectors including environmental water requirement is necessary to know the volume of water to be

abstracted for irrigation. The domestic water demand was calculated based on sub-basin population and the minimum standard required per person per day. Also, livestock water demand was estimated based on sub-basin livestock population and their daily consumption rate. For this study per capita water supply 100 l/c/day (36.5m³/c/year) is used(Adeba et al. 2015).

For the purpose of estimating the total water requirement of Mojo watershed area, the demand of water must be calculated. The demand is calculated on an average basis expressed in liters per capita per day (lpcd).It generally was estimated by dividing the annual-average daily water consumption by the total population served.

$$\text{Average percapita demand} = \frac{Q}{P * 365} \quad \dots (3.10)$$

Where; Q: total annual volume of water in liters and; P: population of the River basin.

IWR & CWR of water demand was computed using CROPWAT 8 modeling while the domestic water requirement were estimated based on total human and livestock population of the watershed. The water demand for domestic and livestock was estimated by multiplying the number of users by standard consumption. It is given according to the following equation (Mahtsente and Birhanu, 2015).

$$CR = \frac{N * q * t}{1000} \quad \dots (3.11)$$

Where: CR is human and livestock consumptive requirement (m³)

N is the user size or population in number

q Is consumptive rate (lit/day) and ; t is the number of days.

Environmental water requirement is Key in order to protect natural reserves and preserve the ecosystems. The total environmental water requirement consists of ecologically relevant low-flow and high-flow components. It has been 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 a fair condition (Smakhtin *et al.* 2004 as cited by Dereje *et al.*, 2015). For this study 35% of mean annual river flow was considered.

3.8.2 Industrial water demand

Industries that produce metals, paper, pharmaceuticals, chemicals, liquor, textiles and others all used water in their production process. It depends on water for all levels of production. Data on industrial water used were difficult to get because most of their own

water sources. Water for industrial used was not registered by municipality. The industries outside Addis Ababa but located in the awash basin, it is assumed that their water requirement was about 0.001% of the yield which is equivalent of the basin (Adeba, *et. al.*2015). The Mojo River is one of sub-basin of Awash river and outside the main city therefore the assumption could be applicable.

3.9 Critical Command Area

The command area (CA) of water source is the extent of area which can be reliably irrigated from that source. If the command area of a water source is larger than the actual area to be irrigated there should be no problem of water shortage. The formula used to calculate the critical command area is scheme water supply (SWS) divided by gross irrigation need (IN_{gross}) or

$$CA = \frac{SWS}{IN_{gross}} \quad \dots (3.12)$$

Where: CA = command area in ha

SWS = scheme water supply in l/sec and

IN gross= gross irrigation need in lit/sec/ha

4. RESULTS AND DISCUSSIONS

4.1 Performance evaluation of hydrological model

4.1.1 Sensitivity Parameters

Sensitivity analysis was done using SWAT-CUP, global sensitivity analysis, as suggested by Misgana (2012) and Zhang et al. (2012) to consider seasonal sensitivity of stream flow parameters for a catchment area. Generally twenty three hydrological parameters related to stream flow yield simulation were considered for sensitivity analysis as shown in appendix 21. The range of variations for these parameters is based on a listing provided in the SWAT –CUP manual (Neitsch et al., 2011) and the previous studies. The number of sensitive parameters to be considered ranged between 2 and 19 and depended on the complexity of the hydrological features in the catchments and modeling efforts (Ndomba and Birhanu, 2008). Accordingly, among the selected parameter for sensitivity analysis, the top thirteen ranking parameters, based on the highest absolute value of t-stat and low p-value, were selected as starting points for model calibration in table 4.3.

The most sensitive parameters during the model calibration step was presented at the top of the ranking as shown in fig. 4.1 below that was the highest value of t- stat index module which represent the ratio of parameter coefficient by the standard error; and the lower value of the” p value” which was related to the rejection of hypothesis that addition in the value parameter provides a significant increase in the variable response (Abbaspour, 2007). In this study, the parameters towards evaporation like (EPCO and ESCO), surface runoff (CANMX) and ground water parameters like (GW_DELAY, ALPHA_BF, and GWQMN) are very low. The parameters involving surface runoff (CN2) and ground water (ALPHA_BNK) were the most Sensitive parameter in flow simulation. On the other hand, according to the result from the global sensitivity analysis the curve number (CN₂), was found to be the most sensitive parameter followed by base flow alpha (ALPHA_BNK) of ground water flow, effective hydraulic conductivity in main channel (CH_K2), available water capacity of soil layer (SOL_AWC), average slope steepness (HRU_SLP), surface runoff lag time (SURLAG), manning’s “n” values for main channel (CH_N₂) and etc. as ranking from one up to thirteen position were selected for model calibration. Table 4.1 below shows the fitted value of thirteen most sensitive parameters for stream flow calibration & validation.

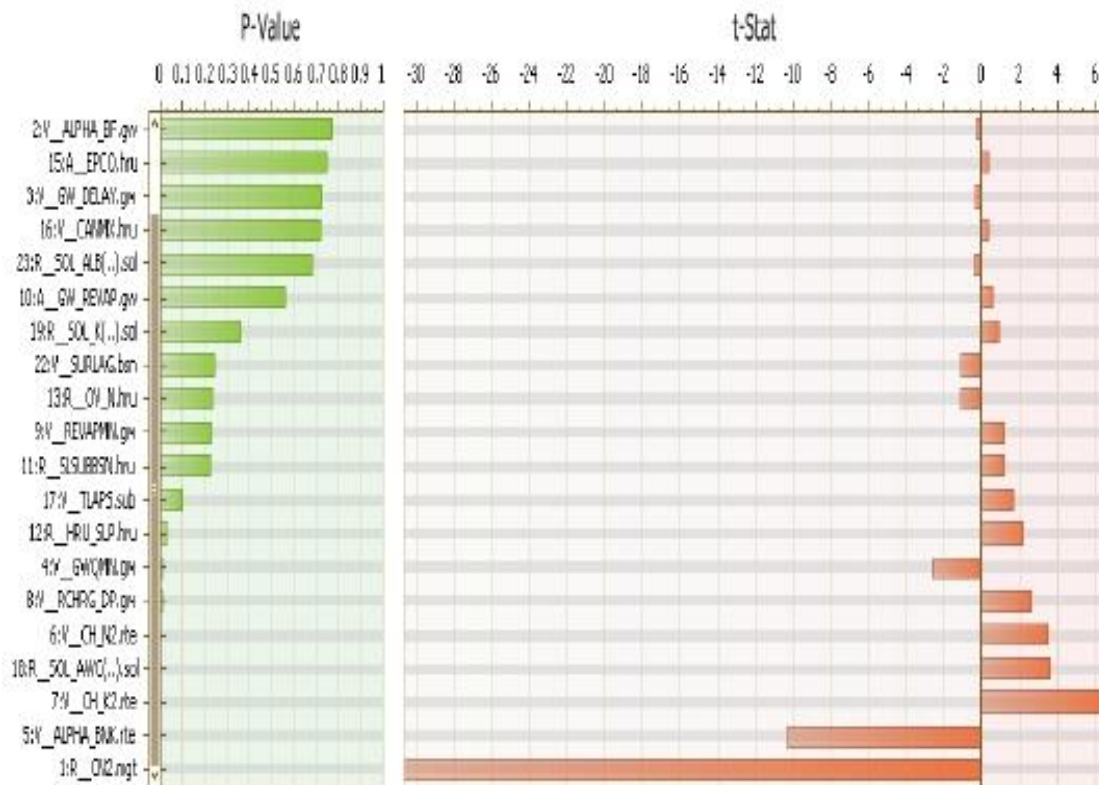


Figure 4.1 Screen shot of Global Sensitivity output of Stream flow sensitivity analysis during Calibration and Validation.

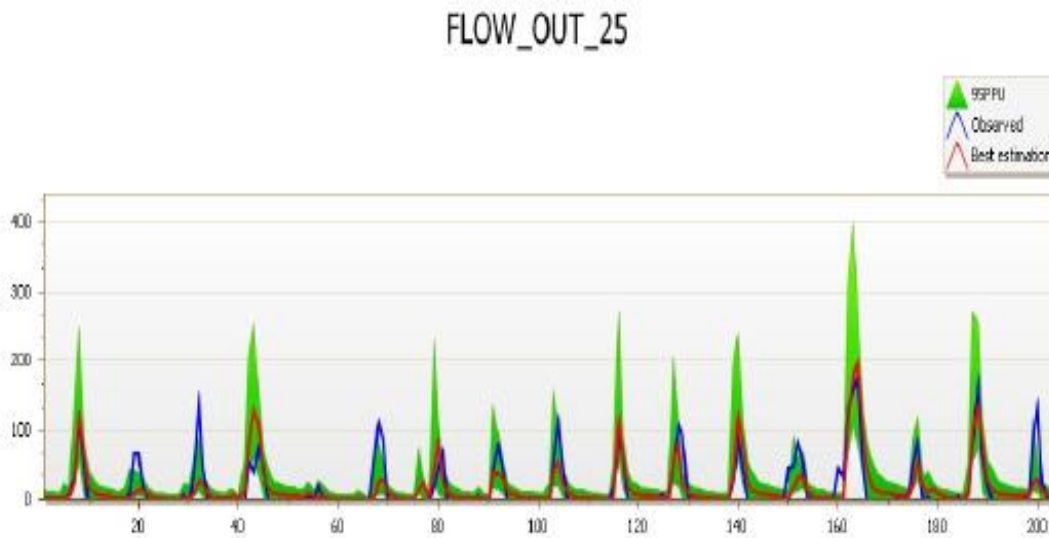


Fig 4.2 95ppu plot by SUFI-2 During Sensitivity analysis for stream flow.

Table 4.1 Summary of 13 most global sensitivity parameter (t- and p -) analysis values

SN	Parameter Name	t – Stat	P-Value	Ranking
1	r_OV.N	0.0476673	0.962245	13
2	r_TLAPS	-0.141392	0.88835	12
3	r_SLSUBBSN	0.50192	0.618783	11
4	r_REVAPMN	-0.923268	0.362015	10
5	v_TLAPS.sub	1.0578358	0.29717716	9
6	r_HRU_SLP	1.279305	0.2089742	8
7	a_GWQMN.gw	-1.385735	0.174352969	7
8	v_CHARG_DP	1.579307046	0.1230133	6
9	v_CH_N ₂	1.781452	0.0832772	5
10	r_SOL_AWC	1.784614	0.0827536	4
11	v_CH_K ₂	2.1667255	0.0369523	3
12	v.ALPHA.BNK	-4.72602276	0.000034599	2
13	r_CN ₂	16.363445523	0.00	1

The rank for each parameter was assigned depending on P-value and t-stat. Here, t-stat provides a measure of sensitivity and hence larger in absolute values are more sensitive. On the other hand, P-value indicates the significance of the sensitivity and hence a value close to zero has more significance. Therefore, ranking in both cases (t-stat or P-value) give the same result i.e. a parameter will have the same rank whether it is ranked based on the t-stat or P value. Table 4.1 above shows the performance evaluation of most parameters depending on the p-values and t- values.

4.1.2 SWAT Model Calibration and Validation

Some of the causes of uncertainty occurrences are due to the changes of land use land cover, changes of forest land into urban area, release of waste water in to the watershed, climatic data like Rainfall and Temperatures as well as un reliable recorded Observed data. Given the above possible errors, calibration and validation results of the Mojo watershed can be qualified as “Good to very Good” for stream flow yield in this study after calibration and validation. This may be due to a good quality of the input data as well as small conceptual model errors in the dominant processes in the watershed. During calibration process to maximize the model efficiency hydrological parameters selected during sensitivity analysis using SUFI-2 algorithm were considered. In other way, the models approximate the reality of the natural systems. Both graphical methods and statistical tests are used in model calibration and validation. The details simulation of the basin was given in Table 4.2

Table 4.2 Details of Model Simulation for the Mojo Basin.

Sl. No	Simulation details	Remark
1	Simulation length	31 years
2	Warm up period	3 year
3	Calibration Period	15 Years excluding warm up period
4	Validation period	15 Years
5	Total number of sub basin	25
6	Total numbers of HRU	42
7	Input metrological data	Measured
8	total basin area	2017.09km ²

The calibration was performed using monthly observed data from the year 1987 to 2001 excluding the warm up periods. The Calibrated model was validated using data from 2002 to 2016 on monthly time step. Both the calibration and validation were taken for equal periods of fifteen years.

4.1.3 Model Calibration

After sensitive parameters identified the model were calibrated and validated using the hydrological parameters selected during sensitivity analysis. The calibration process using SUFI-2 algorithm gave the final fitted value of the most sensitive parameters for the watershed (Table 4.3).

Table 4.3 Final calibrated sensitive parameters

Parameter Name	Min.value	Max_value	Fitted Value
r_CN2.mgt	-0.2	0.2	-0.021542
r_ALPHA_BNK.rte	0.0	1.0	0.039968
r_RCHRG_DP.gw	0.0	0.2	0.090479
r_CH_K2.rte	0.0	150.0	1.736827
r_CH_N2.rte	0.0	0.5	0.483162
r_TLAPS.sub	-10.0	10.0	-4.996675
r_HRU_SLP.hru	0.0	0.2	0.001056
r_REVAPMN.gw	0.0	10.0	5.79177
r_SURLAG.bsn	0.0	10.0	7.31308
r_SOL_AWC (...).sol	-0.2	0.4	0.026561
r_SOL_K (...).sol	-0.5	0.5	-0.225174
r_GW_REVAP.gw	-0.1	0.0	-0.032535
r_OV_N.hru	-0.2	0.0	0.034993

From the appendix (22) among the 23 parameters for the stream flow analyzed the most 13 parameters had been selected based on the performance evaluation criteria. So it shows the

most sensitive parameters that were selected during both calibration and validation period without any changes of parameters. Initially, the decreasing curve number at moisture condition II (CN₂), and GW_REVAP increasing were over prediction during calibration or first iteration. Setting only CN₂ to their Calibrated values improved efficiency of SWAT. CN₂ is found to be a most important parameter in calibration of SWAT (Feyereisen et al., 2007; Noor et al., 2014; Ridwansyah et al. 2014; and Kumar et al., 2014) as cited by Zelalem, (2016) and contributes directly to surface runoff generation. On this study, model under prediction were adjusted by increasing REVAPMN and SOL_AWC. All above parameters values were adjusted manually for calibration. The performance of the model was evaluated using R², E_{NS} and P_{BIAS} statistical measures for both manual and auto-calibration. Evaluations were performed at monthly time scales and the result of statistical parameters during calibration obtained were 0.80 for R², 0.75 for E_{NS} and -10.6 for P_{BIAS}. The values indicate that there is good agreement between observed and simulated stream flow of Mojo watershed. Figure 4.3 below shows hydrography comparison during model calibration.

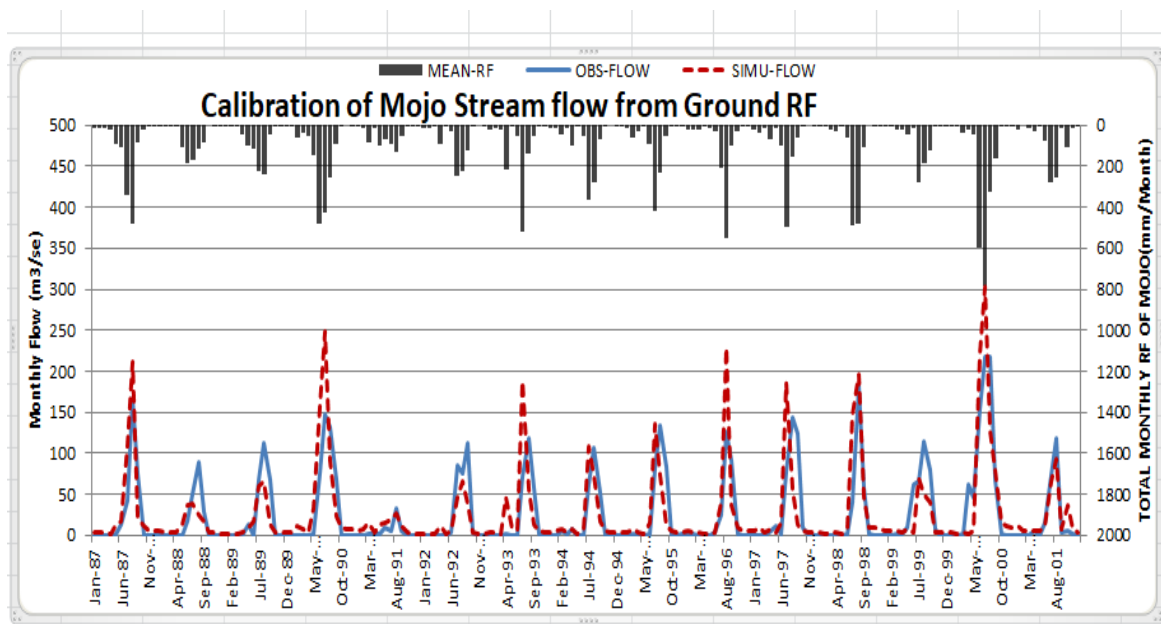


Figure 4.3 Calibration of Observed & Simulated stream flow of Mojo Watershed

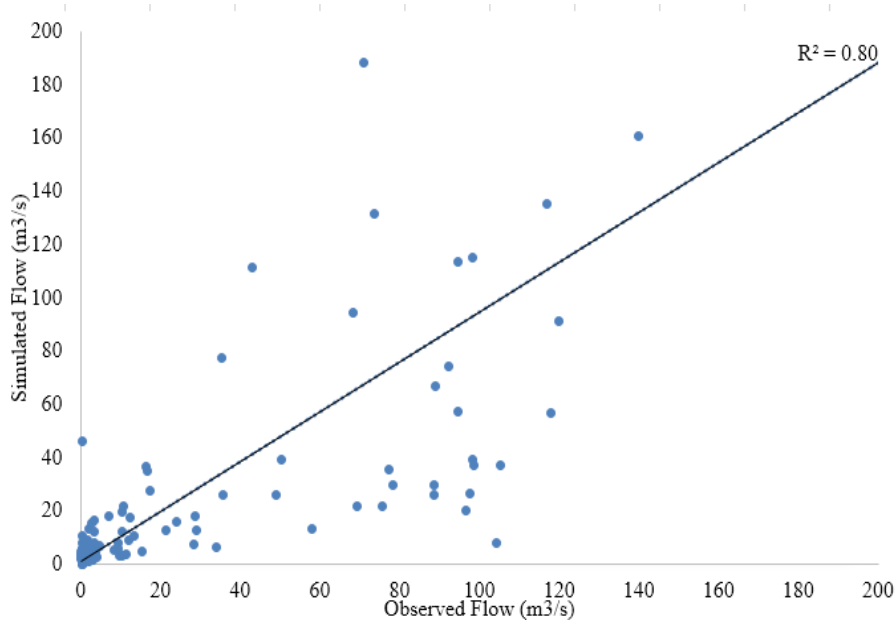


Figure 4.4 Scatter plot of Observed and Simulated flow of the Calibration period

4.1.4 Model Validation

Validation of model results was necessary to increase user confidence in model predicting capability. Fifteen year monthly observed data (2002-2016) were used for model validation without any adjustment of fitted value during calibration period. So the values of 0.76 for R^2 , 0.69 of E_{NS} and -14.4% of P_{BIAS} were obtained. However, the result obtained during calibration and validation period in above is almost similar with the results of Meqaunint et al. (2010), Moriasi *et al.* (2007), Abdi et al. (2012) and Shawul et al. (2013) of SWAT model suitability evaluation. And but different from the result obtained by Lemma (2015) from Kulekhani watershed (153.54 ha) and Hassen et al. (2014) from May bar experimental watershed (113.75 ha) as cited by Zelalem (2016). Here the results obtained confirm that SWAT model is more appropriate to be used for large watershed. Calibrated and validated model predictive performances values for Mojo River on monthly flows base are summarized in Table 4.6 and the time series plot of measured and simulated monthly flow for validation are shown in Fig. 4.5 and Fig. 4.6 below respectively.

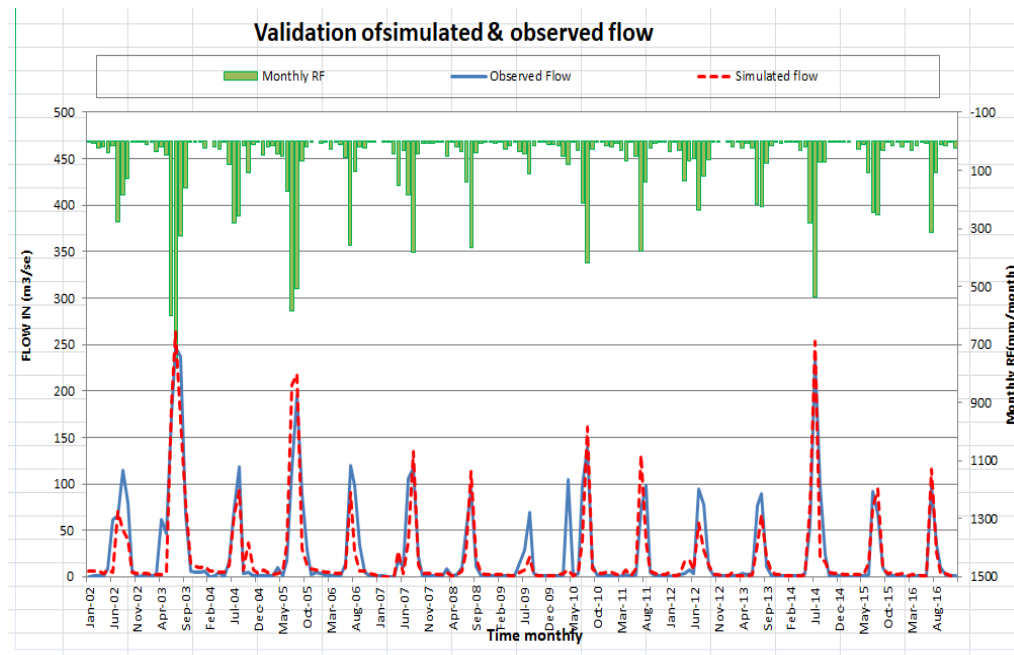


Figure 4.5 Validation of simulated & observed stream flow of Mojo watershed.

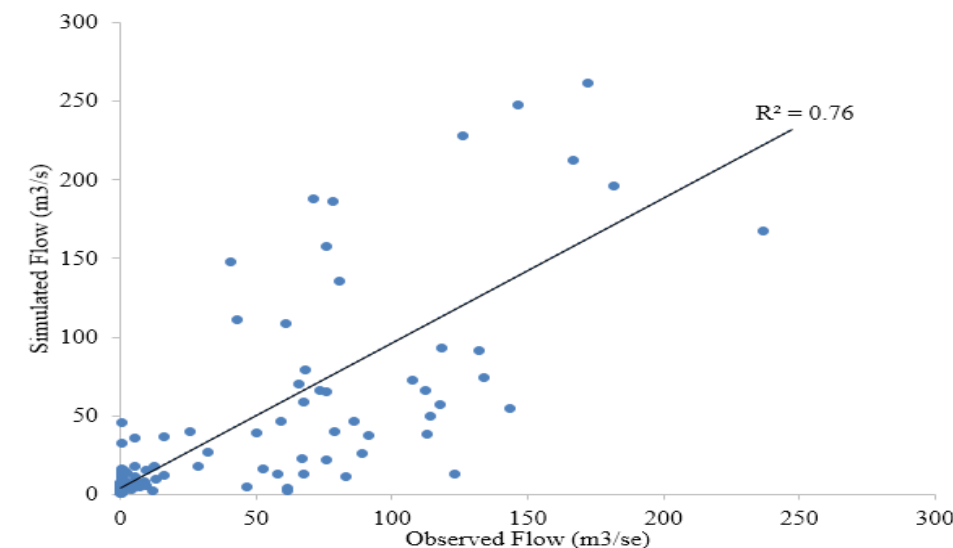


Figure 4.6 Scatter plot of observed and simulated flow for Validation period.

Table 4.4 Model Performance indicator during Calibration and Validation.

Period	Model statistical efficiency measures						
	R^2	NSE	bR^2	PBIAS	RSR	P-factor	r-factor
Calibration	0.80	0.75	0.78	-10.6	0.5	0.82	0.01
Validation	0.76	0.69	0.74	-14.4	0.56	0.77	0.01

As it could be seen from table 4.4 the model underestimated stream flow compared to observed mean monthly stream flow in 1987, 1990, 1993, 1996, 1997 & 2000 during calibration and 2003, 2005, 2007, 2010, 2011 & 2014 during validation period. One of the

factors that have contributed to uncertainty of the model might be the effect of SWAT parameters that are considered to have negligible influence on the stream flow but cumulative of which would have affected the model performances. There were also unconsidered factors in modeling process that resulted in the model error is also another factors. Another source of uncertainty may be stream flow recorded at the gauge stations and uncertainty that rises from filling the missing flow data. In other way, the result of SUFI-2 indicates that the p-factor, percentages of data being bracketed by 95PPU, for the calibration period was 0.82 and 0.77 for the validation period. This was indicates that 82% and 77% of the measured data for calibration and validation respectively were correct simulated flow by the model while the remaining occur due to an errors of input data such as rainfall and temperature.

4.2. Water Balances of the Mojo Watershed

Water availability in Mojo River basin is projected to decrease over time due to increasing population, change in climate, and increase of industry, changes of the land use and land cover. Hydrological models such as SWAT could be used to assess the availability of water resources and the long-term influences of water management on the resources. This helps in planning mitigation measures against water available that the future generation is inevitably going to face. The water yield of the basin when modelled by SWAT was the total amount of water generated by sub basin and entering the main channel system. It was the important parameter to be estimated for efficient management and planning. For different HRUs, runoff is predicted separately and then routed to obtain total runoff for the sub basin. This enhances accuracy and gives a better description of water balance. In other way the water yield in the basin would be obtained as water yield that was draining out of the watershed includes surface runoff contribution to stream flow, lateral flow contribution to stream flow, groundwater contribution to stream flow minus the transmission losses (water lost as a deep percolation and evapotranspiration). As it can be seen from table 4.8 below the simulated annual balance components of the watershed shows that 28.7% of the annual precipitation is losing as evapotranspiration and around 13% is losing by deep percolation. However, as it can be seen from Table 4.7 and Table 4.5 the main contribution of the water to base flow were 62.15% by surface runoff and 33.48% contributed to base flow by ground water contribution and 28.55% contributed to base flow by lateral flow contribution. There were also minor contribution around 40.65% to base flow like revap or shallow aquifer recharge, deep aquifer recharges and lateral soil flow contribution .This

shows that on yearly basis more than half of the stream flow in the watershed was from surface runoff and ground water. As we have seen from the figure 4.6 below simulated temporal variability of average rainfall in relation to surface runoff, deep percolation and evapotranspiration loss. During the period of high rainfall (Jun – Sep) there was high runoff and high water yield contribution to the basin.

Table 4.5 Average Annual water Balances Simulated for a base period

Water Balance Components	Amounts (mm)
Precipitation; Precip	2009.602
Surface Runoff; Sur..Q	1249.04
Lateral Soil flow contribution; Lat..Q	573.67
Ground water contribution to stream flow	672.8
Revap or shallow aquifer recharges	188.32
Deep aquifer recharges	54.96
Total water yields; Twyld	2495.51
Percolation out of the soil; Perc.	264.17
Actual Evapo-transpiration; AET.	216.82
Transmission losses	0.005
Potential Evapo-transpiration; PET	343.85

The table 4.5 shows average annual or yearly a major water contribution and losses during the simulation period. As we have discussed above surface runoff and ground water flow were the major contribution to base flow and deep percolation through the soil layer and Evapo-transpiration were also major losses of water yield.

Table 4.6 Average Monthly Simulated Water Balances of Mojo Watershed for a base period

Column1	PRICP	PERCOL	LAT_Q	SURF_Q	Water		
					Yield	AET	PET
JAN	500.84	8.78	79.8	281.13	98.65	10.13	23.64
FEB	726.98	11.18	92.2	502.22	112.19	12.21	21.42
MAR	1513.32	18.51	37.0	170.16	40.01	23.26	27.30
APR	1692.28	58.86	88.2	40.45	65.45	22.49	24.67
MAY	921.11	93.96	100.90	74.99	38.89	25.54	28.10
JUNE	2681.16	70.17	98.4	214.35	72.91	19.52	29.29
JULY	2039.97	88.95	89.31	92.28	96.15	20.83	27.73
AUG	3068.31	91.40	99.197	97.95	32.16	19.11	25.15
SEPT	3136.97	59.58	97.7	362.32	113.33	20.42	26.30
OCT	2331.31	56.55	98.623	226.40	89.58	16.78	28.81
NOV	1062.11	65.40	89.38	139.37	108.74	13.97	29.04
DEC	421.66	81.75	102.278	401.27	90.67	12.25	28.01
ANNUL	2009.602	264.17	573.67	1249.1	878.3	216.62	343.85

The table 4.6 shows the mean monthly simulated Mojo watershed. In this study the irrigation water requirement were estimated for the dry period (Dec-May) month. In these month the rainfall is very low when compared with other months and ET is very high. As it can be seen from table 4.6 during low rainfall months, there were highest PET and inversely during highest mean monthly rainfall the AET was so high and PET was low.

The contribution of each sub basin during the simulation period is summed up to arrive at the total yield of water by the basin. The water yield is in depth unit and it is multiplied by the area of the basin to get the volume of the water yield. So, using equation (3.9) and (4.0) the total volume of water yield of the watershed was found to be 0.504BCM.

4.3 CROPWAT Model Analysis

Reference Evapo-transpiration, effective rainfall, crop pattern data, and soil data were used for CropWat 8.0 model analysis. The major crops identified from the watershed area in appendix (A-20) analysis were used in the calculation of crop water requirement. Reference Evapo-transpiration, effective rainfall, crop pattern data, and soil data were used crop watt model analysis.

4.3.1 Effective Rainfall

To account for the losses due to runoff or percolation, a choice was made from the four methods given in CropWat 8.0 (Fixed percentage, dependable rain empirical formula, USDA Soil Conservation Service). Rainfall data from 1987-2017 was taken to calculate effective rainfall and dependable rain empirical formula has been used. Rainfall and effective rain was obtained from CropWat 8.0 model. The figure 4.8 below shows the effective rainfall and rainfall calculated from the modelling.

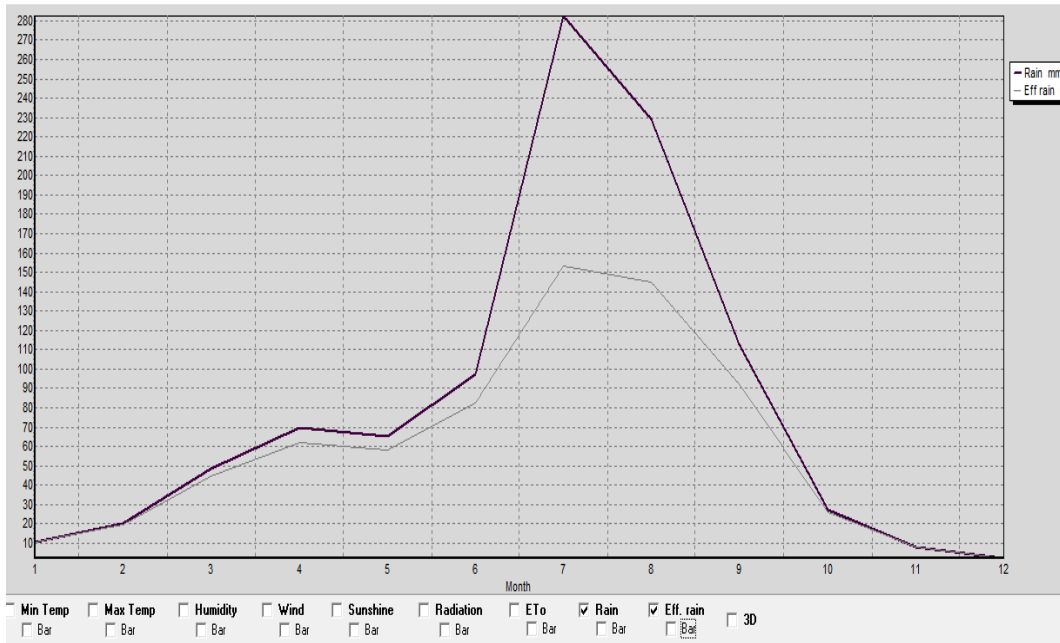


Figure 4.7 Rainfall vs Effective Rainfall calculated by CROPWAT8

4.3.2 Reference Evapo-transpiration

First monthly maximum and minimum temperature, relative humidity, sunshine hour, and wind speed data (1987-2017) was fitted in CropWat8 model. Then, the model calculated crop Evapo-transpiration values based on the FAO Penman-Montieth equation. Figure 4.11 showed the calculated reference Evapo-transpiration. The reference Evapo-transpiration starts to rise at January and reach to a maximum point 4.52 at mid of March.

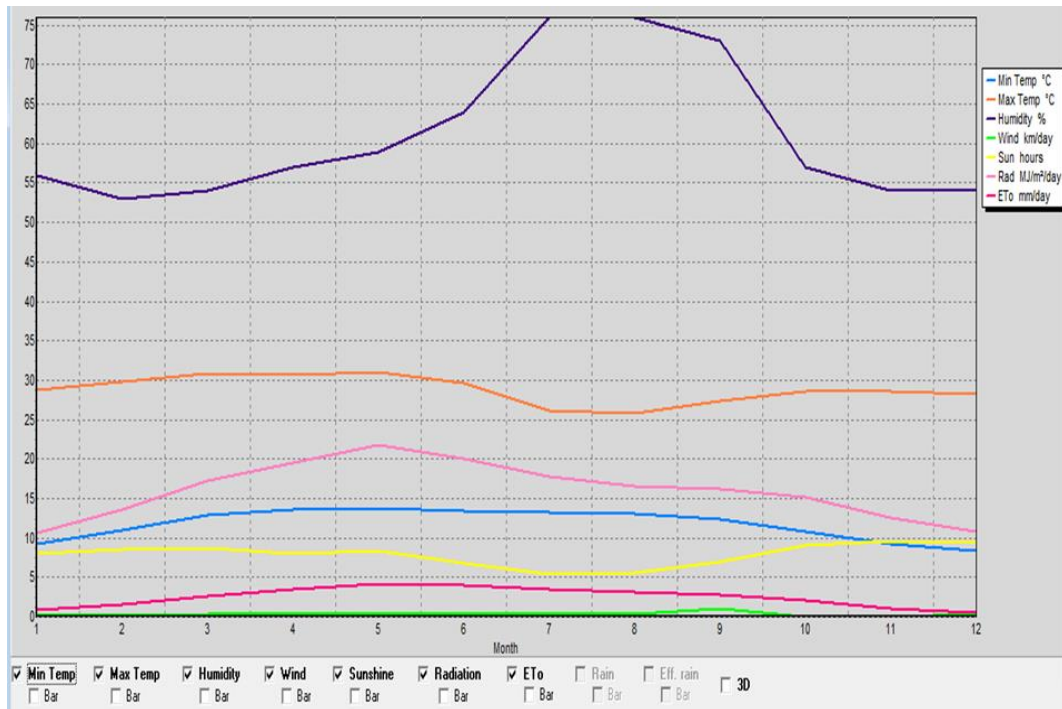


Figure 4.8 All Climatic data used by Penman Monteith for CROPWAT 8 Model

4.4 Crop and irrigation water requirement

To calculate the crop and irrigation water requirement we needed to know annual crop water demand and annual irrigation water demand of the major crops grown in the schemes. To calculate crop and irrigation water requirement of the watershed irrigation schemes: area coverage of the crop, planting and harvesting dates, and major crop cultivated in the schemes were required in (appendix 20). The results of crop water requirement (CWR) and irrigation water requirement (IR) of the major crops in the watershed schemes were presented in the Table (4.9).

Appendix 22 shows the total area that was planned in the future and after the schemes developed to start function. The area was used to calculate net irrigation water requirement and net crop water requirement of the Major Crops in the area. Table 4.9 showed CWR and IWR of major crops in the season.

Table 4.7 Result of CWR and IR of Major cropping in the Mojo watershed in year 2011E.C

Major Crops	Area (ha)	CWR(mm/season)	IR (mm/season)
Maize	72.00	375.90	156.60
Onion	2265.50	371.40	136.90
Cabbages	64.00	512.90	125.60
Peppers	753.50	386.90	139.70
Tomato	137.53	478.30	166.90
Totals	3292.53	2125.4725.7	725.7

The results of crop water requirements and irrigation water requirement were expressed in figural in appendix 15.5

4.5 Net Crop and Irrigation Water Requirement

The net crop water requirement and net irrigation water requirement were determined for irrigated cropping seasons of the watershed schemes in the year by using equation (3.7) and the result is presented in the Table 4.8. The crop water requirement (CWR) and irrigation requirement (IR) of each crop for the entire growing period was summarized in the below table.

Table 4.8 Estimation of total crop water requirement and irrigation requirement

Crops	CWR (mm)	Net IR (mm).
Cabbages	6.22	2.44
Maize	8.22	3.42
Onion	239.95	94.2
Tomato	17.76	31.97
Pepper	81.44	6.97
Totals	353.59	139

Irrigation requirement for a month from Jan to Jun for each Major crop were summarized in the following table.

Table 4.9 Estimation of monthly irrigation water requirement (mm/month) for each Major Crop.

Month	Cabbage	Onion	Maize	Tomato	Pepper
Jan	54.5	54.2	11.2	44.8	53.1
Feb	56	81.8	71.9	73.9	79.9
Mar	96.1	121.5	113.5	119.9	124
Apr	107	79.9	61.9	119	106.1
May	92.7	-	-	56.7	-
Jun	24.8	-			

The total net monthly irrigation requirements (NIR) for all major crops were summarized in table 4.10 below. Based on the analysis the total net irrigation water demand of the watershed area were 1.7, 2.6, 3, 2.9, 0.14 & 0.02 MCM for Jan, Feb, Mar, Apr, May & Jun respectively. As we have been seen from the following table the total annual irrigation water requirement of the Major crop could be obtained by the addition of monthly (mm/month) of all irrigation requirements. So, from the above table (4.9) overall total water requirement of Major crops (Jan-May) were 1804.4(mm/month) and the total annual irrigation requirement was 279.962MCM or 0.279BCM.

Table 4.10 Monthly net irrigation Requirement (MCM) for each Major crop of Mojo Watershed

Crop types	Area (ha)	Jan.	Feb.	Mar.	Apr.	May.	Jun.
Cabbage	64	0.035	0.036	0.062	0.068	0.06	0.02
Onion	2265.5	1.2	1.8	2.7	1.8	-	-
Maize	72	0.0081	0.052	0.082	0.045	-	-
Pepper	753.5	0.4	0.6	0.09	0.8	-	-
Tomato	137.53	0.062	0.1	0.16	0.16	0.078	-
Totals	3292.53	1.7051	2.588	3.094	2.873	0.138	0.02

The above table indicates the monthly irrigation water requirement of Major Crops in the Mojo watershed area.4.6 Compare supply and demand of water and determines critical command area

4.6.1 Water demand analysis

For the purpose of estimation of total requirements of water, the demand is calculated on an average basis expressed in liters per capita per day (lpcd). This was represents the

average daily amount of water required per person during period of a year in normal or drought conditions. The results of crop wat model for irrigation water requirement and domestic water analyzed were used to calculate water demand of the schemes. Mojo watershed covers four distinct woreda such as Liban, Ada'a, Gimbichu and Lume. So, the overall total human consumption in the schemes was obtained by adding the human consumptive used for each woreda human consumptive use.

4.6.1.1 Industrial water demand

In this study the total industrial water requirement in the Mojo sub-basin was estimated to $0.00001 * \text{total yield of the mojo basin (0.504BCM)} = 0.0504\text{MCM}$. Generally, large industries those were found in Mojo Watershed develop their own water supply systems. Only small industries purchase water and, therefore, imposed water on local municipal systems. So the total amount of water demand required for industry was around 0.0000401BCM which was rarely.

4.6.1.2 Domestic water demand

The domestic water demand was estimated based on the basin population and the minimum standard required per person per year (Adeba et al. 2015). A range of estimates of per capita water requirements have been developed, ranging from 20 liters per capita per day (l/c/d) through to 4,654 l/c/d, (Jonathan 2000). Considering a minimum per capita water availability of 145 l/ c/day for urban population and 45 l/c/day for rural population (Adeba et al. 2015).The total domestic water requirement of the basin would be calculated as follow:

a) Human Consumptive water demand

Water required for the purpose of drinking, washing, cooking, sewerage and etc. were classified under domestic water. Mojo River was not required for the purpose of drinking, in some case, at the upper stream of the river like Liban, Gimbichu, Liban and Adai Berga woreda small likelihood of farmers totally around 778493 in numbers were used for domestic requirements. Therefore, by applied the eqn (3.11) the total domestic water requirements were found to been 0.13BCM/year .

b) Livestock water demand

Providing good quality water is essential for healthy livestock husbandry. The daily water requirement of livestock varies significantly among animal species (Table 4.11). The animal's size and growth stage would have a strong influence on daily water intake.

Consumption rates can also be affected by environmental and management factors. Feed with relatively high moisture content decreases the quantity of drinking water required (Taddeset al. 2001).

Table 4.11 Total Water requirement of livestock population in Ada'a Berga Woreda

Types of animals In the Basin	Population	Average Water Requirement (L/day/head)	Water Requirement (MCM/year).
Cattle	144475	54	2.85
Sheep	35975	7.14	0.0937
Goat	38518	7.14	0.1
Horse	2952	45.6	0.049
Mule	776	45.6	0.013
Donkey	51377	45.6	0.855
Hen	15366	2.6	0.15
Poultry	2000	450lit/1000/birds/day	0.0009
Camel	3951	55	0.0794
Totals 4.191			

The total water consumption of livestock in Ada'a woreda of watershed was = 4.2MCM/day.

Table 4.12 Total Water requirement of Livestock Population in Lume Woreda.

Types of animals In the Basin	Livestock in Population	Average Water Requirements (Li/day/head	Water Requirement (MCM/year).
Cattle	1313058	54	25.8804
Sheep	389852	7.14	1.02
Goat	403051	7.14	1.05
Horse	89250	45.6	1.4855
Mule	934	45.6	0.016
Donkey	293573	45.6	4.9
Poultry	105411	450lit/1000/birds/day	0.017
Totals	-	-	34.4

The total amount of water requirement of the livestock population in Lume Woreda was around 34.45MCM.

Table 4.13 Total Water requirement of Livestock Population in Liban Cukala Woreda.

Types of animal In the Basin	Livestock in Population	Average Water Requirements (li/day/head	Water Requirement (MCM/year).
Cattle	1775009	54	34.986
Goat	572040	7.14	1.5
Horse	25006	45.6	0.42
Mule	3730	45.6	0.062
Donkey	280055	45.6	4.7
Hen and Birds	263267	450lit/1000/bird/day	0.43
Sheep	297004	7.14	0.78
Totals			42.982

So, from the table given above the total water consumption of livestock in Liban woreda were around 42.98MCM per year.

Table 4.14 Total Water requirement of Livestock Population in Gimbichu Woreda.

Types of animal In the Basin	Livestock population in million = 10 ⁶	Average water requirement (li/day/head	Water requirement in MCM/year
Cattle	1.14	54	22.8
Sheep	0.062	7.14	0.162
Goat	0.082	7.14	0.252
Horse	0.0089	45.6	0.015
Mule	0.000749	45.6	0.0125
Donkey	0.043	45.6	0.72
Camel	0.000031	55	0.00062
Hen and birds	0.0531	450/1000/bird/day~0.45	0.000024
Totals			23.995344

The total amount of water requirement of Gimbichu woreda livestock were around 23.995MCM

So the overall water consumption of livestock demand of the sub basin was obtained by adding all woreda's water requirement of livestock population. Accordingly, the overall water consumption of livestock demand of the sub basin is estimated to be 105.677 MCM or 0.106BCM. The total water consumption of monthly requirement also expressed as

0.00883MCM/month. So from all above discussion the total water demand of Mojo Watershed were the sums of all water consumption used. The total water consumption for Domestic, Live stocks and Irrigation water requirements were 0.13BCM, 0.106BCM and 0.279BCM respectively. The total annual surface water resources potential of Mojo River basin according to this study was estimated to be about 0.504 BCM/year. The total water demand in the basin is about 0.515 BCM. This shows the deficit of 0.011BCM of water in the Mojo basin is observed. This variation of surplus and demand was occurred due to variation of rainfall in time and spaces. From table 4.8 June to October is the rainy months of the basin, during which availability of water exceeds demand and from (Dec-May) there is water shortage in the scheme. The total annual shortage of supply during this time was around 0.011BCM/year and total monthly shortage in dry month was around 0.00092BCM/month.

The overall analysis of this study showed that there is gap between water availability and demand at Mojo catchment. There is also high conflict among users due to water shortage and lack of well-structured irrigation committee and water management system. The other problem in the catchment is use of traditional irrigation system which waste water and decrease water use efficiency. Therefore, in order to solve water shortage, alternative source of water supply like ground water and water harvesting technologies should be studied and different agricultural water management options should be implemented. In addition to this, to improve the efficiency of irrigation water, different irrigation methods like drip irrigation and sprinkler irrigation should be developed in the area and irrigation scheduling should be practiced.

Other studies also showed similar result concerning problems on water management, shortage of water supply and conflict among water users. Water demand driven by the rapid increase of population and increasing demand for agricultural irrigation is one of the challenges in water allocation. This quick rate of growth brings severe consequences that result from high stresses on water resources and their unprecedented impacts on socioeconomic development. Water shortage is also one of the problems in the river basins. The major reasons are high water demand from population growth, degraded water quality and pollution of surface and groundwater sources, and the loss of potential sources of fresh water supply due to old and unsustainable water management practices. Conflicts often arise when different water users of the river compete for limited water supply (Lizhong, 2005).

4.7 Critical Command Area

The critical command area could be obtained by the equation (3.11) of the above. The critical CA was the month during which smallest area could be irrigated. The results of all major crops of the scheme within gross irrigation need and critical CA were discussed under appendix 2. However from all major crops let we have seen onion crop as example.

Table 4.15 Scheme water supply, net gross irrigation and critical command of onion crop

Months	Jan	Feb.	Mar.	Apr.	May.	Jun	July	Aug	Sep	Oct	Nov	Dec
SWS (MCM)	5.5	5.54	5.82	6.8	8.3	14.1	41.1	71.2	29.9	7.6	5.6	5.5
SWS (li/s)	640.0	641.2	673.6	787.03	960.7	1631.9	4826.4	8240.7	3460.7	879.6	648.2	686.6
Net (li/se/ha)	-	-	6.09	10.6	20.5	18	2.5	-	-	-	-	-
CA(ha)	-	-	110.61	74.25	46.86	90.66	1664.3	-	-	-	-	-

From the table above onion crop could be fully irrigated at 46.86ha which was the smallest area. So, the critical command area of the onion crop was the smallest of the all area which was occurred during May month. The largest areas were 1664.3ha which occurred during month of July. In critical CA the onion crop could be supplied with sufficient water throughout the year.so, it was reliable irrigation during critical CA. the area of 46.86ha is in fact the smallest area according to the calculation in table above. However, under appendix 2, the critical CA, of the Major crops of Onion, Cabbage, Maize, Tomato and Peppers of the schemes were 46.68, 72.45, 51.93, 44.9 and 49.42ha respectively.

From the above all discussion we have concluded that the critical CA of overall major crops of the schemes was the total of all the critical area of the schemes which was around 265.64ha.

5. CONCLUSIONS AND RECOMANDATIONS

5.1 Conclusions

The Main aim of this study was to examine the water availability of Mojo watershed using SWAT model for simulating stream flow. The model was successfully Calibrated and validated for the Mojo watershed using SWATCUP, SUFI-2 algorithms. In the process of model calibration the identified sensitive parameters helps to reduce the number of model parameters to thirteen. The selected parameters gave good results in minimizing the differences between observed and simulated stream flow yield. The model evaluation statistics for prediction of stream flow yield gave good to very good results that were verified by NSE greater than 0.69 and R^2 greater than 0.75. The Uncertainty related to the model and data used for stream flow was minimized by adjusting the value of selected parameters and the performance of the model $R^2=0.80$, NSE=0.75, error index (RSR=0.5) and percent bias (PBIAS=-10.6) obtained during calibration and R^2 value 0.76, NSE value 0.69, RSR value 0.56 and percent bias -14.4 obtained during validation justified the capability of the model in simulating runoff. The Calibrated and validated model used to determine water balance of the watershed. The estimated annual water balance component indicates that 27.8% and 13.15% of the annual precipitation lost by evapotranspiration and deep percolation respectively. Whereas Lateral contribution 28.55%, surface runoff 62.15% and groundwater 33.5% contributed to the total yield of the watershed.

The total surface water yield of the Mojo River is estimated to be 0.504 BCM/year, while the total demand is about 0.515 BCM/year. This shows that there is a deficit of 0.011 BCM/year of surface water in the river. The results from cropwat model for irrigation and crop water requirement of major crops were analyzed. According to the model out put the total of monthly irrigation water requirement for all major crops were 1.7, 2.6, 3, 2.9, 0.14 & 0.02 MCM for Jan, Feb, Mar, Apr, May & Jun respectively. Based on the analysis, the total irrigation requirement of all Major crops was around 0.279BCM. In addition to irrigation, population of the study area uses water for Livestock and Human consumption 0.106BCM, 0.13BCM respectively. During this period, there was also conflict between users at diversion and water allocation.

The critical command area of the onion crop is the smallest of the all area which occurred during the month of May whereas, the largest areas 1664.3ha occurred during the month of July. Therefore, onion crop could be supplied with sufficient water throughout the year.

So, it is reliable to irrigate the smallest (46.86ha) CA of onion crop during critical CA. The critical CA, of the Major crops of Onion, Cabbage, Maize, Tomato and Peppers of the schemes were found 46.68, 72.45, 51.93, 44.9 and 49.42ha respectively. Thus, the overall major crops of the schemes are found to be 265.64ha.

5.2 Recommendation

Land use/land cover and soil map was of poor quality. Therefore, this might greatly affect the water balance yield representative and high resolution geospatial data is recommended to improve the result. Exploitation of new water supply like harvesting rainwater and storing the excess flood during rainy period can alleviate water shortages in the Mojo River to a great extent. So the immediate future task of the decision makers should be to protect the ecology of the watershed from further deterioration of the resources and exploit different sources of water to mitigate the current water shortage. In other way, to solve water shortage, alternative source of water supply like ground water and water harvesting technologies should be studied and integrated water management system should be implemented. In addition to this, to improve the efficiency of irrigation water, different irrigation methods like drip irrigation should be improved in the area.

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7. APPENDICES

Appendix-A₁: Climate, Rainfall and crop water requirement Mojo climate data.

Monthly rain - C:\ProgramData\CROPWAT\data\rain\MOJO RAIN FALL.CRM

Station Eff. rain method

	Rain	Eff rain
	mm	mm
January	10.8	10.6
February	20.3	19.6
March	48.7	44.9
April	69.4	61.7
May	65.2	58.4
June	97.6	82.4
July	282.5	153.3
August	229.0	145.1
September	112.6	92.3
October	27.5	26.3
November	8.1	8.0
December	2.2	2.2
Total	973.9	704.7

Appendix -A2:Mojo rainfall data for cropwat input

Monthly Eto Penman-Monteith - C:\ProgramData\CROPWAT\data\climate\mojo data.PEM

Country Station

Altitude m. Latitude °N Longitude °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m ² /day	mm/day
January	9.2	28.8	56	17	8.1	10.6	1.01
February	10.9	29.8	53	17	8.5	13.6	1.76
March	12.9	30.8	54	26	8.7	17.3	2.92
April	13.6	30.6	57	35	8.1	19.6	3.78
May	13.8	30.9	59	26	8.4	21.7	4.31
June	13.4	29.7	64	26	6.8	20.1	4.12
July	13.2	26.2	76	26	5.4	17.7	3.54
August	13.1	25.8	76	26	5.5	16.6	3.16
September	12.4	27.3	73	86	7.0	16.1	3.15
October	10.8	28.6	57	17	9.1	15.2	2.15
November	9.3	28.5	54	26	9.6	12.4	1.34
December	8.4	28.1	54	26	9.4	10.8	0.86
Average	11.8	28.8	61	30	7.9	16.0	2.67

Appendix-A3: Mojo crop water requirement of onion crop

Crop Water Requirements

ETo station: MOJO Crop: Onion

Rain station: MOJO Planting date: 28/02

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Feb	3	Init	0.70	1.37	1.4	1.1	1.4
Mar	1	Init	0.70	1.63	16.3	12.4	3.9
Mar	2	Deve	0.70	1.88	18.8	15.3	3.5
Mar	3	Deve	0.75	2.22	24.5	17.1	7.4
Apr	1	Deve	0.83	2.68	26.8	19.3	7.5
Apr	2	Deve	0.90	3.16	31.6	21.5	10.1
Apr	3	Deve	0.97	3.62	36.2	20.8	15.4
May	1	Mid	1.03	4.03	40.3	19.0	21.3
May	2	Late	1.01	4.19	41.9	18.2	23.7
May	3	Late	0.96	3.90	43.0	21.3	21.7
Jun	1	Late	0.90	3.61	36.1	23.3	12.8
Jun	2	Late	0.84	3.34	33.4	25.3	8.2
Jun	3	Late	0.79	3.02	21.1	23.7	0.0
					371.4	238.2	136.9

Appendix-A4: Mojo crop water requirement of onion

Crop Water R

ETo station: MOJO Crop: Onion

Rain station: MOJO Planting date: 28/02

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Feb	3	Init	0.70	1.37	1.4	1.1	1.4
Mar	1	Init	0.70	1.63	16.3	12.4	3.9
Mar	2	Deve	0.70	1.88	18.8	15.3	3.5
Mar	3	Deve	0.75	2.22	24.5	17.1	7.4
Apr	1	Deve	0.83	2.68	26.8	19.3	7.5
Apr	2	Deve	0.90	3.16	31.6	21.5	10.1
Apr	3	Deve	0.97	3.62	36.2	20.8	15.4
May	1	Mid	1.03	4.03	40.3	19.0	21.3
May	2	Late	1.01	4.19	41.9	18.2	23.7
May	3	Late	0.96	3.90	43.0	21.3	21.7
Jun	1	Late	0.90	3.61	36.1	23.3	12.8
Jun	2	Late	0.84	3.34	33.4	25.3	8.2
Jun	3	Late	0.79	3.02	21.1	23.7	0.0
Jun					371.4	238.2	136.9
Jul	1	Late	0.36	1.33	2.7	9.1	2.7
					375.9	257.5	156.6

MAIZE (Grain)

28/02

Irr. Req. mm/dec

0.6

0.0

0.0

0.0

4.4

12.9

22.2

26.8

30.0

31.0

19.7

6.5

0.0

Appendix-A5: Mojo Crop Water Requirement of Maize

Appendix-A6: Mojo watershed area of Soil

Soil - C:\ProgramData\CROPWAT\data\soils\mojo soil.SOI

Soil name

General soil data

Total available soil moisture (FC - WP) mm/meter

Maximum rain infiltration rate mm/day

Maximum rooting depth centimeters

Initial soil moisture depletion (as % TAM) %

Initial available soil moisture mm/meter

Appendix-A7: MojoCrop Water Requirement of Cabbage

Crop Water Requirements

ETo station Crop

Rain station Planting date

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Feb	3	Init	0.70	1.37	1.4	1.1	1.4
Mar	1	Init	0.70	1.63	16.3	12.4	3.9
Mar	2	Init	0.70	1.88	18.8	15.3	3.5
Mar	3	Init	0.70	2.07	22.8	17.1	5.7
Apr	1	Deve	0.70	2.27	22.7	19.3	3.4
Apr	2	Deve	0.74	2.59	25.9	21.5	4.5
Apr	3	Deve	0.79	2.95	29.5	20.8	8.7
May	1	Deve	0.84	3.32	33.2	19.0	14.2
May	2	Deve	0.90	3.72	37.2	18.2	18.9
May	3	Deve	0.95	3.89	42.8	21.3	21.5
Jun	1	Mid	1.00	4.05	40.5	23.3	17.2
Jun	2	Mid	1.02	4.04	40.4	25.3	15.1
Jun	3	Mid	1.02	3.87	38.7	33.9	4.8
Jul	1	Mid	1.02	3.70	37.0	45.7	0.0
Jul	2	Mid	1.02	3.53	35.3	54.8	0.0
Jul	3	Late	1.01	3.38	37.2	52.6	0.0
Aug	1	Late	0.95	3.05	30.5	50.7	0.0
Aug	2	Late	0.91	2.81	2.8	5.0	2.8
					512.9	457.2	125.6

Appendix-A8: Mojocrop water requirement of pepper.

ETo station		MOJO	Crop		Sweet Peppers		
Rain station		MOJO	Planting date		28/02		
Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Feb	3	Init	0.60	1.18	1.2	1.1	1.2
Mar	1	Init	0.60	1.39	13.9	12.4	1.6
Mar	2	Init	0.60	1.61	16.1	15.3	0.8
Mar	3	Deve	0.60	1.79	19.7	17.1	2.6
Apr	1	Deve	0.69	2.23	22.3	19.3	3.0
Apr	2	Deve	0.81	2.85	28.5	21.5	7.0
Apr	3	Deve	0.93	3.47	34.7	20.8	13.9
May	1	Mid	1.02	4.01	40.1	19.0	21.1
May	2	Mid	1.02	4.24	42.4	18.2	24.2
May	3	Mid	1.02	4.18	46.0	21.3	24.7
Jun	1	Mid	1.02	4.12	41.2	23.3	17.9
Jun	2	Late	0.99	3.96	39.6	25.3	14.3
Jun	3	Late	0.92	3.50	35.0	33.9	1.1
Jul	1	Late	0.87	3.18	6.4	9.1	6.4
					386.9	257.5	139.7

Appendix-A9: Mojocrop water requirement of tomato.

ETo station		MOJO	Crop		Tomato		
Rain station		MOJO	Planting date		28/02		
Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Feb	3	Init	0.60	1.18	1.2	1.1	1.2
Mar	1	Init	0.60	1.39	13.9	12.4	1.6
Mar	2	Init	0.60	1.61	16.1	15.3	0.8
Mar	3	Deve	0.60	1.79	19.7	17.1	2.6
Apr	1	Deve	0.70	2.26	22.6	19.3	3.3
Apr	2	Deve	0.83	2.91	29.1	21.5	7.6
Apr	3	Deve	0.96	3.57	35.7	20.8	14.9
May	1	Mid	1.09	4.27	42.7	19.0	23.7
May	2	Mid	1.12	4.65	46.5	18.2	28.3
May	3	Mid	1.12	4.59	50.5	21.3	29.2
Jun	1	Mid	1.12	4.53	45.3	23.3	22.0
Jun	2	Mid	1.12	4.47	44.7	25.3	19.4
Jun	3	Late	1.08	4.11	41.1	33.9	7.3
Jul	1	Late	0.96	3.49	34.9	45.7	0.0
Jul	2	Late	0.84	2.91	29.1	54.8	0.0
Jul	3	Late	0.76	2.56	5.1	9.6	5.1
					478.3	358.4	166.9

Appendix-A10:Mojo all Major cropping pattern and irrigation schemes (required)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo station	MQJO											
Rain station	MQJO											
Cropping pattern												
Precipitation deficit												
1. Onion	0.0	1.4	14.8	33.0	66.7	21.0	0.0	0.0	0.0	0.0	0.0	0.0
2. CABBAGE Crucifers	0.0	1.4	13.1	16.5	54.7	37.1	0.0	2.8	0.0	0.0	0.0	0.0
3. MAIZE (Grain)	0.0	0.6	0.0	39.5	87.8	26.1	2.7	0.0	0.0	0.0	0.0	0.0
4. Sweet Peppers	0.0	1.2	5.0	23.9	69.9	33.3	6.4	0.0	0.0	0.0	0.0	0.0
5. Tomato	0.0	1.2	5.0	25.8	81.2	48.6	5.1	0.0	0.0	0.0	0.0	0.0
Net scheme irr. req.												
in mm/day	0.0	0.0	0.4	1.0	2.2	0.8	0.1	0.0	0.0	0.0	0.0	0.0
in mm/month	0.0	1.3	11.8	30.4	68.2	25.4	1.7	0.1	0.0	0.0	0.0	0.0
in l/s/h	0.00	0.01	0.04	0.12	0.25	0.10	0.01	0.00	0.00	0.00	0.00	0.00
Irrigated area	0.0	100.0	98.0	100.0	100.0	100.0	29.0	2.0	0.0	0.0	0.0	0.0
(% of total area)												
Irr. req. for actual area	0.00	0.01	0.05	0.12	0.25	0.10	0.02	0.01	0.00	0.00	0.00	0.00
(l/s/h)												

Appendix-A11: Mojo Croppin pattern and water supply schemes.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo station	MQJO											
Rain station	MQJO											
Cropping pattern												
Precipitation deficit												
1. Onion	0.0	1.4	14.8	33.0	66.7	21.0	0.0	0.0	0.0	0.0	0.0	0.0
2. CABBAGE Crucifers	0.0	1.4	13.1	16.5	54.7	37.1	0.0	2.8	0.0	0.0	0.0	0.0
3. MAIZE (Grain)	0.0	0.6	0.0	39.5	87.8	26.1	2.7	0.0	0.0	0.0	0.0	0.0
4. Sweet Peppers	0.0	1.2	5.0	23.9	69.9	33.3	6.4	0.0	0.0	0.0	0.0	0.0
5. Tomato	0.0	1.2	5.0	25.8	81.2	48.6	5.1	0.0	0.0	0.0	0.0	0.0
Net scheme irr. req.												
in mm/day	0.0	0.0	0.4	1.0	2.2	0.8	0.1	0.0	0.0	0.0	0.0	0.0
in mm/month	0.0	1.3	11.8	30.4	68.2	25.4	1.7	0.1	0.0	0.0	0.0	0.0
in l/s/h	0.00	0.01	0.04	0.12	0.25	0.10	0.01	0.00	0.00	0.00	0.00	0.00
Irrigated area	0.0	100.0	98.0	100.0	100.0	100.0	29.0	2.0	0.0	0.0	0.0	0.0
(% of total area)												
Irr. req. for actual area	0.00	0.01	0.05	0.12	0.25	0.10	0.02	0.01	0.00	0.00	0.00	0.00
(l/s/h)												

ETo file	Rain file	Crop file	Soil file	Planting date	Crop pat file	Schedule file
mojo climate.pem	mojo rain fall.crm	mojo onoin.cro	mojo soil.soi	28/02	untitled	

Appendix-A12: mojo major crop developing stages

Nov	1	Init	0.40	0.50	5.0	10.9	0.0
Nov	2	Init	0.40	0.41	4.1	7.8	0.0
Nov	3	Init	0.40	0.33	3.3	6.8	0.0
Dec	1	Deve	0.47	0.30	3.0	6.0	0.0
Dec	2	Deve	0.60	0.26	2.6	4.7	0.0
Dec	3	Deve	0.74	0.37	4.0	4.1	0.0
Jan	1	Deve	0.87	0.50	5.0	3.3	1.6
Jan	2	Deve	1.00	0.64	6.4	2.5	3.9
Jan	3	Mid	1.13	1.01	11.2	2.9	8.2
Feb	1	Mid	1.17	1.35	13.5	2.2	11.4
Feb	2	Mid	1.17	1.65	16.5	1.8	14.7
Feb	3	Mid	1.17	2.02	16.2	7.2	9.0
Mar	1	Mid	1.17	2.39	23.9	13.0	10.9
Mar	2	Mid	1.17	2.75	27.5	17.6	9.9
Mar	3	Mid	1.17	3.08	33.9	23.2	10.7
Apr	1	Mid	1.17	3.41	34.1	30.5	3.6
Apr	2	Mid	1.17	3.74	37.4	36.8	0.6
Apr	3	Mid	1.17	3.96	39.6	35.8	3.8
May	1	Mid	1.17	4.19	41.9	35.1	6.7
May	2	Mid	1.17	4.41	44.1	35.5	8.6
May	3	Mid	1.17	4.48	49.3	30.8	18.5
Jun	1	Mid	1.17	4.56	45.6	23.2	22.4
Jun	2	Mid	1.17	4.63	46.3	17.8	28.5
Jun	3	Mid	1.17	4.49	44.9	23.4	21.5
Jul	1	Mid	1.17	4.35	43.5	30.9	12.6
Jul	2	Mid	1.17	4.21	42.1	35.6	6.5
Jul	3	Late	1.17	4.03	44.3	37.2	7.1
Aug	1	Late	1.13	3.72	37.2	39.5	0.0
Aug	2	Late	1.07	3.39	33.9	41.9	0.0
Aug	3	Late	1.02	2.98	32.8	39.9	0.0
Sep	1	Late	0.96	2.60	26.0	38.7	0.0

Appendix-A13: Estimation of total crop water requirement and irrigation requirement

Crop	CWR(mm)	Effective Rain (mm)	Net IR(mm)
Cabbage	510.1	94.9	431.1
Maize	376.1	132.1	258.6
Onion	370.3	36.9	338.6
Tomato	477	75.1	414.5
Pepper	385.8	34.7	362.8

AppendixA13:cont.....

Month	Cabbage	Onion	Maize	Tomato	Pepper
March	54.5	54.2	11.2	44.8	53.1
April	56	81.8	71.9	73.9	79.9
May	96.1	121.5	113.5	119.9	124
June	107	79.9	61.9	119	106.1
July	92.7			56.7	
Aug	24.8				

Appendix-A14:Monthly irrigation Requirement (MCM) for each Major crop of Mojo Watershed

Crop types	Area(ha)	March	April	May	June	July	Aug
Cabbage	64	0.035	0.036	0.062	0.068	0.06	0.02
Onion	2265.5	1.2	1.8	2.7	1.8		
Maize	72	0.0081	0.052	0.082	0.045		
Pepper	753.5	0.4	0.6	0.09	0.8		
Tomato	137.53	0.062	0.1	0.16	0.16	0.078	
Total	3292.53	1.7051	2.588	3.094	2.873	0.138	0.02

APPIDIX –A15: water supply, INgross, critical command area of Major crops

Supply and gross irrigation needs as well as critical command area for onion crops

Months	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
SWS(MCM)	5.51	5.54	5.82	6.8	8.3	14.1	41.7	71.2	29.9	7.6	5.6	5.5
SWS(li/s)	640	641.2	673.6	787.03	960.7	1631.9	4826.4	8240.7	3460.7	879.6	648.2	686.6
Ingross(li/se/ha)			6.09	10.6	20.5	18	2.9					
CA(ha)			110.61	74.25	46.86	90.66	1664.3					

Appendix-A15: Cont.....

Mean water supply and gross needs as well as critical command area for cabbage crop

Months	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
SWS(MCM)	5.51	5.54	5.82	6.8	8.3	14.1	41.7	71.2	29.9	7.6	5.6	5.5
SWS(li/s)	640	641.2	673.6	787.03	960.7	1631.9	4826.4	8240.7	3460.7	879.6	648.2	686.6
Ingross(li/se/ha)			5.63	9.33	13.26	17.05	15.27	8.29				
CA(ha)			119.65	84.35	72.45	95.71	316.07	994.05				

Appendix-A15:cont.....

Mean water supply and gross irrigation need as well as critical command area of Maize crops.

Months	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
SWS(MCM)	5.51	5.54	5.82	6.8	8.3	14.1	41.7	71.2	29.9	7.6	5.6	5.5
SWS(li/s)	640	641.2	673.6	787.03	960.7	1631.9	4826.4	8240.7	3460.7	879.6	648.2	686.6
Ingross(li/se/ha)			1.86	6.33	18.5	13.74	2.66					
CA(ha)			362.15	124.33	51.93	118.77	1814.4					

Appendix-A15: cont.....

Mean water supply and gross irrigation need as well as critical command area of Tomato crops.

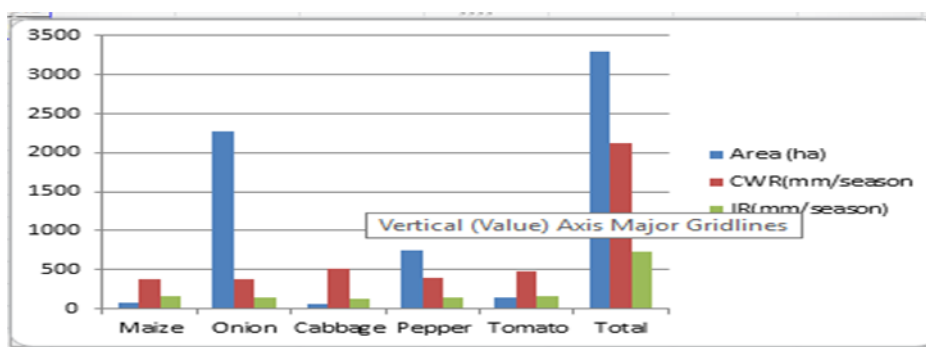
Months	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
SWS(MCM)	5.51	5.54	5.82	6.8	8.3	14.1	41.7	71.2	29.9	7.6	5.6	5.5
SWS(li/s)	640	641.2	673.6	787.03	960.7	1631.9	4826.4	8240.7	3460.7	879.6	648.2	686.6
Ingross(li/se/ha)			5.04	10.36	17.49	19.75	15.26					
CA(ha)			133.65	44.998	54.93	82.63	316.3					

Appendix-A15;Cont....

Mean water supply and gross irrigation need as well as critical command area of Pepper crops.

Months	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
SWS(MCM)	5.51	5.54	5.82	6.8	8.3	14.1	41.7	71.2	29.9	7.6	5.6	5.5
SWS(li/s)	640	641.2	673.6	787.03	960.7	1631.9	4826.4	8240.7	3460.7	879.6	648.2	686.6
Ingross(li/se/ha)			6.17	11.55	19.44	18.63	5.24					
CA(ha)			109.17	68.14	49.42	90.42	921.067					

Appendix 15.5CWR & IR of Major crops in watershed area



Appendix –A16: Mean Monthly Mojo watershed rainfall (mm).

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1987	2.02	5.32	4.98	48	95.75	111.81	226.71	237.06	46.16	0.57	2.08	0.09	780.55
1988	32.3	7.6	52.1	46.0	46.0	112.1	161.3	274.8	149.0	154.1	0.0	2.65	1037.95
1989	8.3	20.3	18.4	0.0	4.2	90.9	541.5	282.1	67.4	87.4	0.0	0.02	1120.56
1990	0.0	0.8	12.0	10.1	33.2	128.0	285.9	230.8	114.1	12.6	25.4	2.46	855.32
1991	27.8	21.8	26.7	74.8	13.6	121.7	235.8	171.8	71.4	99.9	10.9	0.0	876.2
1992	32.0	51.4	13.9	77.2	41.8	77.7	206.3	293.5	97.6	93.3	0.0	0.0	984.7
1993	0.5	0.0	36.6	64.2	10.0	176.8	298.7	258.6	48.7	27.3	0.0	0.0	921.4
1994	14.55	43.34	17.34	97.33	8.02	53.97	365.03	275.78	65.59	0.4	0	0.76	942.11
1995	41.2	5.4	9.9	48.5	14.0	86.2	182.9	287.0	82.9	27.4	10.7	1.9	798
1996	2.0	19.5	0.0	83.3	73.0	76.2	286.5	216.6	82.1	5.4	0.0	0.0	844.6
1997	25.24	40.94	15.92	65.91	12.38	99.83	496.75	157.76	58.74	5.43	0	0.07	978.97
1998	0.0	56.2	34.0	59.2	32.7	182.8	66.1	65.1	72.6	3.1	0.0	0.0	571.8
1999	0.0	22.8	96.6	75.7	205.3	8.9	154.3	233.6	53.3	14.5	0.0	0.0	865
2000	20.5	6.5	6.8	29.7	10.7	124.8	255.7	300.7	243.3	62.8	0.0	0.0	1061.5
2001	0.0	14.9	125.1	84.9	0.2	77.0	175.5	415.3	116.4	22.5	0.0	1.8	1033.6
2002	0.0	131.1	48.2	54.6	3.1	20.6	291.8	228.9	125.4	0.4	0.0	0.0	904.09
2003	5.26	0.14	28.04	2.77	9.75	56.07	359.65	103.27	17.25	24.94	0.09	0.36	607.59
2004	0.0	85.2	7.7	151.9	119.5	73.4	254.2	170.4	246.7	0.0	1.4	0.0	1110.4
2005	2.99	0.96	50.49	4.26	18.14	35.28	139.97	364.9	39.79	5.67	0.26	2.09	664.8
2006	0.0	11.5	8.6	50.4	65.4	77.4	244.3	217.2	139.4	9.5	23.4	13.15	860.24
2007	0.0	4.6	166.4	21.8	104.0	79.5	242.3	143.4	64.3	38.2	0.0	14.32	878.82
2008	8.6	0.0	48.0	34.6	11.0	109.1	179.3	178.0	58.4	0.0	0.0	4.41	631.41
2009	38.3	55.4	64.4	100.3	21.1	81.4	277.9	285.5	120.0	6.0	3.6	0.0	1053.9
2010	0.3	6.1	67.8	119.9	2.0	133.5	172.5	209.1	73.6	22.6	10.3	6.11	823.77
2011	4.19	2.51	3.45	30.04	17.52	279.63	536.14	72.56	72.32	2.86	4.23	0.42	1025.87
2012	0.67	0.98	2.2	26.64	12.28	108.38	243.9	251.72	31.32	2.81	13.23	0.06	694.19
2013	20.3	0.64	26.7	15.57	4.8	8.63	312.44	108.56	11.55	16.69	1	23.32	550.2
2014	40.6	55.9	74.9	84.3	23.2	129.0	393.2	148.6	96.1	0.0	0.0	14.3	1060.1
2015	54.1	23.7	83.8	31.2	111.0	129.7	222.8	227.9	91.4	7.6	0.0	0.2	983.43
2016	12.1	32.7	18.2	258.7	83.6	117.7	531.6	163.9	76.8	2.9	31.5	0.0	1329.7
2017	3.86	2.25	19.78	28.58	5.12	64.44	487	483.78	107.01	0	7.5	0.39	1209.71

Appendix –A17: Mojo station hydrological parameter input

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TMPMX	27.5	26.34	27.1	29.89	28.65	28.66	25.97	26.59	25.575	25.29	24.75	25.69
TMPMN	10.03	12.04	12.29	12.82	12.41	14.72	15.03	13.73	9.12	8.6	8.57	8.67
TMPSTDMX	1.09	1.98	1.98	1.99	2.6	2.9	3.90	3.2	1.985	1.98	1.87	1.54
TMPSTDMN	4.79	2.61	2.64	2.2	2.22	1.93	1.35	1.88	2.37	2.27	2.29	2.57
PCPMM	10.65	8.73	17.49	37.14	34.26	114.79	362.63	213.11	48.99	5.14	1.51	4.32
PCPSTD	1.68	2.87	3.72	9.03	7.85	17.08	30.6	19.65	8.24	2.35	0.29	0.63
PCPSKW	8.62	21.98	11.38	11.43	9.86	8.26	4.46	5.82	9.02	24.05	7.8	7.49
PR_W1	0.01	0.08	0.08	0.08	0.06	0.28	0.54	0.42	0.11	0.04	0.03	0.06
PR_W2	0.81	0.52	0.48	0.5	0.47	0.73	0.8	0.78	0.56	0.34	0.46	0.52
PCPD	2.37	4.17	4.37	4.53	3.37	15.6	23.6	21.8	7.2	1.9	1.67	3.73
RAINHHMX	3.55	2.91	5.83	12.38	11.42	38.26	120.88	71.04	16.33	1.71	0.5	1.44
SOLARAV	30.61	33.27	34.68	34.74	34.56	32.22	29.18	30.77	33.91	33.5	31.64	30.35
DEWPTAV	7.2	7.4	9.06	10.69	9.77	14.11	15.72	15.67	12.71	8.26	6.54	6.51
WNDVAV	2.61	2.68	2.66	2.82	2.78	2.01	1.78	1.65	1.86	2.68	2.75	2.7
HMDAV	0.47	0.44	0.46	0.5	0.48	0.58	0.71	0.74	0.65	0.52	0.47	0.48

Appendix –A18 Mean Monthly Observed Discharge Stream Flow (mm) at Mojo gauge station

YEAR	JAN	FAB	MAR	APR	MAY	JUN	JUL	AUG	SEP	NOV	OCT	DEC	ANNUA
1987	0.73	1.02	4.74	11.51	8.82	16.53	31.82	87.69	26.48	4.54	1.53	1.02	196.
1988	0.73	0.67	0.53	1.21	1.12	6.06	42.29	156.12	110.88	13.22	2.22	1.41	336.
1989	1.53	2.31	1.80	4.24	1.23	4.21	69.77	97.22	82.28	7.39	2.09	1.61	275.
1990	1.11	3.87	3.70	6.59	1.36	6.03	51.85	124.08	73.89	10.63	2.06	1.38	286.
1991	1.16	1.23	3.68	0.87	0.79	4.77	61.68	133.36	90.23	5.31	1.54	1.40	306.
1992	1.23	2.45	1.20	2.19	2.25	7.83	43.16	115.42	84.00	10.44	2.39	1.84	274.
1993	1.55	2.20	1.06	6.76	7.71	18.79	68.80	172.46	110.19	21.58	3.68	2.16	416.
1994	1.65	1.08	1.17	1.83	1.56	8.34	44.12	110.58	77.18	11.48	2.78	1.75	263.
1995	1.27	1.11	0.83	4.33	3.56	6.40	43.60	113.14	91.42	4.88	1.91	1.22	273.
1996	2.18	0.78	3.36	7.25	8.35	40.91	104.84	197.80	88.60	8.37	2.91	2.05	467.
1997	1.81	1.20	0.82	2.27	1.60	6.56	45.86	87.55	20.85	5.06	4.04	1.71	179.
1998	2.37	1.37	4.35	2.05	4.70	16.16	78.84	191.86	107.89	24.84	3.69	2.18	440.
1999	1.62	0.94	1.38	0.66	1.61	8.78	76.42	108.00	108.83	33.51	3.62	1.77	347.
2000	1.56	0.97	1.22	1.73	2.94	6.51	43.17	116.22	67.75	22.04	3.80	2.44	270.
2001	1.67	1.43	2.80	2.60	5.00	23.66	76.15	133.52	63.83	6.30	3.00	2.23	322.
2002	3.42	1.91	2.38	4.86	2.00	12.35	58.89	128.26	43.77	3.78	1.73	1.96	265.
2003	1.80	0.94	2.79	4.47	3.48	14.59	121.79	146.74	105.62	9.16	2.81	2.19	416.
2004	2.07	1.33	1.29	9.05	2.92	20.54	80.11	138.25	66.85	11.68	3.21	2.02	339.
2005	1.83	0.86	3.70	3.64	16.54	16.26	102.50	161.99	82.19	11.59	3.38	2.65	407.
2006	1.61	1.17	5.63	9.90	18.62	20.23	134.57	327.09	187.75	7.38	3.11	2.02	719.
2007	0.37	0.48	0.45	1.10	3.19	7.58	13.58	35.33	18.60	1.15	0.65	0.68	83.
2008	0.65	0.23	0.09	0.51	0.72	2.16	11.97	43.29	7.40	0.77	1.04	0.54	69.
2009	0.54	0.22	0.17	0.91	0.46	0.45	6.61	17.78	8.13	1.50	0.40	0.48	37.
2010	0.34	0.32	0.67	2.29	3.23	3.22	14.58	15.02	13.17	0.68	0.45	0.37	54.
2011	0.54	0.22	0.17	0.91	0.46	0.45	6.61	17.78	8.13	1.50	0.40	0.48	37.
2012	0.48	0.26	0.21	0.72	0.53	1.89	8.45	26.38	5.66	0.58	0.48	0.40	46.
2013	0.32	0.20	0.64	0.63	0.68	4.04	25.54	9.38	6.61	1.15	1.11	0.83	51.
2014	1.87	4.86	3.44	5.21	4.62	3.54	69.24	89.91	36.47	4.35	1.89	1.35	226.
2015	1.12	3.60	9.16	4.12	0.95	4.94	111.61	183.80	108.18	35.84	3.56	2.01	468.
2016	2.07	1.26	0.81	2.75	7.37	39.50	144.52	195.24	133.36	17.40	3.33	5.04	552.
MEAN	1.37	1.35	2.14	3.57	3.95	11.11	59.76	116.04	67.87	9.94	2.29	1.64	281.

Appendix-A19: Mean monthly simulated discharges of stream flow(m³/se) in Mojo gauge

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEP	OCT	NOV	DEC	ANNUAL
1987	5.93	5.61	5.72	3.56	7.93	4.19	70.52	50.03	40.27	4.37	3.75	3.54	205.42
1988	3.91	2.38	2.73	1.87	4.44	186.5	263.92	167.32	79.35	15.42	11.11	9.87	748.82
1989	10.63	6.1	6.31	72.19	91.49	109.9	201.42	107.5	83.01	51.05	26.9	3.79	770.29
1990	7.75	4.41	2.47	3.15	5.89	34.72	206.41	218.08	29.74	12.44	8.22	7.38	540.66
1991	6.57	4.89	4.97	3.84	3.78	10.31	91.1	26.13	6.35	6.48	3.14	2.76	170.32
1992	0.3	0	0.01	1.49	27.32	3.49	36.98	135.34	12.4	3.71	3.1	3.22	227.36
1993	2.18	1.7	5.23	1.35	2.02	5.7	26	113.34	19.6	3.22	2.46	2.3	185.1
1994	2.16	1.87	2.77	1.33	1.09	4.63	7.34	21.61	2.62	0.73	0.63	1.18	47.96
1995	1.2	1.67	4.07	7.9	0.52	4.47	39.25	160.65	8.94	3.7	3.22	4.45	240.04
1996	4.35	2.22	2.26	6.77	1.4	9.02	131.36	37.2	5.56	3.15	2.41	2.03	207.73
1997	4.97	1.36	2.64	16.42	17.67	7.79	57.39	29.3	12.21	2.2	2	1.63	155.58
1998	1.45	4.54	1.23	1.36	1.16	2.48	35.14	66.94	21.61	5.05	2.79	1.96	145.71
1999	1.54	1.18	1.61	1.54	2.52	77.31	253.02	20.15	15.96	4.39	3.52	3.04	385.78
2000	2.62	2.12	1.96	2.31	1.96	15.45	74.22	94.06	8.04	3.26	4.42	2.37	212.79
2001	4.04	1.61	2.2	2.57	1.38	1.57	115.22	206.43	86.31	53.19	1.4	3.28	479.2
2002	9.4	8.04	34.6	20.59	45.89	600.32	783.26	326.77	162.28	16.98	9.9	6.09	2024.12
2003	24.56	0	17.43	27.19	61.34	78.64	280.01	258.3	15.28	107.9	11.21	1.44	883.3
2004	1.54	1.18	1.61	1.54	2.52	77.31	253.02	20.15	15.96	4.39	3.52	3.04	385.78
2005	1.35	9	23.26	19.73	41.25	152.19	276.85	184.07	126.32	2.96	0.17	1.95	839.1
2006	9.4	0.67	34.6	20.59	45.89	600.32	783.26	326.77	162.28	0.28	3.89	0.43	1988.38
2007	6.3	3.9	7.93	1872	306.3	501.4	193.65	108.4	89.26	53.1	18.4	2.38	3163.02
2008	79.35	15.42	11.11	9.87	263.92	167.32	186.5	3.91	2.38	2.73	1.87	4.44	748.82
2009	6.84	35.8	7.28	3.79	93.36	93.7	110.56	10.63	6.1	6.31	5.25	4.48	384.1
2010	6.35	6.48	3.14	2.76	10.31	91.1	26.13	6.57	4.89	4.97	3.84	3.78	170.32
2011	3.11	1.78	1.61	1.54	2.52	77.31	253.02	20.15	15.96	4.39	3.52	3.04	387.95
2012	0.28	3.89	0.43	600.32	783.26	326.77	162.28	45.89	0.67	34.6	20.59	0.67	1979.65
2013	7.04	14.35	3.98	13.45	14.99	19.34	56.4	105	11.23	4.56	6.12	1.56	258.02
2014	2.12	10.4	23.26	19.73	87.91	189.03	276.85	184.07	126.32	2.96	0.17	1.95	924.77
2015	12.76	12.42	15.48	32.19	45.76	123.56	253.02	39.76	27.91	4.39	3.52	3.04	573.81
2016	10.12	18.34	13.79	87.57	109.11	361.06	383.11	105.2	29.09	38.54	30.12	11.09	1197.14

Appendix-A20;Mojo irrigation scheme, tributaries, area(ha), Major Crop, Householder, year constructed and woreda used.

No	Name of the schemes	Location			River Basin	Sub Basin	Source of water	Prod.Area (Ha)		Benefi.(HH)		*Irrigated Crops		Ownership of scheme	Constructed
		Zone	District	PA				Potential	Developed	Planned	Actual	*major	*minor		
65	Sardo Irrigation	East Shoa	Ada'a	Dankaka				50	50	100	70	Tomato	Onion	Farmers	
66	Dabala 1st Irrigation	East Shoa	Ada'a	Katila	Awash	Mojo	Mojo	10	10	10	10	Onion	Tomato	"	
67	Dabala 2nd Irrigation	East Shoa	Ada'a	"	"	"	"	50	50	50	50	"	"	"	
68	Katila Irrigation	East Shoa	Ada'a	"	"	"	"	40	40	100	100	"	"	"	
69	Kaliti 3rd irrigation	East Shoa	Ada'a	kaliti	"	"	"	80	80	178	178	"	"	"	
70	Cirimo irrigation	East Shoa	Ada'a	Karfe	"	"	"	2.75	2.75	10	10	"	"	"	
73	Karfee	East Shoa	Ada'a	Karfe	"	"	"	30	30	60	60	"	"	"	
74	Sirba Udee irrigation	East Shoa	Ada'a	udee	"	Mojo	Mojo	5.6	5	20	15	"	"	community	2000E.C
75	Daloo	East Shoa	Ada'a	Dankaka	"	"	GW	15	15	40	40	"	"	Farmers	
76	Dankaka "	East Shoa	Ada'aa	"	"	"	Mojo	20	20	30	30	"	"	"	
77	Kalitti 2nd "	East Shoa	Ada'aa	Kalitti	"	"	"	270	270	632	632	"	"	"	
78	Bacha Belda "	East Shoa	Ada'aa	Deneka	"	"	"	6	6	1	1	"	"	Individual	
79	Dakko "	East Shoa	Ada'aa	Deko	"	"	GW	3.25	3.25	20	20	"	"	"	
80	Hora "	East Shoa	Ada'aa	Hidii	"	"	Mojo	4	3.25	4	4	"	"	"	
82	Koftu "	East Shoa	Ada'aa	Kaftu	"	"	"	60	60	70	70	"	"	Farmers	
83	Kalitti 1st "	East Shoa	Ada'aa	Kalitti	"	Mojo	Mojo	30	30	40	40	"	"	"	
84	Borora Guda "	East Shoa	Ada'aa	Hidii	"	"	"	150	150	350	350	"	"	"	
85	Hidii "	East Shoa	Ada'aa	Hidii	"	"	"	20	20	60	60	"	"	"	
86	Hidi 2nd "	East Shoa	Ada'aa	"	"	"	"	6.5	6.5	5	5	"	"	"	
88	Sardo 2nd "	East Shoa	Ada'aa	Dankaka	"	"	"	8	8	25	25	Onion	Tomato	Farmers	
90	gayeirri	East Shoa	Ada'aa	Dankaka	"	Mojo	Mojo	367.5	349	723	723	Onion	"	Farmers	
91	Genesiss Farm	East Shoa	Ada'aa	Kuriftu	"	Mojo	River	35	30	3	3	Onion	Lettose	Commerical	1993
94	Solagraw PLC	East Shoa	Ada'aa	Hidii	"	"	G/Water	11.25	7	1	1	"	Tomato	Solgro	2009
109	Daya	East Shoa	Lume	Koka	"	Mojo	G/Water	247.25	227	72	66	Onion	Cabbage	Individual farmer	2000
110	Argisa	East Shoa	Lume	Koka	Awash	Mojo River	River & Shallow well	492	422	135	133	"	"	Individual	"
111	Dunqugi Laftu	East Shoa	Lume	Dun.Boka	"	"	"	86	61	22	20	"	"	Individual farmer	"

Appendix-A20: Continuous.....

112	Dhunqugi Bakale Koramtu	East Shoa	Lume	"	"	"	"	744	683	293	293	Water Melon	Pepper	"	"	"
113	Ejarsa Lafto	East Shoa	Lume	"	"	"	"	72	68	23	23	Onion	Cabbage	"	"	"
114	Deneba	East Shoa	Lume	Ejarsa	"	"	Natural pond	80	65	186	186	Tomato	Lead cabbage	"	"	2002 2002
115	Arega	East Shoa	Lume	jiyo. Bisk	"	"	River & Shallow well	11	5.5	21	21	Water Milan	Pepper	"	"	2008 2008
116	Ballii	East Shoa	Lume	jiyo. Bisk	"	"	River	14	14	1	1	Onion	Tomato	Investare	"	2004 2004
117	Jirmi	East Shoa	Lume	B/Abo	"	"	"	38	34	85	76	"	Pepper	Individual farmer	"	2007 2007
118	Jogola	East Shoa	Lume	J/Inselale	"	"	"	40	3	70	4	"	Tomato	"	"	2005 2005
119	Golba Zeyto	East Shoa	Lume	A/Jogola	"	"	"	27	0.5	54	1	"	-	"	"	2006 2006
120	Dibandiba	East Shoa	Lume	Sh/dib	"	"	"	17.57	5.25	37	1	"	Tomato	"	"	2009 2009
121	Taffiabo	East Shoa	Lume	Sh/dibe	"	"	"	16	13	16	13	"	Sweetpot	"	"	2005 2005
122	Shulki	East Shoa	Lume	TaffiAbo	"	"	"	6.5	3.5	125	125	"	Pepper	"	"	2008 2008
123	Adada Danbala	East Shoa	Lume	Koka	"	"	"	78	72	35	31	"	Cabbage	"	"	2000 2000
124	Darara Danbala	East Shoa	Lume	Adada Danbala	"	"	Shallow well River &	38	35	90	90	"	Soya bean	"	"	2005 2005
125	Edgat Ethiopia	East Shoa	Lume	Darara Danbala	"	"	"	80	45	240	240	"	Soya bean	"	"	2005 2005
126	Yaya PLC	East Shoa	Lumee	Koka	"	"	"	10	8	1	1	"	Papaya	Investare	"	2006 2006
127	Almeta PLC	East Shoa	Lumee	"	"	"	Shallow well	43	30	1	1	Maize	Tomato	Commrcal	"	2004 2005
128	Ethio Veg-Fruit	East Shoa	Lumee	"	"	"	River	42	42	1	1	Grap	Mint	"	"	2005
129	Desaplant PIC	East Shoa	Lumee	"	"	"	River & Deep well	100	100	1	1	Onion	Pepper	"	"	2006
130	Red Fax PLC	East Shoa	Lumee	Bika	"	"	"	4	4	1	1	Omamental	-	"	"	2007 2008
131	Florensis Ethiopia PLC	East Shoa	Lumee	Koka	"	"	Deep well	33	33	1	1	"	-	"	"	2004 2005
132	Syngenta flower Eth.Cuttings PLC	East Shoa	Lumee	"	"	"	River	20	9	1	1	"	Pepper	"	"	2004 2006
133	Jitu Horticulture	East Shoa	Lumee	"	"	"	River & deep well	18	18	1	1	"	-	"	"	2006
134	Water Harvesting	East Shoa	Lumee	"	"	"	"	20	19.5	1	1	Onion	Pepper	"	"	2005 2007
135	Reta (Gegoti)	East Shoa	Lumee	Muda	"	"	River	30	30	1	1	Strobarry	"	"	"	2004 2006
136		East Shoa	Lumee	Kurmas Jogo	"	"	Deppwell	2	2	4	4	Onion & perinial	Farmer	"	"	2004
171		E/Shoa	L/Quqal	"	"	"	Rain	2.53	2.53			Onion	Tomato	"	"	
				"	"	Mojo	"									

Appendix A 21 parameters required for sensitivity evaluation analysis.

S.N	Parameters	Description of parameters	Min	Max	Category
1	r_CN ₂	Runoff Curve Number	35	98	.mgt
2	v_ALPH_BF	Base flow alpha factor(days)	0	1	.gw
3	v_GW_DELAY	Ground water delay (days)	30	450	.gw
4	a_GWQMN.gw	Deer percolation(mm)	0	25	.gw
5	r_sol_z	Soil depth (mm)	-0.8	0.8	.sol
6	v_RCHRG. Dp	Deep aquifer percolation fraction	0	1	.gw
7	a_ESCO_.hru	Soil evaporation compensation factor	0	0.2	.hru
8	r_SLSUBBSN	Average slope length	0	0.2	.hru
9	r_HRU_SLP	Average slope steepness	0	0.2	.hru
10	v_CH_N ₂	Manning coefficient of tributary channel	0	0.5	.rte
11	v_CH_K ₂	Hydraulic conductivity(mm/hr)	5	130	.rte
12	v_ALPHA_BNK	Base flow alpha factor for bank storage	0	1	.rte
13	v_SURLAG	Surface runoff lag coefficient	0	10	.bsn
14	r_OV_N	manning's values over land flow	-0.2	0	.hru
15	v_REVAPMN	Threshold depth of water(mm)	0	500	.gw
16	a_SOL_ALB	Soil albedo	-0.01	0.3	.sol
17	a_EPCO.hru	Plant uptake factor	0	0.2	.hru
18	r_SOL-K	Soil hydraulic conductivity(mm/hr)	-0.5	0.5	.sol
19	r_SOL_AWC	Available water capacity of a soil	-0.5	0.5	.sol
20	r_GW_REVAP	Ground water evaporation coefficient	0	0.2	.gw
21	v_TLAPS.sub	Temperature labs rate(⁰ C/km)	-10	10	.sub
22	r_BIAI.cop.dat	Max. leaf area index	2.0	8.0	.crop.dat
23	r_SOL_BD.sol	Moist soil albedo	-0.75	1.50	.sol

Appendix 22. Total area of Major Crops planned and developed in Mojo Watershed

Major Crops	Potential Area (ha)	Developed Area(ha)
Maize	85.00	72.00
Onion	2430.95	2265.5
Cabbage	69.00	64.00
Tomato	152.53	137.53
Pepper	820.00	753.50
Totals	3557.48	3292.53