ASSESSMENT OF LAND SUITABILITY FOR SURFACE IRRIGATION AND OPTIMAL ALLOCATION OF WATER RESOURCES IN MODJO RIVER WATERSHED (UPPER AWSH RIVER BASIN IN ETHIOPIA)

By

Rekiya Muhammed Belete

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

Presented in Partial Fulfillment of the Requirements for the Degree of Master of Science in Water Resources Engineering (Specialization in Irrigation Engineering)

Office of Graduate Studies
Adama Science and Technology University

August, 2021
Adama, Ethiopia

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APPROVAL PAGE OF THE MSC THESIS

I, the advisor of the thesis entitled "**Assessment of Land Suitability for Surface Irrigation Potential and Optimal Allocation of Water Resources in Modjo River Watershed**" and developed by Rekiya Muhammed Belete, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

______________________	______________________	______________________
Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Rekiya Muhammed Belete have read and evaluated the thesis entitled "Assessment of Land Suitability for Surface Irrigation and Optimal Allocation of water resource in Mojo River Watershed" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Mater of Science in Water Resources Engineering (Specialization in Irrigation Engineering).

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Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the office of postgraduate studies (OPGS) through the Department Graduate Committee (SGC).

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Office of Postgraduate Studies, Dean	Signature	Date

DECLARATION

I hereby declare that this Master Thesis entitled "**Assessment of Land Suitability for Surface Irrigation Potential and Optimal Allocation of Water Resources in Modjo River Watershed**" is my original work. That is, it has not been submitted for the award of any academic, degree, diploma or certificate in any other university. **All sources of materials that are used for this thesis have been duly acknowledged through citation.**

Rekiya Muhammed Belete	________________	_________________
Name of the student	Signature	Date

RECOMMENDATION OF THE ADVISOR

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "**Assessment of Land Suitability for Surface Irrigation and Optimal Allocation of Water Resources in Modjo River Watershed**" prepared under my guidance by Rekiya Muhammed Belete submitted in partial fulfillment of the requirements for the degree of Master of Science in Water Resource Engineering (specialization in Irrigation Engineering). Therefore, I recommend the submission of for further education based on the thesis to the department following the applicable procedures.

______________	___________	___________
Name of Advisor	Signature	Date

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ACRONOMS AND ABBREVIATIONS

AHP	Analytical Hierarchy Process
BCM	Billion Cubic Meter
CROPWAT	Crop Water Assessment Tool
CWR	Crop Water Requirement
DEM	Digital Elevation Model
DSS	Decision Support System
ERA	Ethiopia Road Authority
ETc	Crop Evapotranspiration
ET_O	Reference Crop Evapotranspiration
FAO	Food and Agricultural Organization
GIS	Geographic Information System
GIWR	Gross Irrigation Water Requirement
IWRM	Irrigation Water Requirement Management
Kc	Crop Coefficient
LULC	Land Use Land Cover
M a.s.l.	Meter above Sea Level
MCM	Million Cubic Mete
MCP	Marginal Cost Pricing
MDD	Maximum Daily Demand
MODSIM	Modular Simulation Model
MoWR	Ministry of Water Resources
N	Not Suitable
NMSA	National Meteorological Service Agency
NRCS	Natural Resources Conservation Service
NSE	Nash-Sutcliff Efficiency
PEST	Parameter Estimation
S_1	Highly Suitable
S_2	Moderately Suitable
S_3	Marginal Suitable
SEI	Stockholm Environment Institute
SNNP	South Nations Nationality and People
SWAT	Soil and Water Assessment Tool
Tmax	Maximum Temperature
Tmin	Minimum Temperature
UNEP	Unit Nation Environmental Program
USDA	United State Department of Agricultural
WEAP	Water Evaluation and Planning
WHO	World Health Organizations
WRA	Water Resources Analysis

ABSTRACT

Irrigation is the artificial process of applying controlled amounts of water to land to assist in production of crops. Assessment of potential irrigable land is essential for the development of irrigated agriculture. The impact of unwise use of land resource, absence of land utilization according to its potential suitability and improper distribution of available water resource in the river watershed are still a serious problem in the world including Ethiopia. The main objective of this study was, therefore, to assess surface irrigation potential and to develop water allocation scenario for Modjo river watershed. Land suitability for surface irrigation was identified by considering the irrigation suitability factors such as land use land cover, soil and slope using Arc GIS 10.7.1. The final result of the suitability analysis revealed that 68% (136,437 ha) of the land was suitable for surface irrigation and the reaming 32% (64,928 ha) of the land was not suitable for surface irrigation. Irrigation water requirement for five dominant crop was calculated using CropWat 8.0 model. The results shown that the total gross irrigation water requirements of Onion, Tomato, Cabbage, Maize and Pepper were estimated to be 992, 938, 1012.8, 718 and 746.8 mm. Water Evaluation and Planning model (WEAP) was configured for the Mojo catchment and four demand nodes were added and connected with water sources. The output of the model was analyzed which includes catchment water balance, stream flow, supply requirement and unmet demand for future demand scenarios. From long term mean monthly precipitation the catchment gets 1,964.67, 16.88, 1,372.77, 419.73 and 136.39MCM under annual rain fall, irrigation, evapotranspiration, surface runoff and recharge water estimated. Annual average stream flow was estimated 455.42, 419.51 and 444.05MCM under reference, increasing irrigation and population increase demand scenarios respectively at 2030. The demand has shown fast growth where the supply requirement including the losses was estimated as 10.92, 871.89 and 11.37MCM under reference, increasing irrigation and population increase demand scenarios respectively. Based on scenario analysis by 2030 the total annual unmet demand is estimated at 0.66, 847.32 and 29.19MCM under reference, increasing irrigation and population increase scenarios respectively. Based on the result of this research it has been recommended that suitable area, water supply and demand side management measures should be well implemented in an integrated manner.

***Keywords**: Land Suitability; Surface Irrigation Potential; WEAP Model; Water allocation; Mojo River Watershed*

1. INTRODUCTION

1.1 Background of the Study

Water is necessary for all forms of plant, human and animal life. It is essential for overall human well-being and supports all aspects of human livelihoods. Furthermore, water plays an important role in supporting productive human activities such as agricultural, sanitation, energy and industrial production, fishing, tourism and transportation services (UNEP, 2009).

Water scarcity are the main problems in the world and the population growing every year is not proportional to the water and land resources (Viji, 2016). A key challenge for the agriculture sector is to feed an increasing global population, while at the same time reducing the environmental impact and preserving natural resources for future generations. Large increases in food production are necessary for the world increasing population. Much can be obtained by placing more lands under irrigation. Productivity is also declining in rain-fed agriculture globally; to increase food production water has been considered as the most important component for the transformation of low productive rainfed agriculture into most effective and efficient irrigated agriculture. It is obvious that optimal utilization of water resources in irrigated agriculture provides supplementary and full season irrigation to overcome the effects of rainfall variability and unreliability. In this regard, sustainable food production can be expected through optimal use of water resources in conjunction with development of land potential. Therefore, Overall development depends on food production through increasing irrigable areas with maximum benefits in service of growing population (Mohammed *et al*., 2017).

Surface irrigation offers a number of benefits for the less skilled and poor farmers. Under such circumstances, more than 90 percent of the world uses surface irrigation, even if local irrigators have least knowledge of how to operate and maintain the system (Saymen, 2005). Surface irrigation potential development requires favorable topography, information on water and land resources for proper planning. Therefore, planning process for surface irrigation has to integrate information about the availability of water and the suitability of land resource for crop production.

Ethiopia definitely has essential irrigation potential assessed both from available water and land resources potential, irrespective of the lack of accurate estimates of potentially irrigable land developed area under irrigation. Despite efforts of the government to expand irrigation, the country has not achieved sufficient irrigated agriculture to defeat the problems of food insecurity and rural poverty, as well as to create economic dynamism in the country (Awulachew *et al.,* 2005).

The availability of water for irrigation in community helps to improve food security because of this It will increase the capability for generating greater meals consistency in drought susceptible and meals insecure areas. Considering the available water resources of the country, Ethiopia has huge potential in expanding irrigated agriculture. The country is gifted with sufficient water resources with 12 river basins with an estimated volume of 122 and 2.6 BCM of annual surface runoff and groundwater potential respectively (Awulachew *et al.,* 2007).

Land suitability refers to the ability of a portion of land to tolerate the production of crop in a sustainable way. Such kind of analysis allows identifying the main limiting factors for the agricultural production and enables decision makers to develop crop managements able to increase the land productivity. Land suitability assessment which is often conducted to determine which type of land use is suitable for a particular location.

The water resources utilization has to be quantified to allocate the resources equitably. To secure the world's food demand, the agricultural water requirement must be assessed and scenarios must be developed over the basin for sustainable solutions due to the impact of climate change on water supply. Even if some watersheds might have probably sufficient water resource potential annually to satisfy demands within it, careful study has to be conducted and future directions has to be set in order to utilize this water potential sustainably taking into account of the downstream water users and the future generations.

The water demand assessments done earlier are those fragmented studies done to know the demands of water for a specific project to meet the needs that the project aims. Therefor this research is very crucial in providing information concerning the current and near future water demand of the study area at catchment level. Knowledge on the water demand and resource of the Catchment is very crucial for planning and management of the water resource and allocation of the water resource with in the Catchment. The demand for water coupled with the supply of the Catchment water resource will help the water resource managers to better manage the Catchment water resource in an equitable, efficient and sustainable manner.

1.2 Statement of the Problem

Ethiopia's population is predominantly rural and depends on agriculture for their livelihoods. However, agricultural production has not kept pace with population growth. In the country, it is approximated that more than 90% of the food supply comes from low productivity rain-fed small holder agriculture and hence rainfall is the single most important determinant of food supply and the country's economy (Belete, 2006; Bekele *et al*., 2012). However, the country has ample opportunity to embark on water-led development strategy to tap its full potential.

The impact of unwise use of land resource and absence of land utilization according to its potential suitability is still a serious problem in the country. The problem of increasing competition in the use of water in the watershed resulting from fast population growth, industrial and agricultural expansions also needs to be addressed and understood well.

Although the Ethiopian water resource management policy aims at developing the water resource of the country for the economic and social benefits of the people on equitable and sustainable basis with the widely accepted IWRM (Integrated water resource management) principles, the increasing irrigation area and an increasing population growth affected the stream flow volume of the river. Impact on flow volume put their negative side to trust the earlier water demand assessments to know the demands of water for a specific project to meet the needs that the project aims.

It is very crucial to providing information concerning with the current and near future water demand and supply for better water resource development projects. Knowledge on the water demand of the Catchment is very crucial for Water Resources Plan Model and allocation of the water resource with in the watershed that evaluating depending on by scenarios. The demand of water coupled with the supply of the watershed will help the water resource managers to better manage the study water resource in an equitable, efficient and sustainable manner.

Modjo River is one of the river in Ethiopia in which competition for water among the major users of the river is increasing due to population growth and socio-economic development. Furthermore, land management and the water demand system of the watershed is not fully assessed. Duo 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 land and 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 development. Equal access and sustainable water resource development in a participatory approach of all stakeholders is important to cope with water scarcity. Hence, the aim of this research was to assess the land suitability for surface irrigation by using Arc-GIS 10.7.1 and to allocate water supply and demand of Modjo River by using WEAP model.

1.3 Objectives of the Study

1.3.1 General objective

The general objective of this study was to assess land resources potential for surface irrigation and develop various water use sectors in Modjo river watershed

1.3.2 Specific objectives

In order to meet the general objective of the study, the following specific objectives are set to:

- → Evaluate land suitability for irrigation
- → Assess water availability and water demand
- → Develop water allocation scenarios for the study watershed based on supply and demand analysis

1.4 Research Questions

The study was directed by the following research questions:

- → How much potential irrigable area is available in Modjo watershed for surface irrigation?

→ How much available water and demand in the study area?

→ What are the optimum water allocation scenarios need to develop based on supply and demand analysis for Mojo river watershed?

1.5 Significance of the Study

Ethiopia is endowed with abundant water resources due to its high annual rainfall potential. In developing countries like Ethiopia, owing to the rapid growth of the population, it is unquestionable to plan development activities that can ascertain fast improvement in the living standard of the nation. This can be achieved by the optimum development of land resources. Especially the need for the optimal development of water resources has become more urgent than ever before because water is becoming a scarce resource due to the growing demand for its use in various purposes (Netsanet, 2007).

Land suitability analysis is a prerequisite to achieve optimum utilization of the available land resources for sustainable agricultural production. Access the potential of surface irrigation was studied to make the fragmented land more profitable. Therefore, assessing surface irrigation in terms of suitable land is a very important option for solving the problem (Berhanu *et al*., 2013).

The study is to identify suitable land resources, crop water requirement and water consumption for irrigation. It is beneficial for commercial cereals and 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 suitable land resources using Arc-GIS 10.7.1 modeling and to know the demand and supply relationship in the watershed area.

Therefore, this research is critical to assessing surface irrigation potential and assessing the available water utilization situation in the watershed for the present and future agricultural uses. The results of this study can also be used as bases for the land suitability and equitable water allocation especially during water crises and towards the rational utilization of available water in the watershed.

1.6 Scope of the Study

The study focus on estimation suitable area for surface irrigation through assessment of soil physical parameters (depth, drainage and texture) land use/land cover and slope of the watershed. Identifying suitable potential land for surface irrigation was done to assess the potential of land and to choose the suitable land area for irrigation by using Arc-GIS 10.7.1 model, the irrigation water requirement of selected crops identified for surface irrigation in addition to assess water allocation scenario for proper distribution for the consumer by using WEAP model. Therefore, the study targeted on determining irrigation potential of Mojo watershed in terms of assessed land suitability and optimal water allocation scenario for surface irrigation to satisfy irrigation water demand of selected crops.

1.7 Thesis Organization

This thesis is prepared into six sections. A short and brief summary of each section is given below:

Section one: Introduction: This chapter gives a general overview of the subject matter under study, justification and problem statement of why it is studied, the general and specific objectives and how the objectives can be achieved through research questions, significant, scope and limitations of the study as well as this thesis structures' part.

Section two: Literature review: This chapter discusses the surface irrigation potential and optimal allocation related water demand assessment, water resource assessment models, water allocation and review previous studies.

Section three: Materials and Methods: This chapter gives a brief description of the area under the study, methods of data collection and analysis, software and materials used in the study. Moreover, sectoral demands scenarios development was presented here and action plan development method were also discussed well.

Section four: Results and Discussion: This chapter deals with the result and discussion of the study which assessment of land suitability analysis of surface irrigation, irrigation water requirement to identified command area, modeling of water demand, scenario analysis.

Section five: Conclusion and Recommendation: Conclusion summarizes the main result findings of the research in view of the research objectives and describes the general field. Recommendation shows what should be done based on the research findings and suggest further researches to be conducted in the watershed.

2. LITERATURE REVIEW

2.1 Irrigation Potential

Irrigation development is important to improve smallholder livelihood through increase their crop variety, increase crop production, and lengthen their agricultural seasons. Irrigation potential is an important indicator of the extent of water available and land suitable for irrigation development. According to Edmealem (2018), the area that can be potentially irrigated depends on the physical resources of water, land and soil combined with the irrigation water requirements. Sustainable management of land and water resources is essential for economic development, the alleviation of poverty and the enhancement of the well-being of the Ethiopian people (MOWR, 2006). Therefore, Irrigation practice expansion for potentially suitable lands and optimally using the available water is the most essential.

2.1.1 Irrigation potential in Ethiopia

Ethiopia has a huge potential of water and land resources that could be easily used in expanding irrigation agriculture. Many rivers arising in Ethiopia are also the major water resources in adjacent countries. As stated by Abiti (2011), Ethiopia has 12 river basins 9 wet and 3 dry, annual runoff volumes from the 9 river basins is 122 BCM. Among these Abbay basins (in central and northwest Ethiopia) accounting about 53%, and Baro-Akobo 24%, Omo-Gibe 18% of this amount. The remaining other river basins contribute less than 10%.

The estimations of irrigation potential in Ethiopia differ from one source to the other due to a lack of standard or agreed criteria. Ethiopia has 12 river basins which account annual runoff volume 122 billion m^3 of water and 2.6 - 6.5 billion m^3 of groundwater potential within an average of 1575 m^3 of physical available water per person per year was estimated (Awulachew *et al*.,2007). According to MoWIE (2002) the country comprised of land resources, which are potentially suitable for irrigation and approximately 3.7 million ha identified as potentially irrigable land.

Ethiopia has essential irrigation potential assessed from both available water and land resources potential, irrespective of the lack of accurate estimates of potentially irrigable land and developed areas under irrigation. The country has special features to practice agricultural activities because of its geographical and environmental factors (Bekele, 2000). Despite efforts of the government to expand irrigation, the country has not achieved sufficient irrigated agriculture to defeat the problems of food insecurity and rural poverty, as well as to create economic dynamism in the country. Recent studies indicated that Around 74 million hectares or 66% of the country suitable for agriculture (Getenet *et al*., 2019).

The Oromia regional state has been involved in irrigation development. Currently, there are 199 irrigation schemes in the region. These irrigation schemes developed in the region, covered 33,765 ha of irrigated area, of which 4,627 ha is from small-scale, 2,800 ha from medium-scale, and 26,338 ha from large-scale, making 37,479 people beneficiaries (Awulachew *et al.*, 2005).

2.1.2 Irrigation potential in Awash basin

The Awash River basin is the maximum vital river basin in Ethiopia. According to the growth and transformation plan of the federal and regional state, 89,000 ha currently under irrigation and further 200,000 ha areas of suitable land available for irrigation in the awash river basin (Hague, 2013). The basin homes the largest irrigations schemes of the growth and transformation plan and any future abstraction of water upstream should ensure the availability of water to the growth and transformation plan projects. The total area of the upper Awash catchment is 1.93 Mha out of the total surface area of the sub-basin 66.6% (1.29 Mha) used for agriculture production. This displays that the sub basin is highly exploited for the production of different crops (OWWDSE, 2014) and more than 24,000 ha land is irrigated still now from the only water source of Awash River (Berhanu, 2008). Although the basin is known as the most irrigated basin of the country, there are still a multiple of irrigation expansion projects planned and being implemented on the basin.

2.2 Land Suitability for Surface Irrigation

In agricultural based community, land Suitability refers to the ability of a portion of land to tolerate the production of crops sustainably. The social, economic and environmental factors analyzed before a final land suitability can be given for a specific land utilization. It also deals with the assessment of land performance for the specific use that is crop production. Such kind of analysis allows identifying the main limiting factors for agricultural production and enables decision-makers to develop crop management able to increase land productivity. Land suitability assessment plays an important role in planning and managing sustainable land use (Mohamed and Ahmed, 2017).

Land suitability analysis is a method of land evaluation that assesses the possible uses of land for different purposes, which measures the degree of appropriateness of land for a certain use. Therefore, land suitability analysis can answer the questions regarding which land use is to apply under certain conditions and where the best site to apply this land use. In land suitability assessment particular attention is given to the physical properties of the soil and the terrain conditions in relation to methods of irrigation. In addition to these factors, land cover/land use types are considered as limiting factors in evaluating the suitability of land for irrigation (FAO, 2007). Land suitability assessment plays an important role in the country to have sustainable agricultural development and for planning and managing sustainable land use. Its assessment presents records on the limitations and possibilities for using the land and guides decisions on optimal utilization of the land and water resource.

2.2.1 Structure of land suitability classification

Each class keeps its fundamental which means in the context of the exceptional classifications and as implemented to exceptional styles of land use. Four categories, namely. Orders, Classes, Subclasses and Units are diagnosed with inside the FAO framework classification. In land suitability orders are reflecting kinds of suitability, in land suitability classes are reflecting degrees of Suitability inside orders, in land suitability subclasses are reflecting varieties of limitation, or fundamental varieties of development measures required, within classes in the last land suitability units are reflecting minor differences in required management within subclasses.

2.2.1.1 Land suitability orders

Land suitability orders suggest whether or not land is classified as appropriate or now no longer appropriate for the use below consideration. There are orders represented in maps, tables, etc. with the aid of using the symbols S and N respectively.

Order S suitability (Suitable): land on which sustained use of the kind under consideration is expected to yield benefits which justify the inputs, without unacceptable risk of harm to land resources.

S_1 (highly suitable): land having no significant limitation to a sustained application of a given use. This land is the great possible and does now no longer lessen productiveness.

S_2 (moderately suitable): land having limitation which in the aggregate are moderately severe for a sustained application of a given use. Land that is suitable but has limitations either reduce productivity or require an increase of inputs to sustain productivity compared with those needed on S_1 land.

S_3 (marginally suitable): Land having problem which with inside the combination are excessive for a Sustained application of a given use and could lessen productiveness or benefits. Land with obstacles excessive that benefits are reduced or the inputs required sustaining production need to be increased so that this cost is only marginally justified.

Order N suitability (Not Suitable): Land which has qualities that seem to avert sustained use of the type under consideration. Land can be classed as now no longer suitable for a given use for some of reasons. It can be that the proposed use is technically impracticable, which include the irrigation of rocky steep land, or that it might motive intense environmental degradation, which include the cultivation of steep slopes. Frequently, however, the purpose is economic: that the value of the predicted advantages does now no longer justify the predicted charges of the inputs that might be required.

N_1 (temporarily not suitable): land-having limitations which may be surmountable in time however which cannot be corrected with present understanding at presently acceptable cost. The limitations are severe as to preclude successful sustained use of the land in the given manner.

N_2 (Permanently not suitable): N2 (Permanently not suitable): land having obstacles which seem as extreme as to prevent any possibilities of successful sustained use of the land for a given land use.

2.2.2 Land suitability evaluation factors

As extensively discussed in FAO land evaluation guidelines the land suitability factors for surface irrigation method and the given land utilization types can be expressed corresponding to suitability classes. In this study, the factors considered for land suitability evaluation narrated separately in the following sub-sections.

2.2.2.1 Land use land cover

These two terms, land use and land cover, are often used interchangeably, but the distinction between land use and land cover is that; Land use indicates the actual economic activity for which the land is used i.e. food production, commercial forestry, etc and land cove refers to the cover of the earth's surface i.e. vegetation (by type), bare soil, urban development, etc. without reference to how that cover is used (Ayne, 2007). The major land use and land cover types of the river watershed are agriculture land, forest, and open bush grassland, settlement, and water bodies. Forests and woodlands occur on the better-drained soils of mountains and sides of the valleys, and grasslands occupy areas of heavy clay soil of the valley bottom (Tibebe and Zemadim, 2015).

Land use land cover of the study area is one of the factors used to evaluate the land suitability for surface irrigation. Land use land cover provides a basis for identifying the possible land suitability for irrigation with precise and quantitative economic evaluation (Melaku, 2003). Therefore, matching of existing land cover/use with topographic and soil characteristics to evaluate land suitability for surface irrigation with land suitability classes, present possible lands for new agricultural production (Jaruntorn *et al*., 2004).

2.2.2.2 Soil

All three surface irrigation techniques select heavy soils, those have decrease infiltration rates. A light soil with high infiltration rates can show the ways to deep percolation losses at the top of the fields, resulting in low field application efficiency (FAO, 2002). According to the research conducted by (Tesfaye, 2014), Physical soil properties are the most dominant factors that determine the land suitability for irrigation. Those soil properties are including soil drainage, soil texture and soil depth.

Sandy soils have a low water storage capability and excessive infiltration rate. Such type of soil need frequent but small irrigation applications, in particular when the sandy soil is also shallow. Under those circumstances, sprinkler or drip irrigation are extra suitable than surface irrigation. On loam or clay soils all three irrigation methods can be used, however surface irrigation is extra generally found. Clay soils with low infiltration rates are preferably suited to surface irrigation (FAO, 1989).

Soil Drainage: Evaluation of the soil drainage requirement is an essential element in choosing land for irrigation, especially with varied upland crop production (FAO, 1997). Adequate soil drainage is essential to ensure sustained productivity and to allow efficiency in farming operations. To assess soil suitability for irrigation, FAO - soil map of east Africa (1997) was used. According to FAO- (1997), evaluation techniques used for evaluation of permeability of soil properties of the land, soil drainage area may be categorized as properly drained, moderately well drained, imperfectly drained, poorly drained and really poorly drained.

Soil Texture: Texture refers to the relative percentage of sand, silt and clay in a mass of soil. The percentage of sand, silt and clay is used to decide the textural magnificence of the soil. It helps to determine the capacity of the soil to retain moisture and air, both of which are necessary for plant growth. Soils with a greater proportion of larger particles are well aerated and allowed water to pass through the soil more quickly. Soil textures are categorized by the fractions of every soil separate (sand, silt and clay) found in a soil. Coarse textured soils contain a large proportion of sand; medium textures are dominated by silt, and fine textures by clay (FAO, 2008). The Classification is typically named for the primary constituent particle size or a combination of the most abundant particle sizes.

Soil Depth: Depth is the dimension from the soil surface to bedrock, hardpan and water table to certain soil depth. Soil depth refers to the thickness of the soil materials. In addition, Effective soil depth is the depth of the soil at which the root growth of crops is strongly inhibited. Soil depth plays a major role in influencing plant growth and yield.

2.2.2.3 Slope

Slope is the incline of a surface and is commonly expressed as a percent. Slope is essential for soil formation and management due to its impact on runoff, drainage, erosion and choice of irrigation types. The slope gradient of the land has great impact on choice of the irrigation methods. First Rating factors were given for each slope gradient of the study area based on literature review and FAO guidelines. Using this rating the basin was reclassified in to four classes according to its land qualities and characteristics of the slope for the selection of the land for suitability of surface irrigation potential.

The classes include very highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N). This type of land classification is very common and widely used in many researches and also recommended by FAO guidelines (FAO, 2006) According to FAO standard guidelines for the evaluation of the slope gradient, mostly slopes, which are less than 2%, are very suitable for surface irrigation (FAO, 1999).

2.3 Water Demand Assessment

Water demand is increasing as a result of the rapid population growth, agricultural expansion, industrial development, and higher standards of living in addition to climate change. Awash Basin is one of the largest basins in the country with high population pressure, degradation of land and highly dependent on agricultural economy. This increase in demand for the limited water resources puts pressure to improve the allocation of scarce water. Because irrigation is the major water consumer sector in the world as well as in Ethiopia, so it is important to ensure efficient water allocation (Ahmed and Sayed, 2015). Factors affecting water demand are size of the city, living standard of the people, climate condition, quality of water, industrial and commercial activities etc. water consumption in a community is characterized by several type of demand including domestic, commercial and industrial and public institution.

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 data 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).

2.3.1 Irrigation water demand

While there are big variations inside the sector, agriculture is frequently the sector this is best placed to deal with variability in water availability. Many of the inputs to agricultural production are annual rather than fixed capital costs, meaning that production levels can be increased and decreased on an annual basis with less significant losses. Important exceptions to this exist, including high-value permanent crops such as grapes and fruit trees. Conversely, and for the same reasons, the agricultural sector is often well placed to make productive use of additional water in years of surplus. At the same time, agriculture is typically the least economically productive user of water and consequently reductions in agricultural production have less economic impact than reductions in other sectors (DWAF, 2007).

Irrigation currently accounts for 72% of the global water withdrawals and 90% of withdrawals in low-income developing countries. By the mid-1990s, irrigated agriculture supplied nearly 40% of the world's food production on 17% of total cultivated land. Moreover, in many developing countries, supplementary irrigation constitutes an important element of rural development policies, raising rural incomes and employment and permitting increased agricultural and rural diversification through secondary economic activities derived from more extended and more varied agricultural production as compared with rainfed agriculture (Rosegrant *et al*., 2001).

In Ethiopia, below the popular rainfed agricultural production system, the modern degradation of the natural resource base, specifically in highly susceptible regions of the highlands coupled with weather variability have annoyed the occurrence of poverty and food insecurity. Water resources management for agriculture consists of both guide for sustainable production in rain-fed agriculture and irrigation (Awulachew *et al.,* 2005).

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 such as minimum and maximum temperature, sunshine hour, wind speed and humidity, the growth stage of the crop and crop type. The influence of the climate on crop water needs is given by the reference crop evapo-transpiration (FAO, 2012).

2.3.2 Industrial water demand

Adeba *et al*. (2015) reported that industries which produce paper, metals, chemicals, pharmaceuticals, textiles and others all use water in their production process. It relies upon on water for all levels of production. Data on industrial water use are hard to get due to the fact maximum of them use their own water sources. Water for industry use is not registered by municipality. The estimate of water use for industries outside Addis Ababa however positioned in the Awash basin is about 10% of for domestic user. Then the estimate of water use for industries in and around Addis Ababa is about 8% of the whole each day domestic water requirement of the town it is equivalent to approximation 6.13 MCM/year for Addis Ababa and its surrounding.

2.3.3 Livestock water demand

The livestock sector is the fastest-growing agricultural sector, which has led to increasing industrialization and, in some cases, reduced environmental constraints. In rising economies, growing involvement in livestock is associated with enhancing rural wealth and increasing consumption of animal protein. Water usage for livestock production should be considered an integral part of agricultural water resource management, taking into account the type of production system (e.g. grain-fed or mixed crop-livestock) and scale (intensive or extensive), the species and breeds of livestock, and the social and cultural aspects of livestock farming in various countries. Limited availability of water or the presence of contaminants in the supply has a significant impact on animal health and productivity. The water demands of livestock can also compete with the ones of the human population and water required for crop production. Crops can make direct use of rainfall or saved water through irrigation, while animals consume vegetation or pastures, main to ability reductions in water efficiencies for food production. This water must be added to the water directly consumed by the animals to maintain life as well as to the water used during product processing. This apparent ‘inefficiency’ of water use has been highlighted in recent accounting models of global water use (Schlink *et al*., 2010).

2.3.4 Commercial and institutional water demand

The water demand of towns include the needs of such commercial and institutional consumers as clinics, public schools, offices, shops, hospitals, hotels and restaurants. This type of water demand is usually linked directly to population size. For medium and small-sized towns, population of 80,000 to 30,000, it was estimated at 5% of the domestic water demand and for large towns, the estimate was 10% (MoWR, 2006).

2.4 Water Resources Assessment Models

A comprehensive evaluation of the water resources available in a location or a river basin is critical for locating sustainable answers for water-related problems regarding both the quantity and quality of the water resources. Research at the improvement and application of water stability fashions at different spatial and temporal scales has been finished since later a part of the nineteenth century. As a result, a great deal of experience on various models and methods has been gained. (Robert *et al*., 2013).

Several hydrologic models are broadly used for the evaluation of the water resource. The Soil and Water Assessment Tool (SWAT) model is a basin scale model where runoff is based on land use and soil type (Arnold *et al*., 1998) had a comprehensive structure that models basically all hydrologic processes in the watershed over long periods of time. The model has also been applied in the many basins for example: (Githui *et al*., 2009) used SWAT version to simulate stream flow in Western Kenya. Sang (2005) also applied the SWAT model in the Nyando Basin in Kenya. Magoma (2009) examined the applicability of SWAT in the Rugezi wetland catchment in Rwanda. The results showed important rainfall-runoff linear relationships that could extrapolate to estimate amounts of stream flow under various climates. Then the Water Evaluation and Planning (WEAP) model attempts to address the gap between water management and watershed hydrology and the requirements that an effective IWRM be useful, easy to-use, affordable, and readily available to the broad water resource community. In addition, the data structure and level of detail may easily customize to meet the requirements of a particular analysis and to reflect the limits imposed when data are limited (Yates *et al.,* 2005).

2.4.1 Model selection criteria

In order to select which model to use for water demand and utilization analysis, the following key points are the governing criteria. These are; physical detail, user friendliness, water quality assessment ability, spatial scale, data demanding, support, price and similar issues have to be seen carefully.

Hydrological models have become a basic tool in hydrology, and their development, which was closely linked to increasing power of computer processing, started in the 1960s. They are now indispensable tools for planning, design and management of hydrological related infrastructure. They can also improve system understanding which is required for decision-making and policy analysis. So, the number of hydrological models now available has increased to such an extent that it has become a relatively hard task to choose one from amongst them when a simulation is to be done.

A big variety of generic simulation fashions within interactive graphics-based interfaces has been evolved by public and personal organizations. They all are designed to examine water associated planning and management problems in water structures and to fulfill the wishes of these at different stages of planning and decision-making process (Assaf *et al*., 2008).

Water Resources Graphical Interface–Simulation Tool (WARGI-SIM) developed at University of Cagliari, Italy, is a user-friendly tool specifically developed to assist customer's knowledge interrelationships between demands and resources for multi-reservoir water structures below water shortage conditions, as frequently occur in the Mediterranean regions. The Decision Support System (DSS) makes it possible to take into account a large number of system components that typically characterize water resources models. The tool is flexible and generalized in the system configuration and data input, in the attribution of planning and operating policies and in processing output (Sechi and Sulis, 2010).

Modular Simulation Model (MODSIM) is a generic system management DSS originally conceived in the late 1970s at the Colorado State University, United State, and continuously maintained. MODSIM simulates water allocation with inside the system at each time step through sequential answer of a network flow optimization problem where nonlinearities (i.e.

evaporation, groundwater go back flows, channel losses etc.) are assessed inside a successive approximations solution procedure (Sechi and Sulis, 2010).

Water Evaluation and Planning (WEAP) model is a general simulation model evolved Water Evaluation and Planning (WEAP) model is a general simulation model developed at the Stockholm Environment Institute, Boston, Massachusetts. It integrates a few physical hydrological strategies with the control of demands and infrastructure to allow for multiple scenario analysis, including alternative climate scenarios and changing anthropogenic stressors. WEAP model simulations are constructed as a set of scenarios with different simulation time steps. The physical hydrology model updates the hydrologic state of the system at each time step, and thus provides mass balance constants used in the allocation phase within the same time step. The main point of the water management analysis in WEAP is the analysis of water demand configuration.

Though, WEAP and MODSIM have better advantages over the other models and are equally important to model water demand in the study area. Therefore, WEAP model is easy and best suited to model water demand in my study area as it can be licensed online annually free of cost.

2.4.2 Geographical information system (GIS) application for water resource assessment

GIS is a computer-based device for managing spatial data in digital form tasked. In such system, large quantities of data can be maintained and retrieved at more speeds and decrease value which is not the case with traditional method. GIS also performs manipulations and analysis of the available information. It can serve as a powerful analytic and decision-making tool for irrigation development. Large area quantity of GIS in addition to its capacity to gather keep and manage various types of data in a unique spatial database helps appearing various kinds of evaluation and consequently extracting information approximately spatially distributed phenomena. Some of essential applications of GIS are processing of digital elevation model, mapping of the watershed and established spatial variation of slope, land use, land cover and soil formation via the suitable maps. Determining the suitability of land for surface irrigation requires thorough evaluation of soil properties and topography (slope) of the land within field. Since all kinds of rural land are involved by different land cover and land use types, its suitability evaluation for surface irrigation also provides guidance in cases of conflict between rural land use and urban or industrial expansion indicating which areas of land covers or land uses are most suitable for irrigation (Lillesand *et al*., 2015). Different scholars used GIS as a tool to investigate irrigation potential and land suitability in their study area.

2.5 Water Allocation

Water allocation is the process of distributing water supplies to meet the various requirements of a community. Determining how to allocate water supplies requires the consideration of certain factors, including the source of the water and methods for obtaining it. Water resources can be neither developed nor controlled rationally without an evaluation of the quantity and quality of water available. Water resources assessment (WRA) is a tool to evaluate water resources in relation to a reference frame, or to evaluate the dynamics of the water resource in relation to human impacts or demand. Water allocation systems serve to equitably apportion water resources among users; protect existing water users from having their supplies diminished by new users; govern the sharing of limited water during droughts when supplies are inadequate to meet all needs; and facilitate efficient water use (Robert *et al*., 2013).

2.5.1 Criteria for water allocation

Appropriate means of resource allocation are necessary to achieve optimal allocation of the resource. Several criteria are used to compare forms of water allocation introduced by Weragala and Neelanga (2010), such as: Flexibility in the allocation of supplies, Security of tenure for established users, real opportunity cost of providing the resource is paid by the users, predictability of the outcome of the allocation process, equity of the allocation process and political and public acceptability.

2.5.2 Optimal water allocation mechanism

Dinar *et al*. (1997) talk the ideas of four basic mechanisms for water allocation: user-based allocation, marginal cost pricing, public allocation and water markets allocation.

User-Based Allocation: Many research have proven a huge variant of policies for allocation inside such systems; through timed rotation, the depth of water, a place of land, or shares of the flow (Yoder, 1994). User-based allocation requires collective movement establishments with authority to make selections on water rights (Dinar *et al*., 1997).

Water Markets: Water markets allocate water by tradable water use rights and sell efficient water utilization through permitting customers to promote and purchase their water rights freely. Furthermore, it argues that water markets are uncommon in truth and are not true free markets. Due to the transaction costs, technological constraints, political constraints and many special reasons the real-worldwide water markets do now no longer benefit first-best allocations. The absence of properly described water rights is likewise seeing as a major obstacle in formulating water markets with inside the growing world (Rosegrant and Gazmuri, 1994).

Marginal cost pricing (MCP): A marginal cost pricing (MCP) mechanism, in principle, objectives a rate for water to equal the marginal cost of providing the final unit of that water. A rate described as located rate (marginal value) of water on a demand curve, which corresponds to located quantity (i.e. Reference quantity). An allocation that equates the water‘s unit rate (the marginal cost of water) with the marginal cost is taken into consideration an economically efficient, or socially optimal, allocation of water resources. The limitation of MCP, however is, it is hard to implement at a river basin level because, it is difficult to collect sufficient information to estimate the correct volume of water (Malual, 2015).

Public (Administrative) Water Allocation: Public allocation promotes the equitable water use, can guard the poor and may preserve environmental needs. But frequently results in inefficient use of water and failure to create incentives for water customers to preserve water, enhance use performance and permit tradable water transfers to attain most blessings in an entire river basin and additionally public allocation mechanisms frequently cause waste and miss-allocation of water, in addition to fragmented funding and control of the present resource.

The amount primarily based totally administrative allocation is the maximum common water allocation mode in the growing international today (Meinzen and Mendoza, 1996); (Molle, 2004). In general, state managed administrative allocation (public allocation) has more than one targets and is greater involved with equity, sovereignty and satisfying more public good (Dinar *et al*., 1997).

2.5.3 Optimal water allocation models

More that specialize in Water Evaluation and Planning (WEAP) version below this section allocation of restrained water resources among agricultural, municipal and environmental uses now calls for the total integration of supply, demand, water quality and ecological considerations. The Water Evaluation and Planning system, or WEAP, goals to contain those issues into a practical yet robust tool for integrated water resources planning (Yates *et al*., 2005).

The WEAP model applications generally include several steps. The study description sets up time frame, spatial boundary, system components and arrangement of the problem. The Current Accounts, which can be viewed as a calibration steps in the development of an application, provide the actual water demand, resources and supplies for the system. Scenarios built on the current accounts and allow one to investigate the impact of alternative assumptions or policies on future water availability and use. Finally, the scenarios are evaluated with regard to water sufficiency, benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables (SEI, 2015). So for this study WEAP model is selected because of its inclusive, straightforward, flexible data input, interfacing with Excel (import-and export). As a database, WEAP provides a system for maintaining water demand and supply information. As a forecasting tool, WEAP simulates water demand, supply, flows, storage and discharge.

2.6 Previous Studies Made on Surface Irrigation Potential and Its Allocation-General Perspective

Girma (2015**)** assessed the suitability of Walga sub-basin for surface irrigation development and producing a geo-referenced map of potentially irrigable sites. The methodology of the existing suitability encompasses the evaluation of slope, LULC, major soil physical properties such as texture, depth, drainage and PH. Suitability of the area’s slope, soil, land use land cover and surface water resources were evaluated and a geo-referenced map of each parameter was presented on Arc GIS. The overall suitability map of the area of the intended irrigation system was produced using a suitability model developed on Arc GIS. The result of the suitability model revealed that about 45.72% (135,519.18 ha) of lands were in the range of highly suitable to marginally suitable for surface irrigation development. Potentially suitable sites for surface irrigation development were evaluated for the selected crops (Maize, soya bean and Sesame).

By maintaining 20% of the stream flows for downstream ecological balance, flows in each stream can satisfy gross irrigation water requirements of the selected crops in the potentially irrigable sites.

Meseret *et al*. (2020) evaluated surface irrigation potential of the Dhidhessa River Basin, Ethiopia using SWAT model. The study specifically targeted on estimating to be water assets and their capacity for surface irrigation water use in the basin. This changed into executed by utilizing Geographic Information System (GIS)-primarily based totally tools, a hydrological Soil and Water Assessment Tool (SWAT) model, and a Crop Water and Irrigation Requirements Program of FAO (CROPWAT) model. In irrigation water potential assessment, we selected six crops (cabbage, maize, tomato, pepper, groundnut and sugarcane). By using the SWAT model for the period from 1986 to 2012 using the available hydro-meteorological and geo-spatial data. The annual available water of the basin is 9.26 billion cubic meters (BCM) while the 70% and 80% dependable flow is 7.56 and 6.97 BCM, respectively.

Ali *et al.* (2018) Analyzed current and future water demands in the Upper Indus Basin under IPCC climate and socio-economic scenarios using Water Evaluation and Planning (WEAP) modeling. After the development of the WEAP model, the analysis of the unmet water demand and percent coverage of the water demand for the period of 2006–2050 was computed. Different scenarios were generated for external driving factors (population growth, urbanization, and living standards) and the impact of climate change to evaluate their effect on the current water supply system. The results indicated that the future unmet water demand is likely to reach 134 million cubic meters (MCM) by the year 2050 and that the external driving factors are putting more pressure on the supply service.

Calibration and validation of SWAT model and estimation of water balance components of Shaya mountainous watershed was also studied (Alemayehu *et al*., 2013). The study was aimed at analyzing the influence of hydrologic parameters on the stream flow variability and estimation of monthly and seasonal water yield at the outlet of Shaya mountainous watershed. According to the study results, the mean monthly and annual water yield simulated with the calibrated model were found to be 12.9 MCM and 155.5 MCM respectively.

Abraham (2015) reported that the assessment of irrigation potential in terms of land and water in Guder river catchment. To evaluate surface water potential of the catchment HECHMS simulation hydrological model was used. Guder river catchment divided into 45 sub watersheds and in each sub-watersheds surface water availability was assessed. The results show that annual volume of water available in each sub-watersheds ranges from 6.3 to 710 MCM.

Shiferaw (2007) assessed irrigation potential evaluation and crop suitability analysis using GIS and Remote Sensing Technique in Beles Sub Basin, Beneshangul Gumez Region. The study aims at evaluation of land use suitability for surface irrigation by using GIS. The result that obtained are 41,650 ha (26.9%) very suitable, 24,100 ha (15.6%) suitable, 44,350 ha (28.7%) marginally suitable, 11,000 ha (7.3%) marginally not suitable and 33,250 ha (21.5%) permanently not suitable. Suitability maps for both maize and cotton were developed. The suitability crops maps were classified in to five suitability classes. Regarding maize 12,450 ha (8.2%) very suitable, 23,140 ha (14.9%) suitable, 54,600 ha (35.3%) marginally suitable, 16,200 ha (10.6%) marginally not suitable and 46,130 ha (30.4%) permanently not suitable of the total Beles Sub basin. Suitability classes for Cotton were16, 150 ha (10.7%) very suitable, 22,540 ha (15.1%) moderately suitable, 49,020 ha (32.6%) marginally, 17,200 ha (11.5%) marginally not suitable and 46,130 ha (30.1%) permanently not suitable.

2.7. Previous Studies Made on Surface Irrigation Potential and its Allocation-in Awash River Basin

Mohammed *et al*. (2019) studied water resources allocation systems below irrigation expansion and climate change scenario in Awash River Basin of Ethiopia using (WEAP) to allocate the water supplies to demanding sectors primarily based totally on an economic parameter to maximize the economic benefits. The outcomes of this look at showed that the total amount of water had to meet the irrigation needs of all of the stations become 306.96 MCM from 1980 to 2016. Seasonally, March, April, May, and June require the most irrigation water demand.

Bayush (2020) assessed surface irrigation potential and optimization of cropping pattern: case study of danse watershed, Oromia Region. The availability of water was determined from surface runoff using curve number method. As a result, the weighted curve number of the watershed was estimated as 84. Using the mean annual precipitation of Ejere station from 1987-

2016, the annual volume of surface runoff generated in the watershed was 18.64 MCM. Land suitability for surface irrigation was identified by considering the irrigation suitability factors such as soil, slope and land use/ land cover through implementing Arc-GIS 10.4. The result of the weighted overlay analysis revealed that out of the total 2170 ha of land 85.36 ha were highly suitable, 1475.68 ha moderately suitable, 596.67 ha marginally suitable and 4.78 ha of the area were unsuitable for surface irrigation development. Irrigation water requirement was calculated by using CropWat 8.0 model. Optimization of cropping pattern was performed with the available land and water resource to maximize the net benefit from crop production using Lingo software. Result signifies that from the dominant crops area allocation of 164 ha onion, 8 ha Tomato, 5 ha Cabbage and 15 ha wheat the maximum production benefit was 57,748,130 Birr.

Ahmednasir (2020) investigated water availability and water demand scenario of Mojo River Watershed in the Upper Awash River Basin in Ethiopia using SWAT model to assess availability of stream flow are 504 MCM. The irrigation water requirement for major crops namely Cabbages, Onion, Maize, Tomato and Pepper were analyzed using CROPWAT 8.0 model. From the result, the total annual surface water availability for irrigation was 279 MCM, human and livestock water consumption are 13 MCM and 106 MCM respectively. From the results the total annual surface water available yields is estimated around 0,401 BCM. So, there was shortage of water found to be 0.0114 BCM/year occurred, which is about 0.0096 BCM/month.

3. MATERIALS AND METHODS

3.1 Description Study Area

3.1.1 Location

The study area is found in the most important Ethiopian rift extending as much as the eastern escarpment. It is part of the upper Awash River basin and covers partially Lumie, Addaa chuluka Gimbichu and Liban weredas in Eastern showa zone of Oromia regional state. However, the vast majority of the study area is found in Lumie and Addaa chuluka weredas. Geographically the study area lies between longitude of 37° 54′ 22″ to 39° 17′ 18″ E and latitudes of 08° 24′ 15″ to 09° 07′ 49″ N the altitude of the watershed ranges from 1591.3 m.s.l. at the river bed to 3043.73 m.s.l. at the upper part of the watershed. The total area coverage of the watershed that obtained through watershed delineation is 2013.65 km^2.

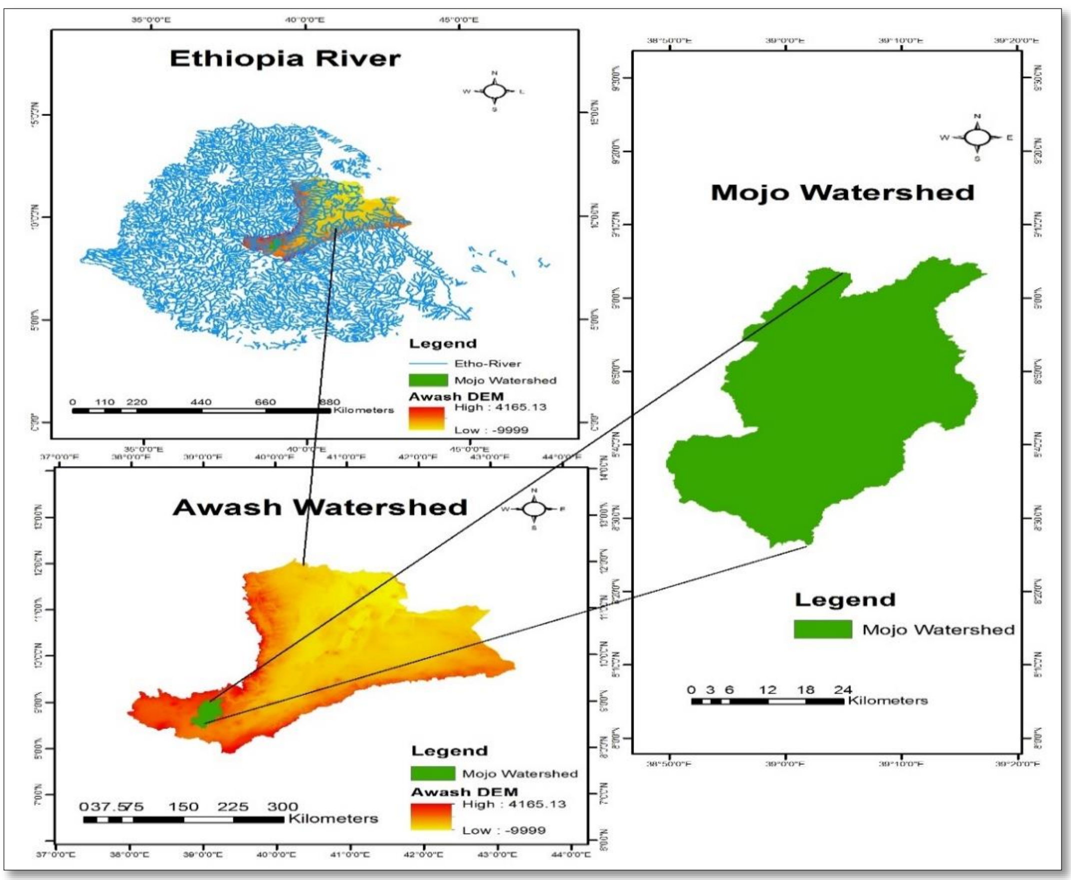

Figure 1: Location of the study area

3.1.2 Rainfall and temperature characteristics of the study area

Effective rainfall was calculated based on 16 years (2000-2015) mean annual rainfall in Mojo watershed estimated as 978.8 mm and the mean minimum and maximum temperature ranges of the watershed are 11.7 and 28.9(°C) respectively. Temperature and rainfall are the most important elements in characterizing the climatic condition of a given watershed area. Climatic zone indicates an altitude increase with decreasing temperature and increasing precipitation. In maximum parts of the country, annual precipitation follows a bimodal distribution. The central and most of the eastern part of the country has two rainy periods and one dry period. Those seasons with their local name of Kiremt rains from June to September, small Belg rains from February to May and dry Bega season from October to January (Tibebe and Zemadim, 2015).

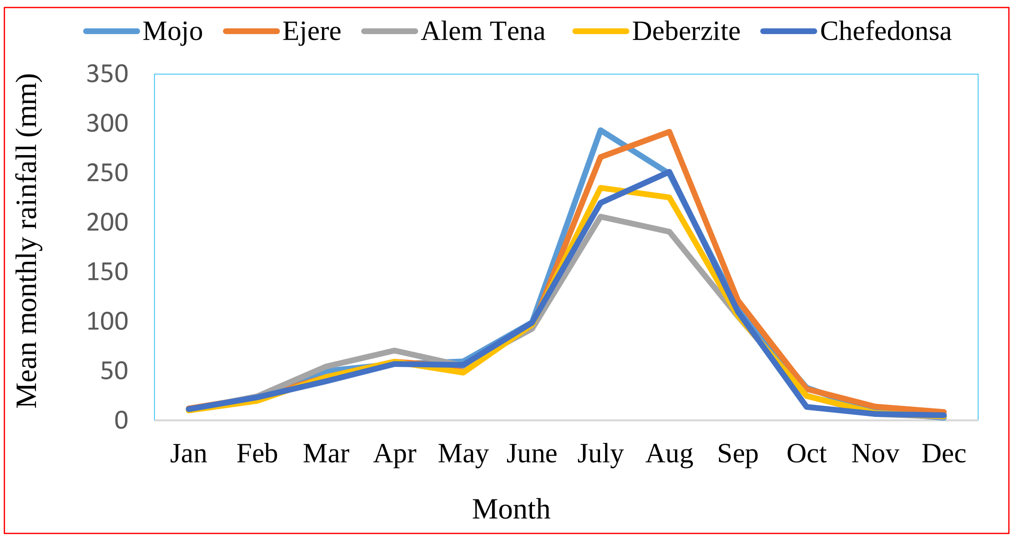

Figure 2: Mean monthly rainfall characteristics of selected weather stations

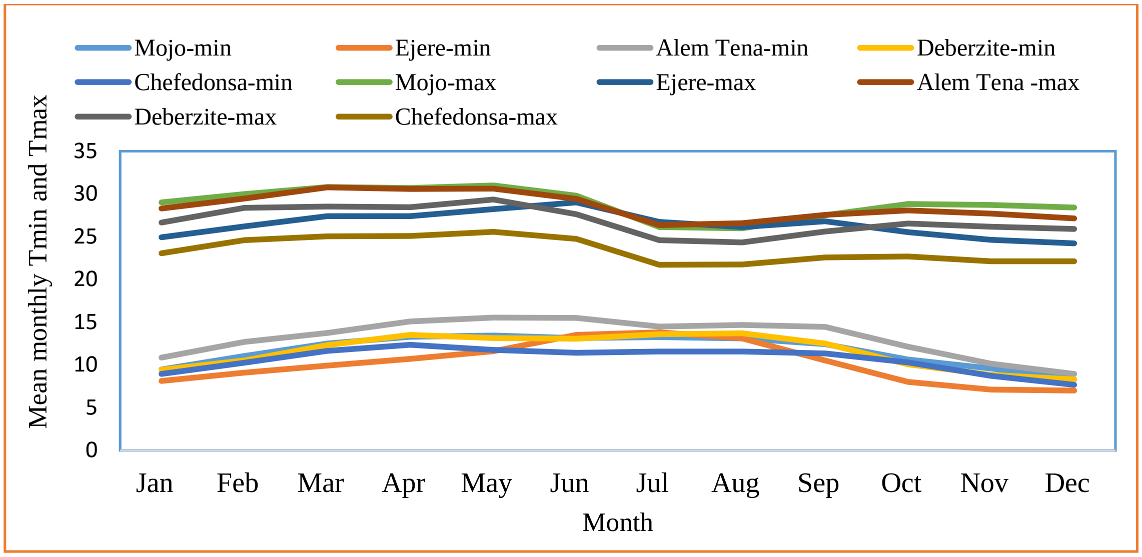

Figure 3: Mean monthly maximum and minimum temperatures characteristics of selected weather stations

3.1.3 Topography

The elevation of the watershed boundary extends from 1591.3 to 3043.73 m a.m.s.l. The maximum elevation of Mojo watershed is located in the northeast part of the watershed and the minimum elevation of this watershed is located in the southeast part of this watershed.

3.1.4 Soil and land use land cover condition

According to the FAO/UNESCO soil classification system, Mojo watershed area the dominant soil groups are Pellic Vertisols, umbric Leptosols, vitric andosols, chromic luvisols and chromic cambisols (Zelalem, 2016). Most of the area was covered by Pellic vertisols with an area coverage of around 121,087.7 ha, umbric Leptosols areas coverage around 15,313 ha, vitric andosols areas coverage around 2585 ha, Chromic Cambisols covered 59,779.4 ha and chromic cambisols covered 2,599.9 ha.

A Vertisol, is a soil type in which there is a high content of expansive clay minerals, many of them known as montmorillonite, that form deep cracks in drier seasons or years. In a phenomenon known as argillipedoturbation, alternate shrinking and swelling causes self-ploughing, where the soil material consistently mixes itself, causing some vertisols to have an extremely deep A horizon and no B horizon. This heaving of the underlying material to the surface often creates a microrelief known as gilgai.

When irrigation is available, crops such as cotton, wheat, sorghum and rice can be grown. Vertisols are especially suitable for rice because they are almost impermeable when saturated. Rainfed farming is very difficult because vertisols can be worked only under a very narrow range of moisture conditions: they are very hard when dry and very sticky when wet.

Mojo watershed has eleven types of land use/cover such as irrigated agriculture, open shrub grassland, plantation forest, urban settlements, rural settlement, degraded land, flower farm, distributed high forest, intensively cultivated, open bush shrub land and water body . From this land use/land cover intensively cultivated land is the most dominant 168,803.9 ha of land.

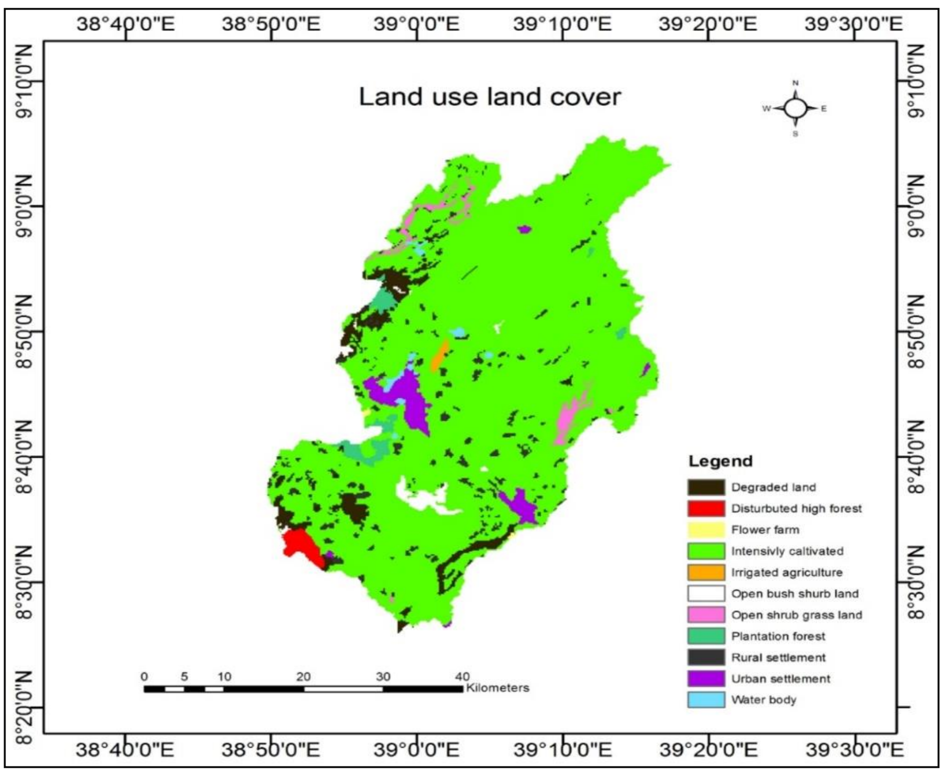

Figure 4: Land use land cover map of the watershed

3.2 Materials and Software Used

The materials and software used in this study were including DEM, soil data, LULC data, Arc GIS 10.7.1, CROPWAT 8.0, WEAP and Microsoft excel. To effectively execute and to assess the irrigation potential and optimal allocation. Arc-GIS software is used for determining land suitability analysis for surface irrigation. CROPWAT 8.0 software was used to determine the crop water requirements of selected crops in the watershed. Finally, WEAP model was used to find the utilizations of water and water allocation scenarios analysis based on demand and supply.

3.3. Data Collection and Checking Data Quality

3.3.1 Secondary data collection

Secondary data was very important for the study to accomplish the objectives.
Meteorological data (rainfall, maximum and minimum temperature, relative humidity, wind speed and sunshine hour) for five stations (Mojo, Ejere, Deberzite, Alem Tena and Chefedonsa) for the year 2000-2015 were collected from National Meteorology Agency (NMA) of Ethiopia. Stream flow data for Mojo River station recorded from 2000-2015, spatial data such as topographic, soil data, land use land cover data and digital elevation model (DEM) data of Awash River basin were collected from Ministry of Water, Irrigation and Energy (MoWIE). All water consumption like livestock, domestic, irrigation, major crops and areas were obtained from East Showa Agricultural Offices and the four weredas (Lome, Ada'a, Gimbichu and Liban).

Table 1: 'Data required and its sources'

Types of Data Required	Description	Sources
Meteorological data	Precipitation, Temperature, Humidity, Sunshine hour, Wind speed.	National Metrological Service Agency (NMSA) of Ethiopia
Hydrological Data	Flow data	Department of water resources and hydrology of Ethiopia
Remote sensing data	Digital Elevation Model (DEM) of Awash River Basin	Ministry of water resources and energy of Ethiopia in Department of GIS and Remote sensing

Water Demand Data	Water use rate, Population number, Water consumption, Agricultural sector, Urban sector, Land use data.	East Showa Agricultural Offices
Biophysical Data	Land use/land cover, topography and soils	Ministry of water resources and energy of Ethiopia in Department of GIS and Remote sensing

3.3.2 Filling missing rainfall data

Before using the rainfall record of a station, it is necessary first to check the data for continuity and consistency. To fill missing rainfall data, the normal rainfall is used as a standard of comparison. The normal rainfall is the average value of rainfall at a particular date, month or year over a specified 16-year period. Simple arithmetic mean and normal ratio method are the common methods used for filling missing rainfall data. To calculate the percent of difference to decide whether to use arithmetic mean or normal ratio method, the following equation has been used.

$$\%\, difference = \left(\frac{N_x - N_i}{N_x}\right) * 100 \tag{3.1}$$

Where, Nx = the normal annual rainfall amount from the missing data station,

Ni = the normal annual rainfall amount from one of the nearby stations.

For this study, the missing values of rainfall recorded were completed by using the Arithmetic mean method. The method is used for the difference between the normal annual precipitations at surrounding gauges are within the range of 10% of the normal annual precipitation of station with missed data. The missing data estimated by;

$$P_X = \frac{1}{M}(P_1 + P_2 + P_3 + P_4 + \cdots P_n) \tag{3.2}$$

Where, P_x = missing rainfall data at station x,

P_1, P_2, P_3 and P_4 = precipitation at surrounding gauges station, M = the number of nearby gauge stations.

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

$$P_X = \frac{N_X}{n}\left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} + \cdots + \frac{P_n}{N_n}\right] \quad (3.3)$$

3.3.3 Consistency of rainfall data

To prepare the rainfall data for further application, their consistency was checked using double mass curve analysis. A plot of accumulated rainfall data at the site of interest against the accumulated average at the surrounding stations was used to check the consistency of rainfall data. The rainfall data of Mojo, Ejere, Deberzite, Alem Tena and Chefedonsa stations from the year of 2000-2015 were collected for consistency checking.

Double mass curve compares data for a single station with that of a pattern composed of the data from other stations. The data of the yearly 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. To check the degree of consistency, (Nemec, 1973) provided the value of the coefficient of correlation as follows.

Table 2: Correlation coefficients

Range of correlation coefficient	Description
$r = 1$	Direct linear correlation
$0.6 \leq r < 1$	Good direct correlation
$0 < r < 0.6$	Insufficient reciprocal correlation
$r = -1$	Reciprocal linear correlation

Source: Nemec (1973)

3.4 Methodologies

The study of the previous finding related to the present study and all the necessary data were collected from different data sources further analysis was performed. The study consists of four main parts. First quantified to determine the land suitable for surface irrigation, compute irrigation water requirement of the command are, utilization of water and finally develop water allocation scenarios for the study watershed based on supply and demand analysis of Mojo watershed filling of missing data and data quality checking was done.

3.4.1 Assessment of land suitability for surface irrigation

3.4.1.1 Land use/land cover suitability analysis

Land use land cover types of the observe area have been weighted based on their suitability for surface irrigation system. The land use land cover type was reclassified into four suitability classes and given value from S1 to N. Here S1 represents highly suitable, S2 moderately suitable, S3 marginally suitable and N currently not suitable. After weight has been given for the LULC, reclassified map of the study area has been developed (Jansen and Gregorio, 2007) legend of the land classification system was used.

Table 3: Land use land cover suitability criteria

Category	Suitability class	Description of land cover types
S1	Highly Suitable	Intensively Cultivated Irrigation agriculture Flower farm
S2	Moderately suitable	Open bush shrub land Open shrub grass land
S3	Marginally suitable	Plantation forest Degraded land Distributed high forest

N	Not suitable	Water body Urban settlement Rural settlement

Source: FAO (1996) an interactive multi-criteria analysis for land resource appraisal

3.4.1.2 Soil suitability analysis

Soil analysis of study area which used for evaluation of suitable land site for surface irrigation was analyzed by clipping soil physical properties from soil georeferenced shape file which had been obtained from Ministry of Irrigation and Electricity. Then, preparing soil feature layers of each physical soil parameters; soil texture, soil drainage, soil depth and soil type then, the feature layers converted into raster layer using conversion tool "To Raster". Finally soil suitability map of each soil physical parameter was developed with the factor rating of S1, S2, S3, and N1 through reclassified the raster layers based on the FAO soil classification guide line. The factor of rating for each selected soil physical parameters was shown below.

Table 4: Soil suitability factor rating

S.N	**Soil texture Class**	**Soil Depth Range(cm)**	**Soil Drainage**	**Factor Rating**
1	C, SiC, SC	>120	Well	S1
2	Si-CL,CL-C	100-120	Imperfectly	S2
3	SL, SCL	50-100	Poor	S3
4	Course Sand	<50	Very poor	N

C = Clay, SC = Sandy Clay, SiC = Silty Clay, Si = Silt, L = Loam, CL = Clay Loam, Si-CL= Silty Clay Loam, SCL = Sandy Clay Loam, SL = Sandy Loam

Source: FAO (1996) guideline for land evaluation land evaluation team based on practical observation. To identify potentially suitable soils for the intended irrigation system, the three soil suitability factors (depth, texture and drainage) were weighted on Arc GIS 10.7.1. In the soil suitability evaluation of a percent influence for weighted overlay analysis were taken 1 by 4 by 1(a scale for overlay analysis). The percentage of influence was given to soil in an equal manner in the weighted overlay analysis.

In the way of weight overlay tool in spatial analyst tool (Arc GIS version Spatial analyst > overlay > weighted overlay analysis) three determinants reclassified raster soil map was performed to determine soil suitability for surface irrigation. Then the new value was reassigned for each soil factor. The new value was given based on a common evaluation scale factor rating from 1 to 4 for weighted overlay analysis. S1 represent highly suitable, S2 represent moderately suitable, S3 represent marginal suitable and N represent not suitable area of land and the percentage (%) of influence was given to soil in an equal manner in the weighted overlay analysis on Arc GIS 10.7.1.

3.4.1.3 Slope suitability analysis

The slope of the Mojo River watershed has been derived from DEM by using the, Special Analysis Tools, in Arc GIS 10.7.1 Software. The derived slope shape file has been further processed to yield important derivative products such as slope suitability. The slope derived from the DEM was classified based on the classification system of (FAO, 1996) using the "Reclassification" tool, which is an attribute generalization technique in Arc GIS 10.7.1.

The four suitability ranges or slope suitability criteria has been categorized according to their suitability range as follow 0-2% slope highly suitable, 2-5% slope is moderately suitable, 5-8% slope is marginally suitable and slope >8% is categorized under currently not suitable classified for surface irrigation.

Table 5: Slope suitability classification for surface irrigation

S.N	Slope range (%)	Factor Rating
1	0-2	S1
2	2-5	S2
3	5-8	S3
4	>8	N

Source: FAO (1996)

3.4.1.4 Weighing of irrigation suitability factors

Potentially irrigable land was obtained by creating irrigation suitability analysis which involved the weighting of values of all data sets such as soil, slope, land use and land cover. Weighted overlay is one method of modeling suitability. ArcGIS 10.7.1 uses the following process for this analysis. Each raster layer is assigned a weight in the suitability analysis. Assigning a weight to each raster in the overlay process allows controlling the influence of different criteria in the suitability model.

By using Arc GIS 10.7.1 to identify potentially irrigable land for surface irrigation, The three suitability parameters identify potentially irrigable sites in the watershed as highly, moderately, marginally and unsuitable class for surface irrigation development. To prioritize the influence of these factor values, weighted overlay analysis uses evaluation scale from 1 to 4 by 1. For example, a value of 4 represents the least suitable factor in evaluation while, a value of 1 represents the most suitable factor in evaluation. Weighted overlay only accepts integer raster's as input, such as a raster of land cover/use, soil types, and slope, to find suitable land for irrigation.

What is Analytical Hierarchy Process (AHP) and How to Use it?

Analytical Hierarchy Process (AHP) is a mathematical tool of problem solving that has become popular amongst management personnel in the late 1990's and early 2000's. The AHP method has been created after understanding the structure of a problem and the real hindrance that managers face while solving it. This structure has been explained in this article.

The AHP method has inbuilt checks and balances. These checks and balances, therefore ensure that you reach logically consistent solutions when you compare the relative importance of the criteria in the process of assigning weights to them.

Although the AHP is one of the most advanced methods available in the field of management science and operations research, the complexity involved in using this tool makes it difficult to apply. Thankfully software tools have been built which automate the mathematics intensive part. The user has to follow a simple methodology of data collection which is then fed into the tool to get the results.

Step 1: Define alternatives

The AHP process begins by defining the alternatives that need to be evaluated. These alternatives could be the different criteria that solutions must be evaluated against. They could also be the different features of a product that need to be weighted to better understand the customer's perception. At the end of step 1, a comprehensive list of all the available alternatives must be ready.

Step 2: Define the problem and criteria

The next step is to model the problem. According to AHP methodology, a problem is a related set of sub problems. The AHP method therefore relies on breaking the problem into a hierarchy of smaller problems. In the process of breaking down sub-problem, criteria to evaluate the solutions emerge. However, like root cause analysis, a person can go on and on to deeper levels within the problem. When to stop breaking the problem into smaller sub problems is a subjective judgment.

Step 3: Establish priority amongst criteria using pairwise comparison

The AHP method uses pairwise comparison to create a matrix. For example the firm will be asked to weigh the relative importance of protection from downfall vs liquidity. Then in the next matrix, there will be a pairwise comparison between liquidity and chance of appreciation and so on. The managers will be expected to fill this data as per the expectations of the end consumer or the people who are going to use the process.

Step 4: Check consistency

This step is inbuilt in most software tools that help solve AHP problems. For instance if I say that liquidity is twice as important as protection from downfall and in the next matrix I say that protection from downfall is half as important as chance of appreciation, then the following situation emerges:

Liquidity = 2 (protection from downfall)

Protection from downfall = ½ (chance of appreciation)

Therefore, Liquidity must equal chance of appreciation.

However, if in the pairwise comparison of liquidity and chance of appreciation, if I have given a weight of more or less then 1, then my data is inconsistent results, hence prevention is better than cure.

Step 5: Get the relative weights

The software tool will run the mathematical calculation based on the data and assign relative weights to the criteria. Once the equation is ready with weighted criteria, one can evaluate the alternatives to get the best solution that matches their needs.

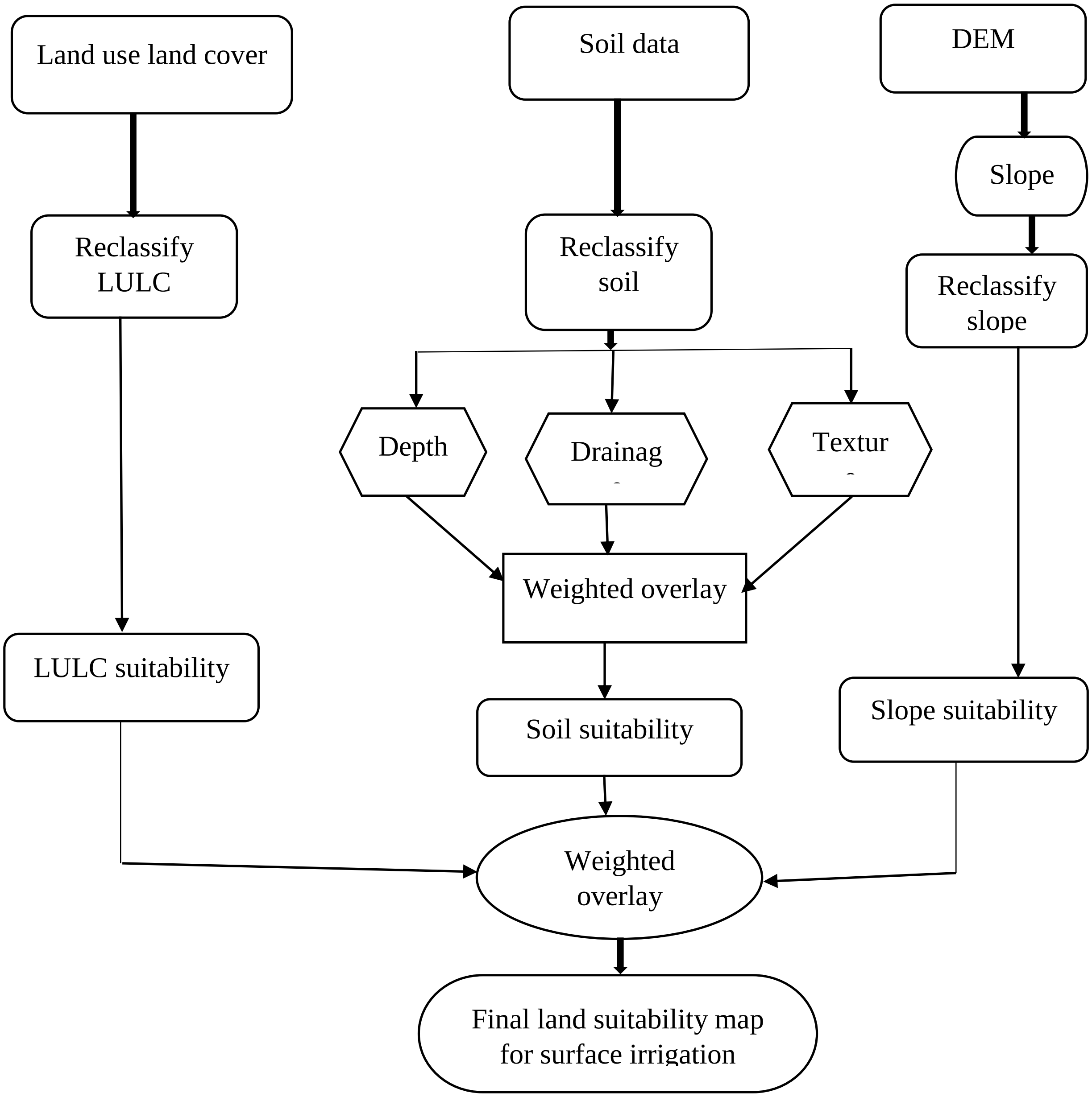

Figure 5: Flow chart of land suitability for surface irrigation

3.4.2 Computation of irrigation water requirements

Potentially suitable sites for surface irrigation development are evaluated for major crops. The reference crop evapotranspiration, effective rainfall, net irrigation and gross irrigation water requirement will be estimated using CROPWAT 8 software to calculate Reference Evapotranspiration (ETo), Irrigation water requirement (IWR), Net irrigation water requirement (NIWR) and Gross irrigation water requirement (GIWR).

Reference evapotranspiration (ETo): It was calculated from climatic data using the FAO penman-monteith method using the following equation (3.4).

$$ETo = \frac{0.408\Delta(Rn - G) + \frac{900\gamma}{T+27.3} * U2(es - ea)}{\Delta + \gamma(1 + 0.34U2)} \quad (3.4)$$

Where, ETo = reference evapotranspiration [mm/day]

Rn = net radiation at the crop surface [MJ/day m2]

G = soil heat flux density [MJ/day m2]

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

U2 = wind speed at 2m height [m/s] es saturation vapor pressure [k Pa]

Ea = actual vapor pressure [k Pa]

es –ea = saturation vapor pressure deficit [k Pa]

Δ = Slope vapor pressure curve [k Pa/ O C]

γ = Psychrometric constant [k Pa/ O C]

Crop evapotranspiration (ETc): The crop evapotranspiration (ETc) is the crop water requirement (CWR) for a crop Onion, Tomato, Cabbage, Maize and Pepper during a certain time period. Crop evapotranspiration was calculated by multiplying the Kc values at each growth stage of the specific crop by the corresponding ETo values (Andreas, 2002).

$$ETc = ETo * Kc \quad (3.5)$$

Where, ETc = Crop evapotranspiration (mm/day)

ETo = Reference crop evapotranspiration (mm/day)

Kc = crop coefficient (fraction)

Net irrigation requirement (NIR): Depends on the climate and cropping pattern. The mean monthly rainfall data and Hydro-Meteorological data are used in calculating the net irrigation requirements for dominant crops in the study area. The different losses such as runoff, seepage, evaporation and percolation take place during the application and transport of irrigation water. Operations such as leaching, transplantation and land preparation require certain amounts of water. Thus, CWR includes ET, losses during the application of water needed for these purposes (Salam *et al*., 2019).

$$NIR = ET_c - P_{ef} \tag{3.6}$$

Where, NIR = the net irrigation requirement of crops (mm)

ETc = crop Evapotranspiration (mm/day)

P_{ef} = effective rainfall (mm).

Effective rainfall (P_{ef}) is the portion of rain, falling during the growing period of the crop, which is available to meet the consumptive water need or the evapotranspiration the requirement of the crop. It is the part of the rainfall that is effectively used by the crop after losses by surface runoff and deep infiltration. The average rainfall for 16 years is used and the data on the monthly basis was given in CROPWAT for calculating effective rainfall. Rainfall data from 2000-2015 was taken to calculate effective rainfall and USDA Soil Conservation Service method was selected from the four methods(Fixed percentage, dependable rain empirical formula, USDA Soil Conservation Service) given in CropWat 8.0 model.

Gross irrigation water requirements (GIWR): GIWR of the crops at the identified potential irrigable sites were estimated based on efficiency from the source to the identified command area. Then, gross irrigation water requirement was computed using the following formula.

$$GIWR = \frac{NIR}{E} \tag{3.7}$$

Where, GIWR = the gross irrigation requirement of crops (mm)

E = overall Efficiency of irrigation in percentage.

The irrigation efficiency expresses the percentage of the quantity of water used efficiently for the growth of the crop in the field to the quantity of intake water from the water source. In the Ethiopian standard of surface irrigation system, E mostly accounts in the range of 40% up to 60% under surface irrigation system. However, for the estimation of gross irrigation requirements in the study area, E was taken as 50% for surface irrigation.

3.4.3 Estimation of water demand

3.4.3.1 WEAP model input data

1. General: as a time-horizon input in the model, current account year of 2016 and last year of scenarios of 2030 was set.

2. Spatial data: Digital Elevation Model (DEM) was used to generate the boundary of the study area by using Arc-Hydro tools in ArcGIS 10.7.1 software. These shape files also uploaded into WEAP system and used for schematic view of the study area.

3. Catchments: land area (201,365 ha), Kc (crop coefficient), monthly stream flow, climate (monthly precipitation, maximum and minimum temperature relative humidity) are model inputs under catchment category.

4. Population: estimated population data of 2016 and projected population data of 2030 years was entered as a basic input for the model.

5. Demand Sites: A demand site here is defined as a set of water users that share a physical distribution system that are all within a defined region or that share an important withdrawal supply point. Because of this demand sites for the model: irrigation, domestic, livestock, industrial demand.

A) Population data and population projection

According to the 2007 Population and Housing Census, the population of four weredas covering the study area was 510,892. Most of the population (66.6%) centers are in the rural areas and the remaining other one are in the urban areas.

For population projection of the watershed, the method used by Ethiopian Central Statistics Authority (ECSA) was applied. Among the other projection methods, this method is considered to be better for forecasting the Population of the project area. Because most of Ethiopian towns and rural areas are adopting this method and there is lack of sufficient data to use other forecasting techniques. In this method, the assumption is made that all towns and rural areas irrespective of size tend to grow according to the following equation (ECSA, 2007).

$$P_N = P_O * e^{KN} \tag{3.8}$$

Where: P_N = Number of population after N years

Po = Present population

N = Number of years

K = Growth rate

B) Irrigation data

Thus, having rough data collected, approximate irrigation water requirements were estimated from irrigated area, cropping patterns and climate data and by applying assumed irrigation efficiencies. The total irrigation water requirement for the watershed was estimated using the above approach for the actual irrigated area CROPWAT 8.0 program was adopted to calculate the irrigation water requirement of the watershed such datas are Climate/ETo, rainfall and crop files are the major input data necessary to calculate irrigation water requirement. Programme developed by the Food and Agricultural Organization (FAO) of the United Nations.

C) Domestic data

In order to know the domestic demand, it is necessary to assess the human population in the watershed. Hence the population living inside Mojo watershed was estimated based on the method described in equation 3.8.

The domestic water demand is then estimated based on the principle of production of watershed's human population and the minimum standard required per person per year. That means, this domestic demand estimation was done by using the approach of the number of people multiplied by their water consumption. The municipals existing inside the watershed have no clearly documented data on current and future water consumption rates. So, WHO water consumption recommendation was taken for this study purpose.

D) Livestock data

The livestock population distribution over the watershed has been assessed as shown in Appendix Table 24. The livestock water requirement is satisfied by direct drinking and through the feed. The importance and quantity of water intake vary with the weather, diet, management of livestock, and variations between species. Generally, the water requirement for livestock in the watershed is calculated based on values indicated in Appendix Table 26.

E) Industrial data

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 10% of the domestic used (Adeba *et al*., 2015).

F) Annual water use rate

The total volume of water delivered to the system in a full year expressed in gallons. When demand fluctuates up and down over several years, an average is used. Average Daily Demand (ADD) - The total volume of water delivered to the system over a year divided by 365 days.

3.4.3.2 Water Evaluation and Planning (WEAP) schematization

Model Schematization of the model includes the existing, under-construction and planned water supply and use systems. The Schematic view is the starting point for all activities in WEAP. It is formed from the setup "area". It defines the physical elements comprising the water demand supply system and their spatial relationships, the study time period, units and the hydrologic pattern. The graphical interface of the model is used to describe and visualize the physical features of the water supply and demand system (SEI, 2015). The system formed is a spatial layout called the schematic. GIS Vector Layers were added as overlay or background on the Schematic as shown Figure 7: below.

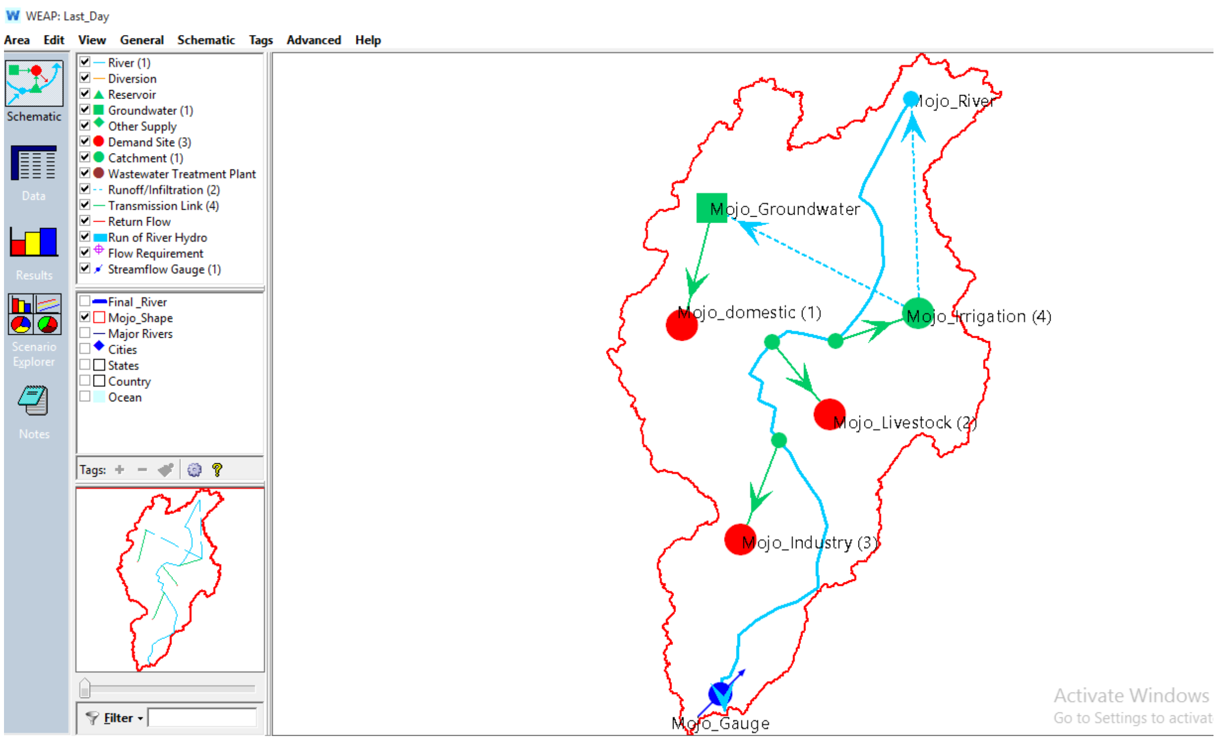

Figure 6: The model schematic in WEAP model

3.4.3.3 Model calibration and validation

Model calibration

Model calibration (parameter estimation) involves automatic and/or manual adjustment of model parameters to minimize the difference between observed and predicted values. WEAP includes a linkage to a Parameter Estimation Tool (PEST) that allows the user to automate the process of comparing WEAP outputs to historical observations and modifying model parameters to improve its accuracy (SEI, 2011).

It is possible to use PEST to help calibrate one or more input variables in the WEAP model. PEST is a freely available parameter estimation tool that is currently used in many fields. It is designed to work flexibly with any computer model that can take a text file as input and produce a text file as output. While WEAP uses a graphical user interface, it is possible to “wrap” WEAP in another program that will take a text file as input allowing PEST to be run.

WEAP model was calibrated using observed stream flow data obtained from MoWIE for Mojo watershed. Naturalized stream flows for a period of the years (2000 to 2006) were used to calibrate WEAP model. The calibration was done using both manual and PEST auto calibration methods.

Model validation

Calibrated model parameters can result in simulations that satisfy goodness-of fit criteria, but parameter values may not have any hydrological meaning. Values of model parameters were a result of curve fitting. This is also reflected in having different sets of parameters values producing simulations which satisfy these criteria. It is therefore necessary to test if parameter values reflect the underlying hydrological processes and were not a result of curve fitting. This is called model validation (Klemes, 1986).

Validation is comparison of the model outputs with an independent data set without making further adjustments. Model validation involves testing the ability of a model to simulate the hydrologic response of a Catchment for conditions different from that used during the calibration period (Legesse, 2003). The calibrated model was then run for a validated period of the years (2007 to 2015) to validate and evaluate the accuracy of the calibrated model.

3.4.3.4 Compare the water supply and demand of watershed area

The water availability was computed for both average monthly and annually. It would been the yield from contribution of surface runoff during high rainfall and lateral flow. In the other way the total volume of water in the basin can be calculated as follow. Total water yield = surface runoff + lateral flow – environmental loss during simulation period multiply with total area of basin. To know the water demand, it is necessary to assess the human population, livestock population, irrigation activities in the basin and industrial firms available in the basin.

3.4.3.5 Developing water allocation scenarios based on demand and supply

The water evaluation and planning model adopted with greater focus on water use and demand projection in the watershed. This model was intended to analyze the impact of different scenarios on demand variation.

The present day water avilibility was assessed based on the rain fall to the area. The question is about the future water avilibility given the impact of climate change the answer for the above question is to set different scenarios and analyzed rationally.

Development of scenarios is based on future assumptions and expected increases in the various indicators. This forms the core or the heart of the WEAP model since this allows for possible water resources management processes to be adopted from the results generated from running the model. The scenarios are used to address a lot of “what if situations”, like what if there is a population increase, increasing irrigation and what if reservoirs operating rules are altered. Scenarios creation can take into consideration factors that change with time (Sissay, 2018).

Considering major planning and economic conditions in the watershed, the following three scenarios that would have significant of the impact on the water supply and demand are selected and formulated. The first scenario is the current situation the second one is population increase and the last one is increasing irrigation area.

Reference Scenario (2016): A “Reference” scenario was established to simulate likely evolution of the watershed system without any interventions. This current scenario treats all conditions of the reference to remain constant (no significant changes in land use would take place, constant water demand and constant growth rate.

Population increase scenario (2016-2030): The assumptions of population are related with the population increasing rate. This can be modified in the “Key Assumptions” data view.

The GTP1 consumption per capital it supposed to increase from 15l/d in 2015 to 25l/d in 2030 for rural population and 25 l/d to 40 l/d for urban population. This data are entry data for Scenario “Population Growth Scenario” the coming 15 year population is calculated in equation (3.8).

Increasing irrigation area (2016-2030): For the study area considering the soil, topographical characteristics and the existing land occupation, the corresponding net irrigable area was determined to be 620.4 ha. For the same “Reference 2000-2015” interval, the future irrigated area will be increased by 68218.5 ha because of building of a large dame at Mojo watershed. This irrigation area is added to the reference irrigation area.

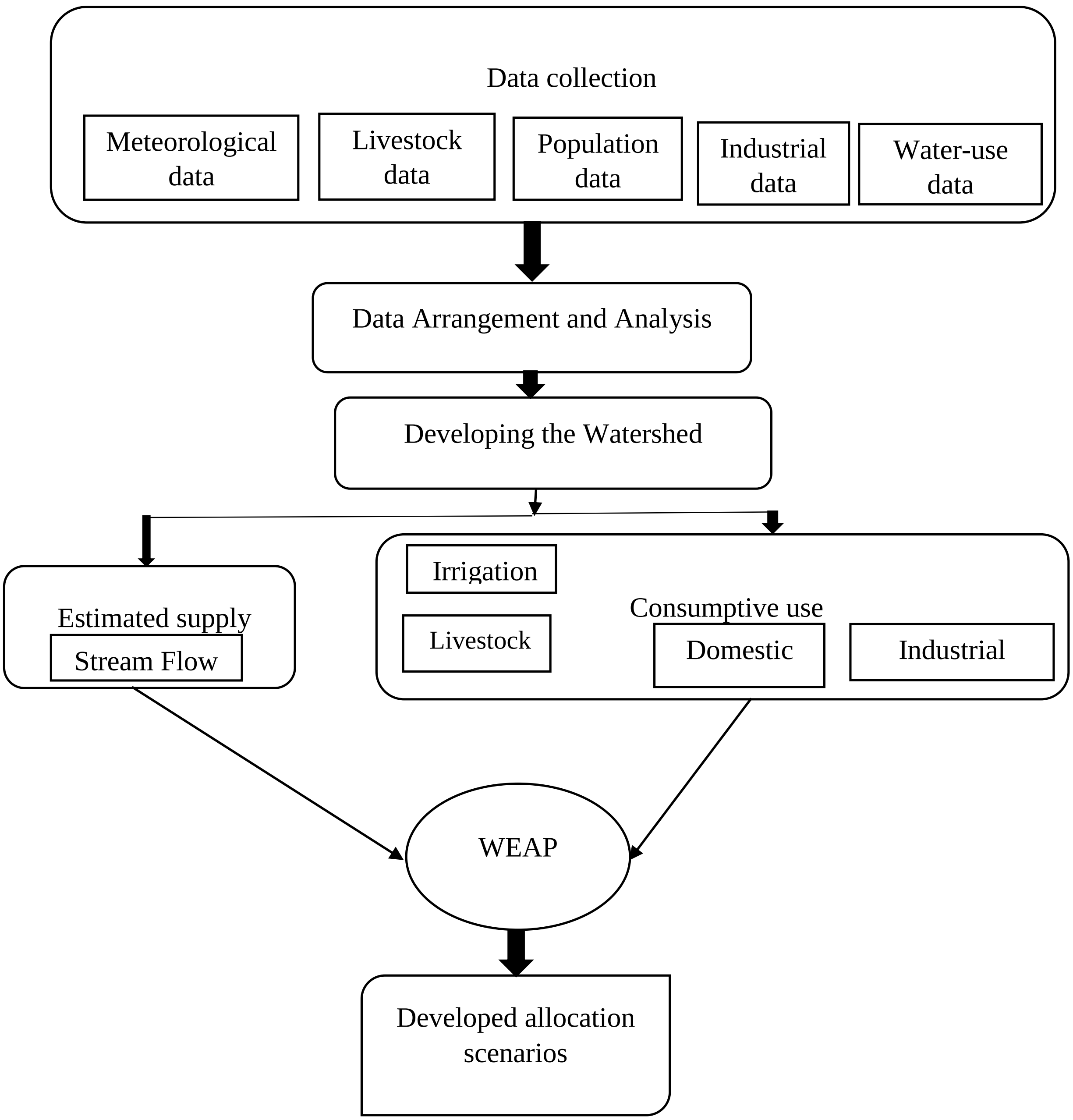

Figure 7: Methodological framework for developing water resources allocation scenarios

4. RESULTS AND DISCUSSION

4.1 Identification of Potential Irrigable Area

4.1.1 Land use land cover suitability

According to land use/land cover suitability classification, most of the watershed area was categorized as highly suitable for surface irrigation. In this study, flower farm, irrigation agriculture intensively cultivated land use types were classified as highly suitable (S1) which covers 84.2% of the watershed area. Open shrub grass land and open bush shrub land then leveling classified as moderately suitable (S2) and covers 2.8% of the total area. Plantation forest, distributed high forest and degraded land were reclassified as marginally suitable (S3) with 6.2% of area coverage. Settlement and water body were reclassified as not suitable (N) with area coverage of 6.8% of the watershed.

Table 6: Land use land cover suitability class of the watershed

S.N	Land use type	Suitability Factor	Description	Area(ha)	Area (%)
1	Degraded land	S3	Marginally suitable	8164.8	4.0
2	Distributed high forest	S3	Marginally suitable	1647.2	0.8
3	Flower farm	S1	Highly suitable	134.7	0.1
4	Intensively cultivated	S1	Highly suitable	168803.9	83.9
5	Irrigation agriculture	S1	Highly suitable	485.7	0.2
6	Open bush shrub land	S2	Moderately suitable	2755.3	1.4
7	Open shrub grass land	S2	Moderately suitable	2735.3	1.4

8	Plantation forest	S3	Marginally suitable	2877	1.4
9	Rural settlement	N	Not suitable	7454.3	3.7
10	Urban settlement	N	Not suitable	5081.7	2.5
11	Water body	N	Not suitable	1225.6	0.6
Total				201365.5	100%

The results clearly show that from the total area of the watershed 93% (187,504 ha) of the land use land cover type was suitable for surface irrigation. The remaining 7% (13,861 ha) of the land was not suitable for irrigation.

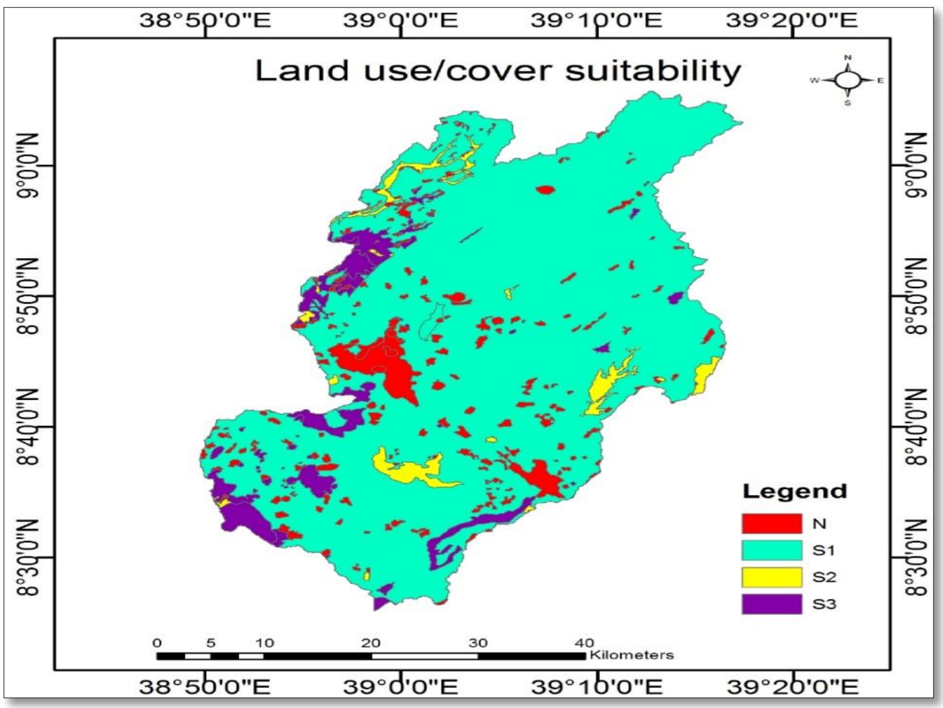

Figure 8: Land use land cover suitability map of the watershed

4.1.2 Soil suitability

There are several soil physical parameters to determine soil suitability analysis, but the three soil physical properties (drainage, texture and depth) were taken into account to evaluate soil suitability in the watershed. The results are presented in the following sub-sections.

4.1.2.1 Soil drainage suitability

The drainage suitability map of the area shows the well-drained area, which covers 32.3% indicates a highly suitable class and 60.1% of the area covered by moderately suitable. The remaining unsuitable class or undrained area, which occupies 7.6% was not suitable for surface irrigation.

Table 7: Drainage suitability area

S.No	Soil drainage	Suitability range	Area (ha)	Area (%)
1	Well	S1	64964.7	32.3
2	Imperfect	S2	121087.7	60.1
3	Excessive	S3	15313.1	7.6
Total			201365.5	100%

Based on the soil permeability of the study area, the soil drainage of the Mojo River watershed was dominantly characterized as well excessive and imperfect drainage. The result is analyzed as follow. The highly suitable drainage classes covers of 64964.7 ha, moderately suitable drainage classes has the areal coverage of 121087.7 ha and the marginally suitable drainage suitability classes has 15313 ha areal coverage.

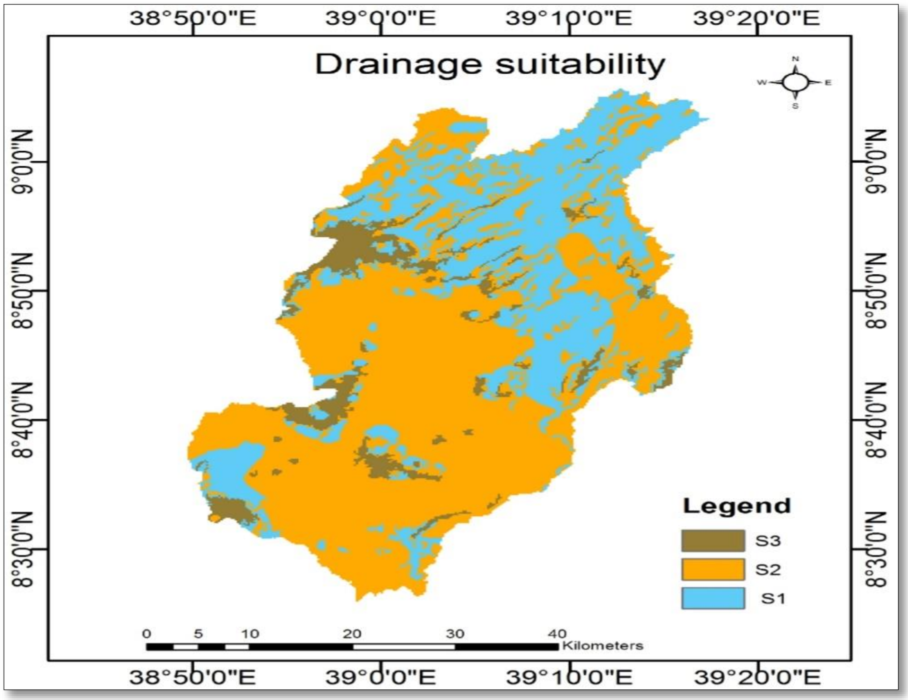

Figure 9: Soil drainage suitability map

4.1.2.2 Soil texture suitability

Soil textural class suitability analysis for surface irrigation development of the area revealed that 60.1% of the soils in the area were under highly suitable (S1), 10.2% of the soil were categorized under moderately suitable (S2) class and 29.7% of the soil textural class in the area were categorized under marginally suitable (S3) class.

Table 8: Soil texture suitability

S.N	Soil texture	Suitability Factor	Description	Area(ha)	Area (%)
1	Clay	S1	Highly suitable	121088	60.1
2	Loam, Clay loam	S2	Moderately suitable	20498	10.2
3	Sandy Clay Loam	S3	Marginally suitable	59779	29.7
Total				**201365**	**100%**

Table 8 clearly shown that 121088 ha of the total area was highly suitable for irrigation in the study area then 20498 ha of the total area where ranges from moderately suitable to marginally suitable classes for surface irrigation are 59779 ha. From the result found observed that most of the study area was suitable for potential surface irrigation in terms of soil texture.

Clay texture soils which have a good characteristic for irrigation was categorized as highly suitable class whereas, loam and sandy clay loam soils were categorized as moderately and sand clay loam are marginally suitable soil texture classes respectively.

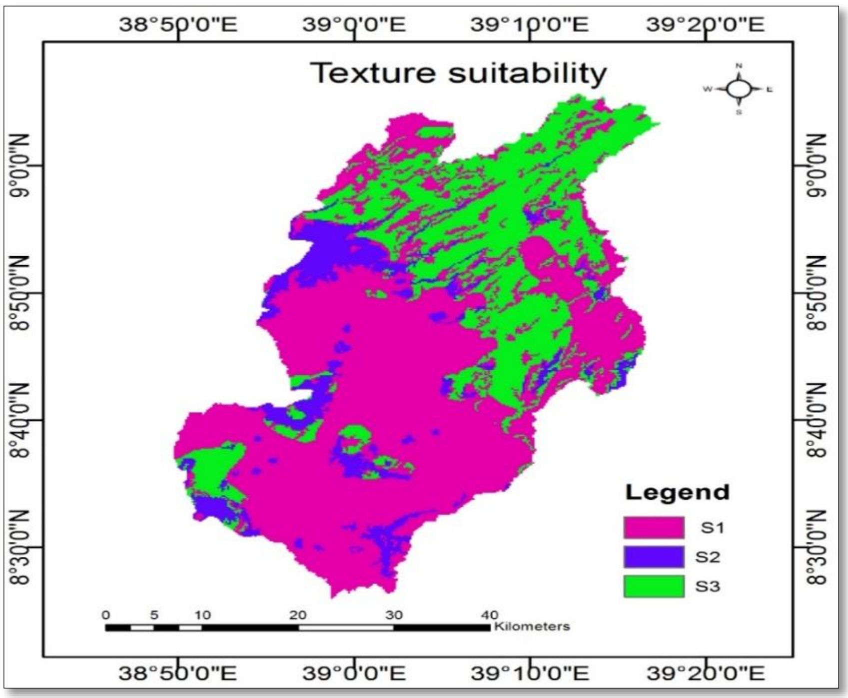

Figure 10: Soil texture suitability map

4.1.2.3 Soil depth suitability

The soil depth of the study area was divided into four: >120, 100-120, 50-100 and < 50 cm with a suitability class S1, S2, S3, N according to (FAO, 1996) respectively. Soil depth in Mojo watershed was evaluated for surface irrigation in terms of highly suitable, marginally suitable and not suitable class with the area coverage of 59.2%, 32.3% and 8.5% respectively. Based on the soil depth assessment most of the study area was dominantly suitable for surface irrigation development. As the result shows, 59.2% of the total area was highly suitable for surface irrigation development concerning soil depth suitability. The soil depth classes and their geographical location of the watershed was illustrated in Figure 11.

Table 9: Soil depth suitability classification

S. N	Soil depth rate(cm)	Suitability Classes	Description	Area (ha)	Area (%)
1	>120	S1	Highly suitable	121063	59.2
2	50-100	S3	Marginally Suitable	64964	32.3
3	0-50	N	Not suitable	15338	8.5
Total				**201365**	**100%**

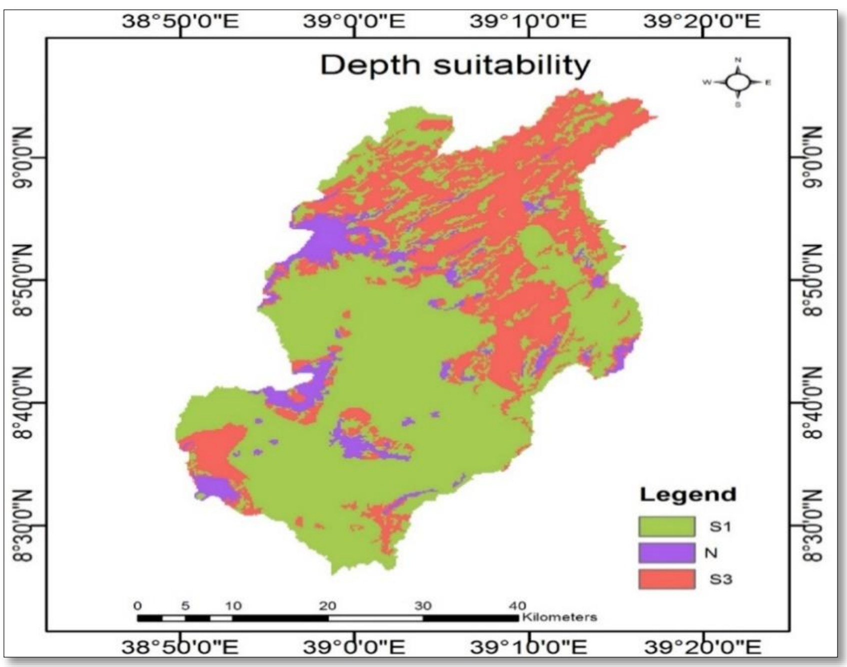

Figure 11: The soil depth suitability map of the watershed

4.1.2.4 Overall soil suitability

In the suitability analysis of each parameter, Soil drainage has three suitability classes (highly suitable, moderately suitable and marginally suitable classes), soil texture also have three suitability classes in the watershed (highly suitable, moderately suitable and marginally suitable classes) and soil depth has three suitability classes (highly suitable, marginally suitable and not suitable classes) for surface irrigation.

Table 10: Overall soil suitability classification

S.N	Suitability Factor	Description	Area(ha)	Area (%)
1	S1	Highly suitable	136442	67.8
2	S2	Moderately suitable	64923	32.2
Total			**201365**	**100%**

From Figure 12 observed that the overall soil suitability of map of the study area is cover by highly suitable and moderately suitable classes for surface irrigation purpose. The soil suitability classes indicate 67.8% of the area of the watershed was in the range of highly suitable and 32.2% of the watershed was categorized under moderately suitable class are with respect to the combined effect of soil drainage, texture and depth classes.

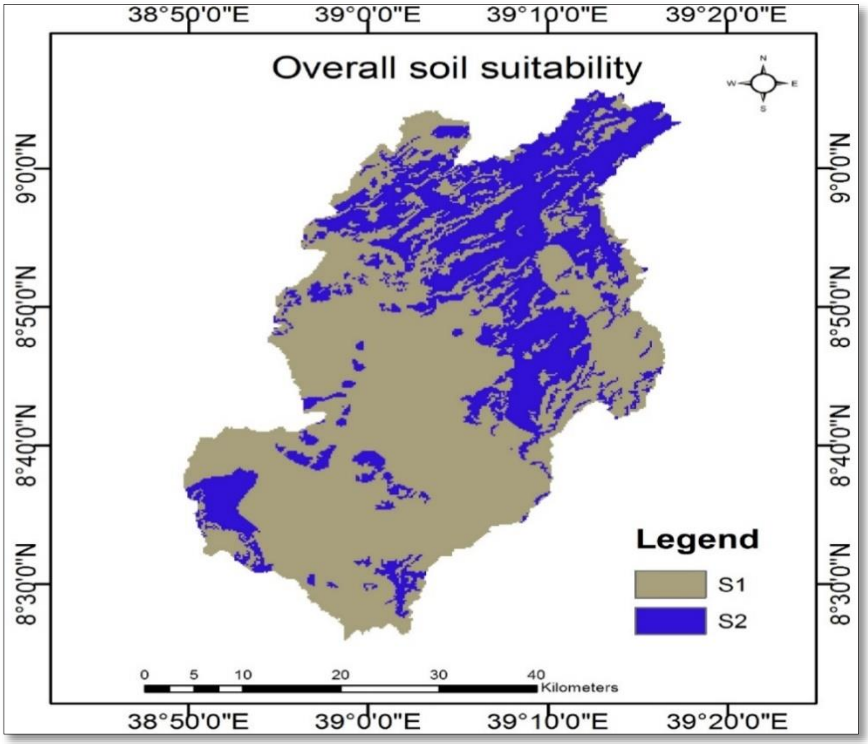

Figure 12: Overall soil suitability map of the catchment area

4.1.3 Slope Suitability

Based on FAO land suitability types there are four slope classes (S1, S2, S3 and N) in the watershed (Figure 13). The slope map of the study area was derived from the virtual elevation version in Arc- GIS and categorized in to four classes for surface irrigation suitability, i.e., from 0-2% as highly suitable (S1), 2-5% as moderately suitable (S2), 5-8% as marginally suitable (S3) and >8% as not suitable (N).The slope suitability for irrigation is shown in Figure 13.

Table 11: Slope suitability class of the watershed

S.N	Slope (%)	Suitability Classes	Description	Area (ha)	Area (%)
1	0-2	S1	Highly suitable	121048	50.3
2	2-5	S2	Moderately suitable	2585	1.3
3	5-8	S3	Marginally suitable	62379	31
4	>8	N	Not suitable	15353	17.4
Total				201365	100%

The slope suitability table elaborates the total amount of slope classes in the percentage of area coverage and the result shows from highly suitable to not suitable degrees in terms of slope suitability for surface irrigation. Table 11 shown that 50.3% of the total area where highly suitable for surface irrigation area covers 121048 ha, 1.3% of the total area where moderately suitable area covers 2585, 31% of the total area where marginally suitable area covers 62379 and the remain 17.4% of the total area where currently not suitable for surface irrigation in the study area covers 15353 ha. Therefore, in terms of slope suitability, most parts of the total area (50.3%) were potentially suitable for surface irrigation in the study area.

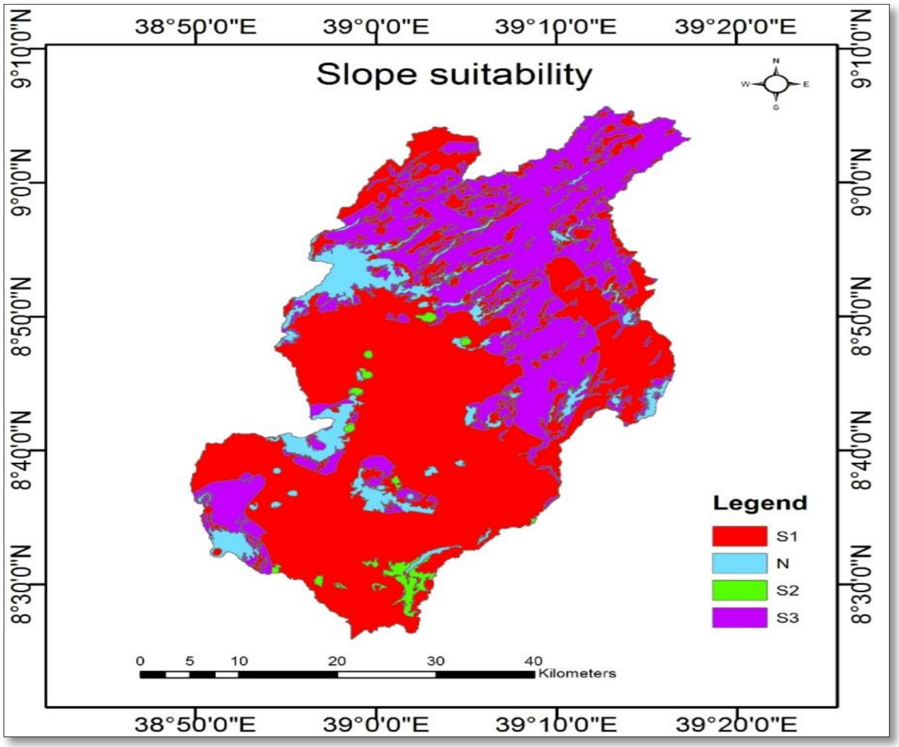

Figure 13: Slope suitability map of the watershed

4.1.4 Suitability factor analysis

Factors derived have different degrees of influence on suitability evaluation. The factors considered in this study are slope, soil and land use land cover. The relative importance of each parameter has been determined. Therefore, the higher the weight, the more influence a particular factor would have on suitability evaluation. Final criteria weight in percentage analyzes of suitability factor of LULU, soil and slope of the study area in the Table 12:

Table 12: Weight of factor from comparison matrix

Factors	LULC	Soil	Slope	Weighted factor	Weighted percentage
LULC	1	1/3	1/5	0.106	**10.6**
Soil	3	1	1/3	0.257	**25.7**
Slope	5	3	1	0.632	**63.2**
Total	**9**	**4.33**	**1.53**	**1**	**100%**

Cr = 0.01

The results shown that the categorized factor percentage of weight of LULC, soil and slope sequentially has 10.6%, 25.7% and 63.2% degree of influence when assessing suitable land for surface irrigation in the study area.

4.1.5 Suitable land for irrigation

Suitable land for surface irrigation was identified based on the specified suitable criteria analysis by overlaying the suitability criteria which involved weighting of values of all data sets such as land use land cover, soil drainage, soil texture, soil depth and slope of the study area.

Table 13: Suitability Class of the study area

S.N	**Suitability Factor**	**Description**	**Area(ha)**	**Area (%)**
1	S1	Highly suitable	136437	68
2	S2	Moderately suitable	2644	1
3	S3	Marginally suitable	59700	30
4	N	Not suitable	2584	1
Total			**201365**	**100%**

The final result of the suitability analysis was categorized according to their suitable level with respect to their area as shown in (Table 13). From the total area coverage of the study area 68% (136437 ha) was classified as high suitable, 1% (2644 ha) moderately suitable, 30% (59700 ha) marginally suitable, whereas 1% (2584 ha) currently not suitable for surface irrigation.

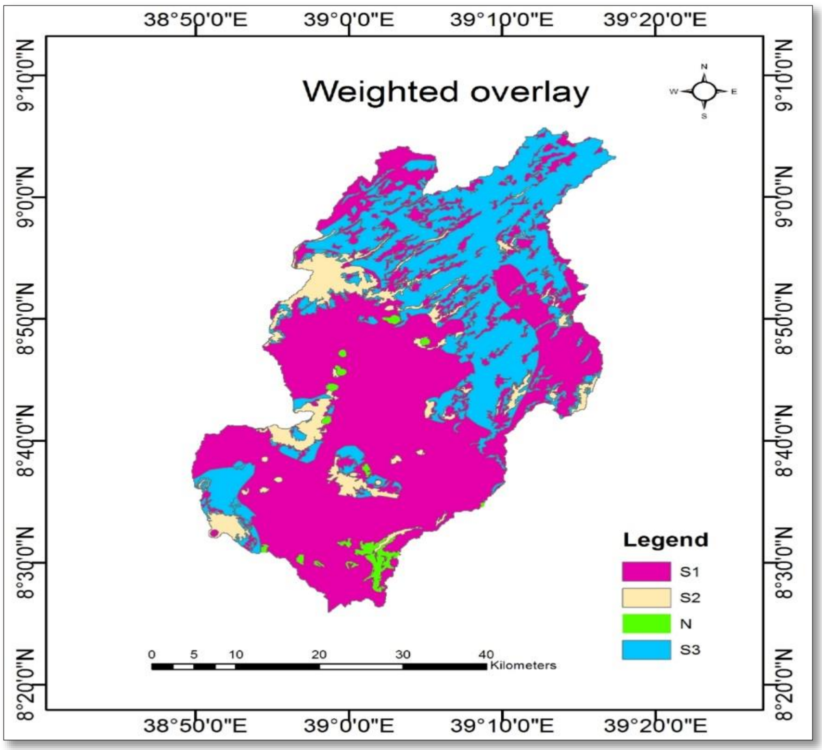

Figure 14: Final land suitability map of the watershed

According to Berhanu (2018), land suitability evaluation for upper Awash Basin of Holeta River. The result of the suitability of land evaluation ratings based on the qualitative land suitability for irrigation indicated that 18.16% (9504 ha) are highly suitable (S1), 55.84% (29,217.9 ha) are moderately suitable (S2), 25.91% (13,558 ha) marginally suitable (S3) and 0.086% (45 ha) are not suitable (N) for surface irrigation systems. Hence, the majority of the study areas are in a range value of highly to marginally suitable for surface irrigation purposes.

Generally, the assessment of land suitability for surface irrigation in Mojo watershed showed that 92.4% of the slope ranges from highly suitable to marginally suitable classes and 67.8% of the soil and 84.2% of the land use/land cover was highly suitable for surface irrigation development. This indicates the study agreed with the study conducted by Bayush (2020), in upper Awash Basin in Dens watershed for assessment of irrigation potential of the watersheds considering soil type, slope and land use land cover. The result shows that 50.75% of the slope ranges from highly suitable to marginally suitable. In this study, 78% of the land use land cover and 76.4% of the soil was highly suitable for surface irrigation.

4.2 Irrigation Water Requirements of the Identified Command Area

The estimation of irrigation water requirement of selected crops was done using reference evapotranspiration, crop coefficient, crop water requirement or consumptive use, effective rainfall, net irrigation requirement and gross irrigation water requirement. The average annual rainfall for the study area is 978.8 mm and the effective rainfall used by the crops is 702.7 mm which is 71.9% of the average annual rainfall.

Table 14: Net and gross irrigation water requirements

Crop type	**Net irrigation water requirement (mm)**	**Gross irrigation water requirement (mm)**	**gross water required (m^3 ha^{-1})**
Onion	496.0	992	9920
Tomato	469.0	938	9380
Cabbage	506.4	1012	10128
Maize	359.0	718	7180
Pepper	373.4	746.8	7468

Irrigation water requirements at the identified potential irrigable area under surface irrigation methods were estimated. The total net and gross irrigation water requirements are 496 mm and 992 mm for onion, 469 mm and 938 mm for tomato, 506.4 mm and 1012.8 mm for cabbage, 359 mm and 718 mm for maize and 373.4 mm and 746.8 mm for pepper respectively. Similarly, the study conducted by Bayush (2020), on net and growth irrigation water requirement for Onion, Tomato and Cabbage are 410.2 and 820.4, 404.2 and 808.4, and for Cabbage 422.7 and 845.4 respectively.

4.3 Model Calibration

Scatter plot for the mean monthly observed and simulated flows at Mojo gauged catchment during the calibration period (2000 to 2006) the simulated flow has captured the observed flow values for Mojo river watershed during calibration period. The result of the calibration led to a better fit between the observed and simulated values of flow. The performance of the model was good for the calibration period with NSE 0.82 and R^2 0.9974. As shown on Figure 16. Scatter plot for the mean monthly observed and simulated flows at Mojo gauged catchment during the calibration period (2000 to 2006) the simulated flow has captured the observed flows of Modjo river watershed for the calibration period.

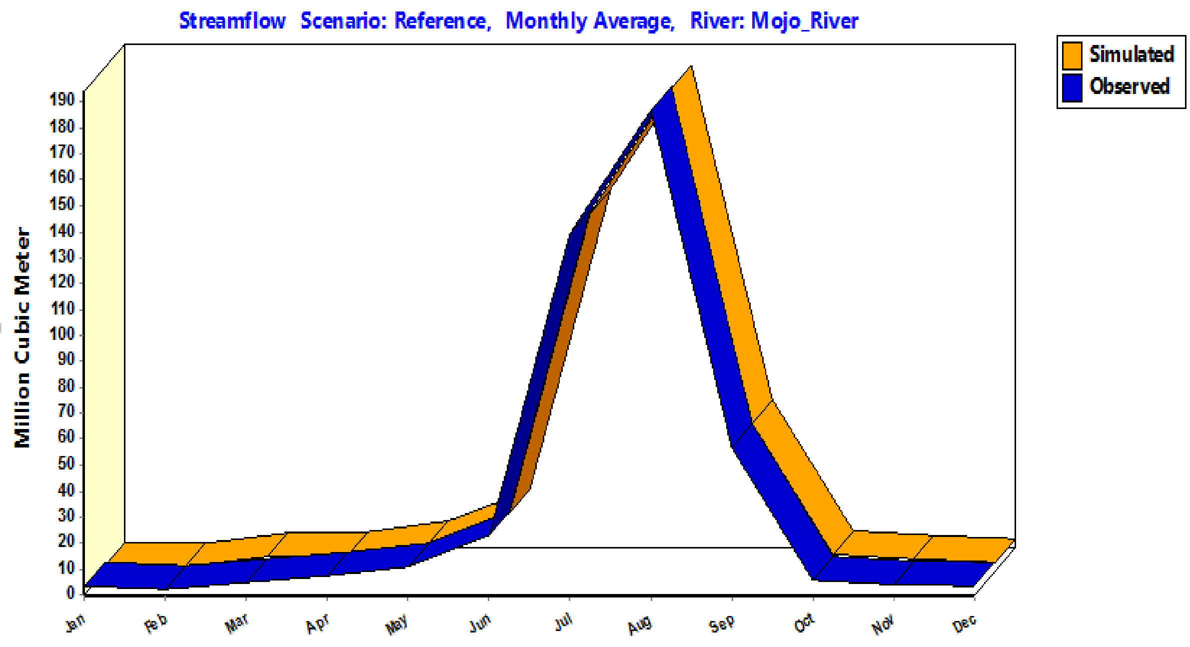

Figure 15: WEAP model calibration (2000 to 2006) for Mojo river watershed

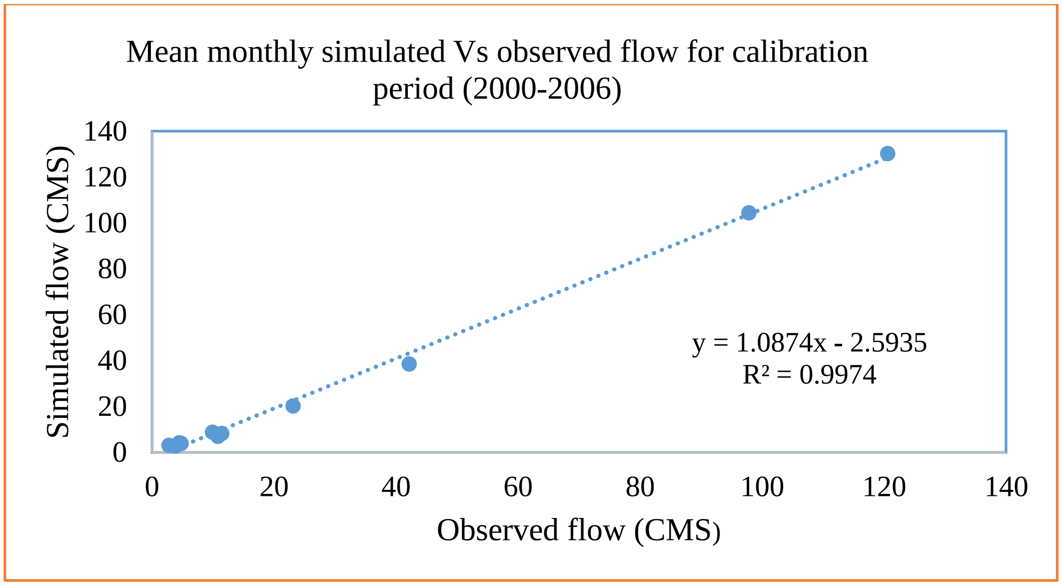

Figure 16: Scatter plot observed and simulated flow of the calibration period

4.4 Model Validation

The performance of the model was also evaluated for the validation period from (2007 to 2015) which is separate from the calibration period. The model performance criteria result shows that NSE is 0.875 and R^2 0.9975 for the validation period which shows good agreement between the simulated and observed flows of the watershed.

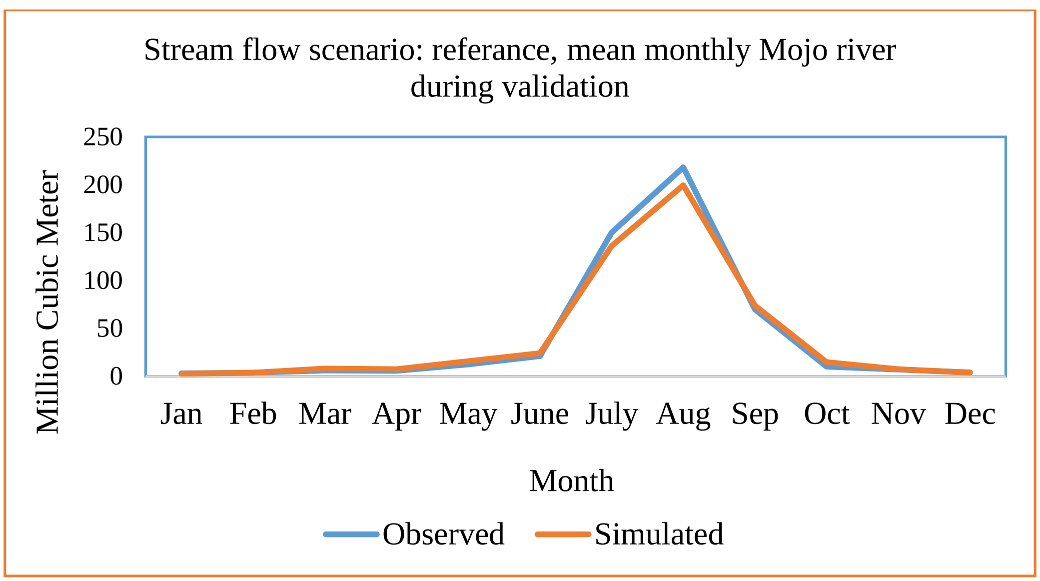

Figure 17: WEAP model validation (2007 to 2015) for Mojo river watershed

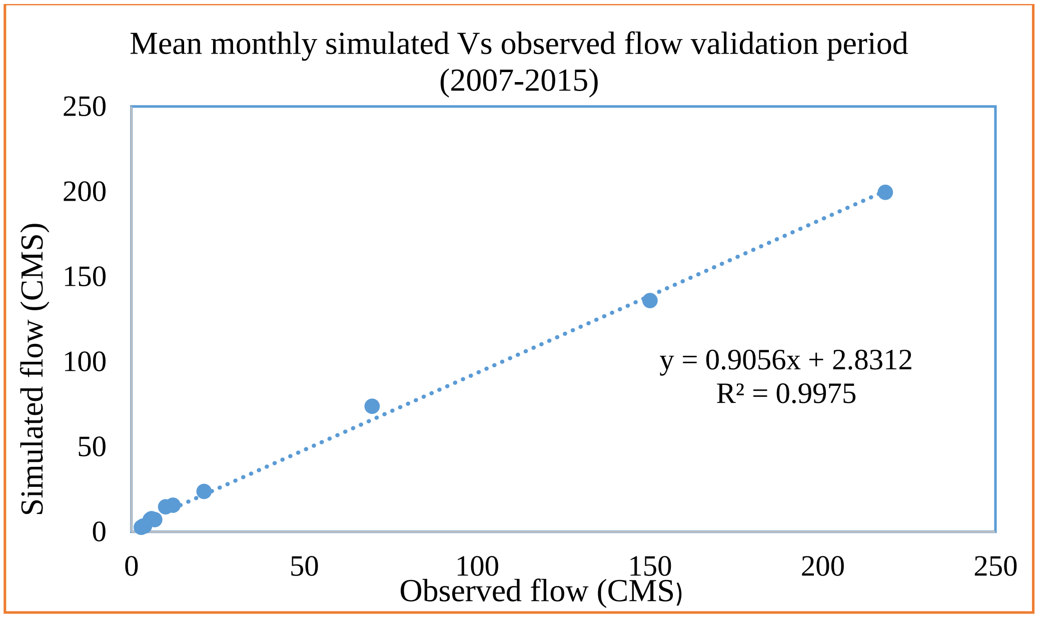

Figure 18: Scatter plot observed and simulated flow of the validation period

4.5 Estimated Water Balance Components of Mojo Catchment

The evaluation of water resource is done based on the meteorological data, hydrogeological data and land use characteristics on the model. The amount of water entered in to the catchment is broken down into different components as surface runoff, recharge, evapotranspiration and change in storage Table 15. From long term mean monthly precipitation the catchment gets 1,964.67 MCM annual rainfall and 16.85 MCM (0.86%) as a form of irrigation. The potential evapotranspiration is estimated as 1,372.77 MCM (69.8%) per annum respectively. The surface runoff and recharge is estimated as 419.73 MCM (21.3%) and 136.39 MCM per annum respectively. The amount of recharge from the total input is about 6.9%.

Table 15: The monthly average water balance components of Mojo river watershed

Water balance components	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
Decrease in Soil Moisture	**51.9**	**62.3**	**24**	**5.97**	**4.53**	**2.5**	**19.4**	**28.2**	**101**	**96.9**	**27.1**	**41**	**464.4**
Evapotranspiration	**-55**	**-72**	**-77**	**-40**	**-25**	**-103**	**-262**	**-286**	**-262**	**-124**	**-27**	**-39**	**-1,372.8**
Flow to Groundwater	**-9.4**	**-8.8**	**-8.8**	**-9.7**	**-11**	**-13**	**-14**	**-15**	**-14**	**-12**	**-11**	**-10**	**-136.4**
Increase in Soil Moisture	**-5.7**	**-7.1**	**-41**	**-66**	**-95**	**-62**	**-134**	**-68**	**-1**	**-3.7**	**-6**	**-2.8**	**-493.1**
Interflow	**-1.7**	**-1.6**	**-1.6**	**-1.7**	**-2**	**-2.2**	**-2.4**	**-2.6**	**-2.5**	**-2.1**	**-1.9**	**-1.9**	**-24.1**
Irrigation	**0.26**	**1.79**	**8.3**	**4.08**	**1.78**	**0.29**	**0**	**0**	**0**	**0.04**	**0.03**	**0.3**	**16.8**
Precipitation	**22**	**28.2**	**104**	**116**	**140**	**200**	**516**	**510**	**238**	**53.4**	**21.8**	**16**	**1,964.7**
Surface Runoff	**-1.9**	**-2.3**	**-8.2**	**-7.9**	**-12**	**-23**	**-124**	**-167**	**-59**	**-8.4**	**-3.4**	**-2**	**-419.7**

4.6 Estimated Stream Flow for Mojo River

The annual stream flow volume of Mojo River was estimated and at the base year the flow is 455.42 MCM. The result of the WEAP simulation estimated that the average annual water flow of Mojo River at 419.51 and 444.05 increase irrigation area and population increase scenarios. The mean monthly flow of the river as shown on the Figure 19 indicates that there is high seasonality where 90.8% of the annual flow is contributed on the 4 months (June, July, August and September). The flow reaches its peak on the month of the beginning of August. The graph which represents by reference is shows the flow volume of the river result from 2000-2015 year and it uses to compare with the scenarios. The annual graph Figure 19 shows the volume of stream flow under reference and two scenarios. As describe in the previous work the land use land cover is change year to year because of anthropogenic effect the surface runoff also increase year to year (Figure 19).

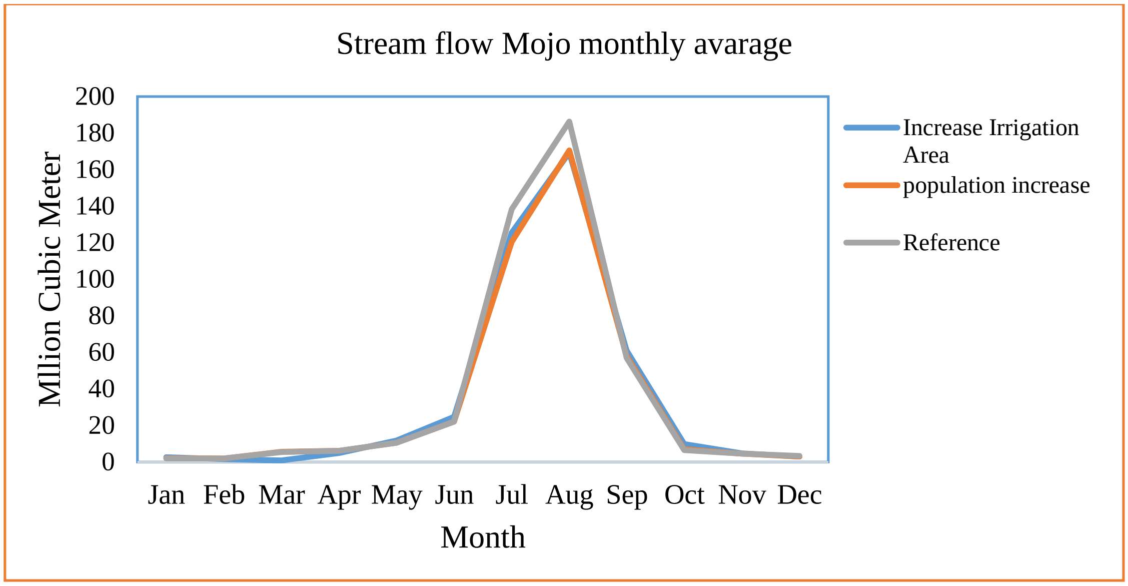

Figure 19: Mean monthly stream flow of Mojo River under different scenarios

In the Figure 19 above the long term monthly flow volumes of Mojo River in different scenarios. At the rainy season the long term volume of flow is high in all scenarios. Especially the month July, August and September have high volume of flow. The reference in the above graph is represents from 2000-2015 volume of flow used to compare the scenarios.

4.7 Demand and supply Requirement

The water demand and supply requirements were simulated under reference and two future demand scenarios for the four (4) demand sites (domestic use, livestock use, industry and irrigation use) that were set up on the model. The annual total water demand and supply of the catchment without including losses reuse and demand side management shows rapid growth. Under the reference scenario the total annual water demand for the baseline is estimated as 10.92 MCM. These results indicate that, the utilization is low compare with a population within the basin. Based on the scenario analysis by 2030 the total annual water demand is estimated as 871.89 MCM and 11.37 MCM under increase irrigation area and population increase scenarios respectively.

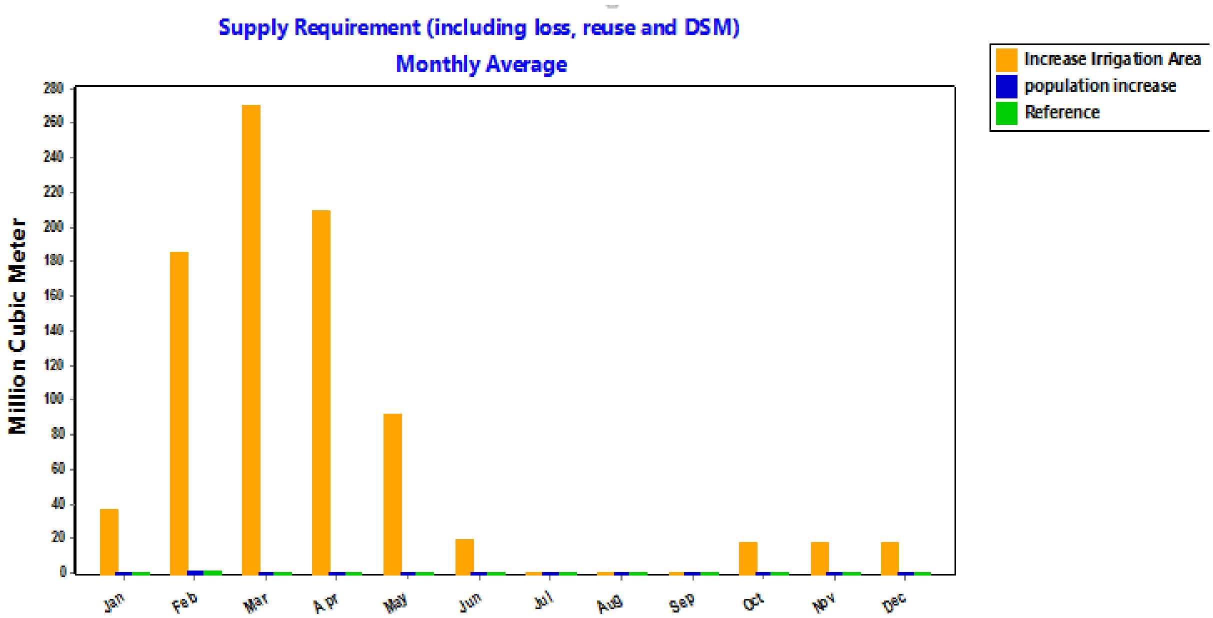

Figure 20: Monthly water supply requirement simulated, under reference and two future demands scenarios

4.8 Demand Sites Reliability

Reliability is the percent of time steps in which a demand sites demand was fully satisfied. The reliability of each demand site has been analyzed under the reference and two future demand scenarios in WEAP model and the result is shown in Table 16. As shown on the Table 16 below the demand sites which do have less reliability are irrigation sites. The reason behind is that the water demand of this site is very high during the low river flow months where there is scarcity of water and this site is mainly dependent on the natural flows of the rivers. The demand for water of the irrigation site becomes low during the periods where water resource availability becomes high.

Table 16. Water demand Vs resource, 2030 reference and two scenarios

Demand sites	Increase Irrigation area	Population increase	Reference
Irrigation	73.44	95.83	95.83
Domestic use	100	100	100
Livestock use	98.96	98.96	98.96
Industry use	98.96	98.96	98.96

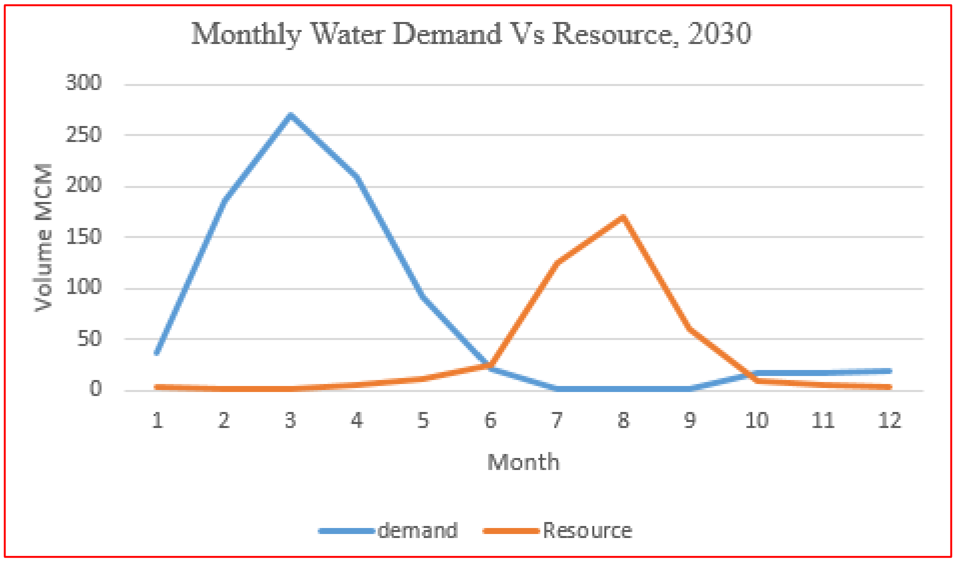

Figure 21: Monthly water demand Vs resource, 2030 under irrigation area increase scenario

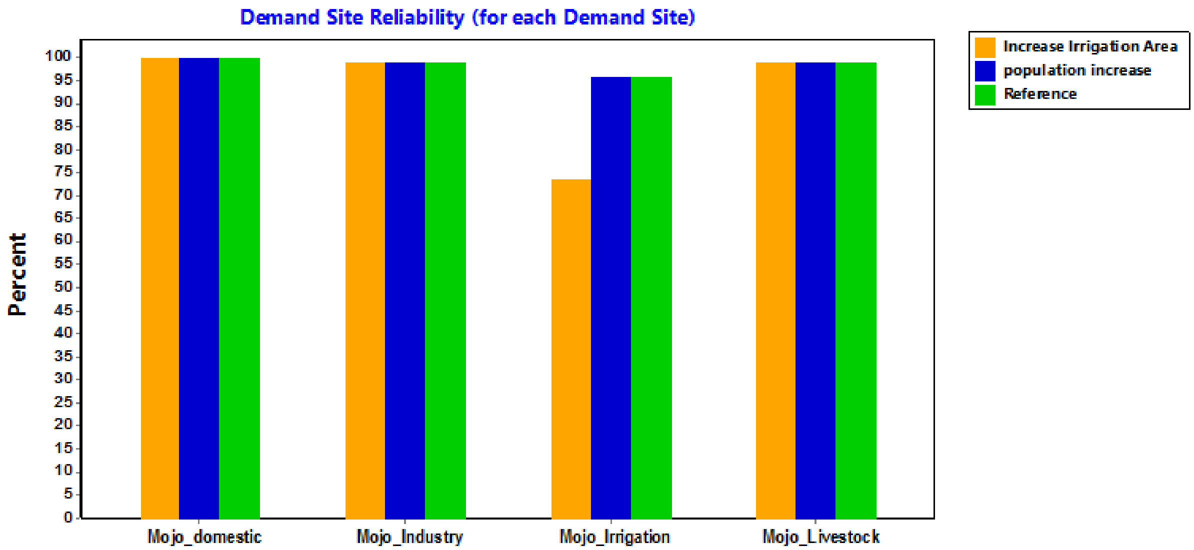

Figure 22: Demand sites reliability (%) for each demand sites under the reference and two future demand scenarios

4.9 Unmet Demands under Different Scenarios

The annual total unmet demand for all of the demand sites was estimated as shown below on Figure 23. The unmet demand is increasing at fast rate mainly due to the current and expected future expansion of irrigation which uses huge amount of water. Based on the scenario analysis by 2030 the total annual unmet demand is estimated at 0.66, 847.32 and 29.19 MCM under reference, increase irrigation area and population increase scenarios respectively. Therefore, the analysis showed that the main water demand sites which get water scarcity problem or high unmet demand are due to increasing of irrigation area. The graph below shows that the unmet demand in different scenarios decrease due to at high annual flow volume of the river water and it rises at low annual flow volume of the river water.

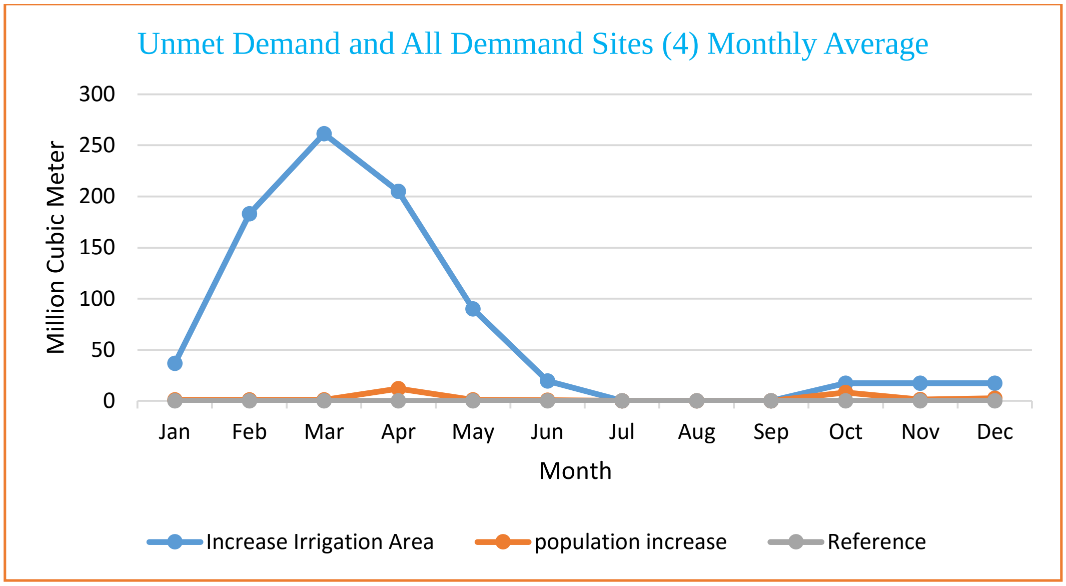

Figure 23: The monthly unmet demand of all demand sites, MCM for all demand scenarios (2016-2030)

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

To enhance agricultural production and optimal allocation the need for irrigation and proper distribution is unquestionable. The main aim of this study was to assess land resource potential for surface irrigation and propose optimal water allocation for various water use sectors in the study area. Assessment of land suitability for irrigation and optimal allocation of water is important to utilize limited resources efficiently and for the sustainable production of crops and food security of the ever-increasing population in the study area.

Land suitability for surface irrigation was evaluated by assessing land use/cover, soil and slope suitability. To identify soil suitability for irrigation soil texture, drainage and depth were considered. Each of the data layers was classified into different classes of suitability. Weighted overlay of the classified such as LULC, soil and slope by using Arc GIS 10.7.1 to get suitable land for surface irrigation from the total area coverage of the study area 68% (136,437 ha) was classified as high suitable, 1% (2,644 ha) moderately suitable, 30% (59,700 ha) marginally suitable, whereas 1% (2,584 ha) currently not suitable for surface irrigation.

Irrigation water requirements at the identified potential irrigable area under surface irrigation methods were estimated by using CropWat 8.0 model. The total irrigation water requirements for Onion, Tomato Cabbage, Maize and Pepper was 992, 938, 1012.8, 718 and 746.8 mm respectively.

The WEAP model simulated monthly flow has shown a good agreement with the observed flow. Water balance results from long term mean monthly data shows the precipitation are 1,964.67 MCM was estimated evapotranspiration are high percentage then the other those are 69.8%.

The average annual flow volume of Mojo watershed was estimated as 455.42 MCM. The total water supply requirement of water demand sites was high estimated as 871.89 MCM under increase irrigation area.

The percentage of irrigation water demand out of the total simulated water demands are 73.44%, 95.83% and 95.83% under increasing irrigation area, increasing population and reference respectively.

Based on the scenario analysis by 2030 the total annual unmet demand is estimated at increase irrigation area is 847.32 MCM. Increase irrigation area scenario the study clearly indicates that water scarcity was recognized until the end period of scenario.

5.2. Recommendation

Based on the results found and challenges faced during study period, the following recommendations are set for the water demanding sectors and other researchers.

- This study was limited to three soil physical properties which are soil drainage, texture, and depth to assess land suitability for surface irrigation. Since other soil physical and chemical properties may have their own influence to characterize the suitability of land for surface irrigation. Therefore, further research suggested to be incorporate considering additional factors such as river proximity, soil type, soil reaction (PH) and salinity and alkalinity to assess land suitability over the study area.

- This study was focused on estimation of surface water availability. The amount of surface water is not only for surface irrigation so estimation of groundwater potential also important resources for irrigation development. Therefore, further study shall demonstrate considering estimation of available groundwater supposed to utilize for irrigation development in the study area.

- Do to the occurrence of insufficient water, alternative source of water supply like water harvesting technologies shall consider during extended studies to alleviate water shortage in the watershed.

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APPENDICES

Tables in the Appendix

Appendix Table 1: Monthly rainfall at Mojo station

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2000	0	0	12	10.1	33.2	128	286	231	114.1	12.6	25.4	0
2001	0	28.5	79.4	22.5	111	132	185	176	54.9	0	0	0
2002	0	0	8.9	13.7	6.5	62.4	194	169	95.2	0	0	14.9
2003	40.6	55.9	74.9	84.3	23.2	129	393	149	96.1	0	0	14.3
2004	15.5	0	99.3	115	9.8	97.6	394	201	116.9	99.1	32.4	0.1
2005	36.6	19.1	161	150	195	201	321	309	143.5	14.6	10.9	0
2006	1.6	38.5	90.5	61.6	19.2	109	344	363	131.8	24.9	2.6	12.3
2007	54.1	23.7	83.8	49.6	111	130	223	228	91.4	7.6	0	0
2008	1.5	0	0	61.9	76.7	137	431	404	188.7	89.4	50.8	0
2009	39.2	6	26.3	62.9	12.7	95.3	214	330	66.2	215	6.5	34.6
2010	0	85.2	7.7	152	120	73.4	254	170	246.7	0	1.4	0
2011	0	0	47.4	54.9	122	54.6	193	176	170.4	0	0	0
2012	0	0	37.8	43	46.9	91.8	524	420	147	0	0	0
2013	0	0	85.8	32.9	121	98.5	420	232	69.2	36.4	0	0
2014	0	16.8	51.9	2.9	7.6	27.4	261	257	154.3	96.3	0	0
2015	0	0	0	0	186	118	157	275	93.9	8.5	21	0
Mean	**11.8**	**17.1**	**54.1**	**57.3**	**75.1**	**105**	**300**	**255**	**123**	**37.7**	**9.4**	**4.7**

Appendix Table 2: Monthly rainfall at Ejere station

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2000	0	0	10	20.9	16	97	259.2	162.6	143	21	32.6	10.2
2001	0	12.8	99.3	14.7	75.3	131	306.5	224.4	42.3	0	0	14.5
2002	2.2	9.5	49.3	4.3	39.4	29.2	203.2	254.3	100.4	0	0	49.2
2003	29	50.8	5.7	101	0	113	318.9	359.5	124.9	0	0	66.2
2004	47	2.9	76.4	64.9	0	74	165.6	392.7	100.1	28	0	0
2005	50	0.6	81	71.3	25.7	90.8	227.3	327.9	118.4	6.9	8	0
2006	0	14.8	87.3	174	29.4	89.6	259.6	128.2	20.1	0	46.2	46.2
2007	8.7	21.8	69.1	39.8	80.4	78.9	255.7	266.4	149	27	17.6	0
2008	9.3	1	0	71	60.8	119	263.9	254.1	76.4	49	58	0
2009	50	0	4.3	53	18.7	33.7	169.9	310.3	78.1	54	8.7	17
2010	0	46	89.3	101	53.4	163	197.6	128.5	149.6	0	0	5.5
2011	28	0	78.8	56.4	101	139	151.9	332.1	139.6	0	0	0
2012	0	0	42.8	29.2	26.5	129	464	322.7	127.5	29	0	8
2013	0	13.8	15.2	45.8	4.4	127	584.6	612.8	236.8	92	3.5	0
2014	5	22.9	32.6	79	103	129	535.7	943.4	212.9	205	70	0
2015	6.6	0	0	22	41.6	15.3	0	0	0	0	0	21.5

Appendix Table 3: Monthly rainfall at Deberzite station

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2000	0	0	8.6	50.4	65.4	77.4	244	181	139.4	40	23.4	3.4
2001	0	4.6	166	21.8	104	79.5	242	143	64.3	38.2	0	0
2002	8.6	0	48	34.6	11	109	179	178	58.4	0	0	21.3
2003	38.3	55.4	64.4	100	21.1	81.4	278	286	120	6	3.6	35.4
2004	41.6	1.05	67.8	120	2	134	173	209	73.6	22.6	10.3	0
2005	21.8	0	122	77.3	86.5	96.7	168	187	153.3	0	2.9	0
2006	5	109	0	52.2	32.2	108	329	141	122.8	78.3	5.2	16.1
2007	5.8	0	0	57.9	92	77.4	327	155	123.2	13.2	6.2	0
2008	0	0	0	41.1	47.6	55.5	226	254	148.6	3.2	45.2	0
2009	40.9	0	13.9	16.8	16.8	38	125	244	45.5	67.5	0.6	20.9
2010	0	36.2	87	130	37.2	101	198	205	125.5	0	0	0
2011	0	0	85.2	25.2	64.8	86.7	240	296	147.3	0	1.6	0
2012	0	0	110	39.2	26.9	59.7	176	194	67	1.6	0	2.2
2013	0	0	32.3	51.2	50.8	162	387	315	160.9	0	2.57	0
2014	1.25	21	37.5	22.8	76.3	62.7	315	423	140.5	110	20.7	0
2015	0	0	18.9	3.8	131	116	172	43	92.8	2.8	17.9	7.4
Mean	**10.2**	**14.2**	**53.9**	**52.8**	**54.1**	**90.2**	**236**	**216**	**111.4**	**23.9**	**8.76**	**6.67**

Appendix Table 4: Monthly rainfall at Alem Tena station

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2000	0	0	0	127	89	51.7	208	144	155.8	52.7	54.2	0
2001	0	24.6	158	15.7	114	114	212	155	72.8	0	0	0
2002	1.5	35.4	24.3	82.9	15.5	45	181	151	33.1	0.5	0	19
2003	19	16.7	116	54	29.4	84.6	393	105	96.5	0	0	21.7
2004	89.4	0	58.4	174	0	78.8	123	145	110.6	40.5	0	2.5
2005	32.7	1.2	101	131	80.4	55.1	104	237	136	12.5	5.5	0
2006	1.2	64.9	148	46.4	48.9	55.3	167	125	69.4	27.7	0	15.4
2007	10.1	15.2	52.1	47.8	102	117	157	172	125.5	36.8	5.2	0
2008	0	0	0	36	90.1	163	245	227	121	31.5	44.6	0
2009	0.9	0	19.6	28.8	31	61.3	148	303	57.5	80.4	0	24.3
2010	0	55.4	135	58.7	95.8	81.6	186	145	64	0	16.2	1.5
2011	0	0.8	45.7	0	79.5	86.7	157	235	216	0		0
2012	0	0	0	50.7	32.2	108	351	192	247.7	0	0	0.5
2013	4.2	0	130	4	77.2	97.1	285	152	157.7	36	1.5	0
2014	0	19	46.3	4	158	15.5	259	228	112	90.3	1.5	0
2015	0	0	18.9	0	162	103	146	178	51.4	1.5	3.7	0.7
Mean	**9.94**	**14.6**	**65.8**	**53.8**	**75.3**	**82.3**	**207**	**181**	**114.2**	**25.7**	**8.83**	**5.35**

Appendix Table 5: Monthly rainfall at Chefedonsa station

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2000	0	0	23.8	40	18.9	96.2	183	227	138	31.7	19.1	0
2001	0	23.8	110	17.4	69.1	89	203	111	46.6	0	0	6.3
2002	0	0	41.7	20	17	59.6	156	266	53.4	0	0	12
2003	12.1	43.4	54.3	78	0	73.7	228	353	113.8	0	0	15.5
2004	14.2	1.3	36	72.2	4.3	122	223	185	108.8	0	5.6	0.8
2005	62.8	24	47.6	143	113	181	187	187	83.6	0	0	0
2006	2.5	10.4	28.5	148	27.5	113	347	167	148.3	22.5	0	18.7
2007	29.2	15.2	55.6	78.1	96.8	180	217	326	104.5	0	2.1	0
2008	0	0	0	41.7	86.7	72.3	315	265	83.6	10.8	29.6	0
2009	45.7	1.5	23	21.8	63.7	63.4	278	333	103.2	0	13.5	24.8
2010	0	46.4	26.3	100	89.1	145	248	207	161.8	0	0	7
2011	0	0	46.8	48.7	29.9	65.9	221	275	108.3	0	0	0
2012	0	0	10.4	87.1	61.7	135	239	313	103.1	0	0	0.4
2013	1.1	0	78.5	53.1	351	89.4	258	262	180	43.9	3.3	0
2014	0	25.6	19.4	5.2	36	79	204	265	83	38.8	1.5	0
2015	0	0	15.3	0	59.7	90.3	138	222	69.1	1.1	17.9	7.4
Mean	**10.5**	**12**	**38.6**	**59.7**	**70.3**	**103**	**228**	**248**	**105.6**	**9.3**	**5.79**	**5.81**

Appendix Table 6: Monthly maximum temperature at Mojo station

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2000	28.5	29.7	30.9	30.6	30.6	29.1	24.3	24.3	26.4	27.5	28.4	28.2
2001	28.1	29.6	29.5	30.9	30.1	28.3	26.3	26	27.8	29.7	29.5	29.6
2002	29.2	30	29.4	29.9	30.5	29.4	28.1	27.5	28.7	28.4	29.3	27.7
2003	28.6	30.4	29.9	29.6	32	30	25.5	26.8	29.43	30.3	28.9	27.6
2004	29.2	29.4	30.2	31.1	33	30.4	27.4	29.1	30.3	29.4	30.5	28
2005	30	30.3	31.3	32.5	31.7	31.6	27.3	28.1	28.14	30.1	28.4	28.1
2006	30.2	31.7	30.9	30.2	32.9	30.7	27.9	27.3	29.5	31.2	30.3	30.1
2007	31.2	33.7	33.8	32.8	34.1	32.1	27.5	28.2	31.04	30.6	30.3	29.9
2008	29.2	28.5	31.5	30.6	30.5	28	24.8	24.6	26.3	27.8	26.1	27.4
2009	27.6	29.5	31.1	31	31.8	32	25.8	24.8	27.62	27.3	28.5	28
2010	28.6	29.3	29	30	29	29.8	25.6	25.6	26.57	29	28.9	28.3
2011	30.5	30.5	30.4	31.7	30.7	30.2	27	26	25.67	27.7	28.4	27.8
2012	29.1	29.3	32.2	30.8	30.7	29	24.8	24.9	26.98	29.3	30.2	30.3
2013	29.4	31.5	31.9	31.8	30.7	28.8	24.7	24.8	27.8	29.6	29.7	30.6
2014	29.8	31.3	31.3	31.7	32.3	31.3	27.2	25.6	27.2	28.4	29.3	29.2
2015	29.7	31.6	31.6	31.9	30.6	29.6	27.8	27.9	29.1	30.6	29.9	29.7
Mean	**29**	**29.9**	**30.8**	**30.7**	**30.9**	**29.8**	**26.1**	**26**	**27.5**	**28.8**	**28.7**	**28.4**

Appendix Table 7: Monthly minimum temperature at Mojo station

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2000	9.4	10.1	13.3	13.3	14.7	13.6	14.4	13.9	13.4	11.7	9.46	7.74
2001	7.7	10.3	12.6	13.1	14	13.6	13.6	14	12.4	10.7	10.4	7
2002	9	8.7	12.3	12.6	12.4	12.9	14	14.5	12.3	10.6	9.16	9.44
2003	9.7	11.1	10.8	12.7	13.4	12.4	8.8	8.5	9.94	8	9.6	6.1
2004	9	9.4	10.2	11.2	12.9	6.95	7.6	9.18	8.6	6.9	6.9	6.5
2005	8.5	9.7	11.2	12	10.8	9.8	7.1	6.47	6.78	7.12	6.84	4.8
2006	8	11	10	9.9	12.3	9.2	7.4	6.8	9.4	11.2	8.5	8.1
2007	8.9	12.2	13.2	12.7	13	11.7	8.1	9.3	10.8	8.1	8.5	8.5
2008	9.8	10.1	11.3	14.2	14.6	14	13.8	13.8	13.5	12.3	9.4	6.5
2009	9.6	11.2	13.8	14.2	14	13.9	14.6	14.1	12.2	10.3	8.7	11.6
2010	9	13.3	13.5	14.2	14.6	14.4	14.5	14.8	13.6	11.4	9.95	7.6
2011	11.2	11.2	12	13.7	14.9	14.3	14.3	14.3	13.1	10.1	10.6	6.75
2012	8.2	8.6	10	13.5	14.5	14.4	14.3	13.9	12.8	9.8	8.19	8.6
2013	7.7	8.8	13.4	14	14.1	14.2	14.4	13.9	12.6	10.2	9.4	5.4
2014	7.4	11.1	13.3	13.3	13.5	13.3	14.6	13.8	13.5	10.1	9.2	6.5
2015	5.5	8.8	11.4	12.4	14.2	13.4	14.1	14	12.9	11.4	11	10.2
Mean	**9.44**	**11.2**	**12.5**	**13.26**	**13.44**	**13.12**	**13.24**	**13.1**	**12.4**	**10.6**	**9.55**	**8.3**

Appendix Table 8: Monthly maximum temperature at Ejere station

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2000	25	24.7	27.9	28.7	29.4	30.7	29.06	28.25	28.75	27	25.5	25.3
2001	25	27.4	28.5	28.8	30.3	31.6	30.18	28.47	28.1	27	25.4	25.1
2002	25	27.7	28.3	28.8	31.1	31	31.49	30.2	28.13	27	25.8	25.6
2003	26	27.7	28	28.6	29.5	30.3	29.16	27.92	28.24	27	25.3	24
2004	26	26	28.2	28.4	29.9	29.6	30.24	29.31	27.93	25	25	24.6
2005	26	27.6	28.2	28.4	28.4	29.3	28.75	29.49	28.73	26	25.2	24.3
2006	26	27.2	28.3	27.9	28.9	30.6	29.35	28.27	27.88	26	25.3	24.5
2007	25	27.3	28.5	28.4	29.5	29.3	28.13	28.85	28.61	26	24.5	24.1
2008	26	25.6	28.2	26.7	28.6	29.8	29.97	27.72	28.22	26	24.9	24.4
2009	25	26.5	28	27.8	28.9	30.2	29.32	28.92	28.61	26	25.3	24.2
2010	25	26.9	26.7	28	29.2	30.4	27.39	27.13	27.33	27	24.8	24.2
2011	24	24.4	22.5	22.9	23.8	22.3	19.86	20.19	22	24	23.1	23.6
2012	26	24.8	26.6	26.4	27.5	25.9	20.64	20.88	23	24	24.4	24.5
2013	25	26.5	27.4	28.2	28.2	26.7	21.85	20.72	22.68	23	23.7	23.2
2014	25	25.6	26.2	25.3	27.8	26.6	23.06	22.7	22.46	22	22.3	24.5
2015	25	25.6	26.2	25.3	27.8	26.6	23.06	22.7	22.46	22	22.3	24.5
Mean	**25**	**26.4**	**27.4**	**27.4**	**28.7**	**28.8**	**26.97**	**26.36**	**26.45**	**25**	**24.6**	**24.4**

Appendix Table 9: Monthly minimum temperature at Ejere station

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2000	5.2	6.5	6.9	10.7	13.7	14.9	14.7	13.9	10.6	8.2	6.7	6.6
2001	7.5	7.4	10.6	9.9	13	14.7	14.6	14.3	9.2	7.3	6.5	6.8
2002	7.6	7.5	11	11.5	13.2	15.1	14.6	13.6	9	7.5	7	9.1
2003	8.3	8.7	9.9	11.5	10.6	13.9	15	14.1	10.6	6.9	7.5	6.7
2004	9.4	8.6	9	11.4	10.9	10	14.6	13.3	10	7.8	7.6	7.6
2005	8.2	7.9	10.1	10.8	12.5	14.4	14.5	12.9	10.9	7.2	6.3	5
2006	7.6	9.2	9.2	10.8	11.2	14.8	14.7	14	10.6	8.9	7.5	8
2007	7.9	9.6	9	9.5	12.2	14.8	14.4	13.1	11.7	6.4	6.8	5
2008	6.8	7	6.9	10.1	10.8	14.5	14.7	12.9	9.7	8.1	7.3	5.9
2009	8.3	8.8	9.6	11	11.3	14	14.5	15.5	9.7	8.4	6	9.4
2010	8.2	11.9	11.5	12.3	14.2	15.1	15	14.4	11	7.3	6.9	5.9
2011	11	10.9	10.4	11	11	10.6	11.5	11.9	11.4	9.5	10.4	9
2012	10.1	9.8	11.5	13.8	14.6	14.1	12	11.9	10.7	10	9.9	9.3
2013	7.4	10.7	9.6	10	11.8	8.4	10.9	11.7	10.8	11	10.4	8.8
2014	11.3	11.2	12.5	13.2	12.4	11.7	12.7	11.6	13	12	10.3	9.2
2015	7.9	8.4	10.6	10.8	12.1	10.1	11.8	11.6	11.9	11.5	10.3	9

Appendix Table 10: Monthly maximum temperature at Alem Tena station

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2000	29.2	30.4	31	31.37	29.7	29.2	25	25.41	27.2	27.5	27.2	27.1
2001	28.4	31.4	32.7	31.45	30.2	27.5	26.6	26.46	27.7	28.1	29.2	28.2
2002	27.7	28.9	30	29.86	32.2	29.8	28.3	27.12	28.1	28.9	29	28
2003	28.6	28.2	31.1	30.16	30.7	30.2	27.1	28.24	27.9	27.7	27.6	26.9
2004	27.9	29.1	31.9	29.17	30.7	30.2	27.1	28.24	27.9	27.7	27.6	26.9
2005	28.9	29.1	28.9	30.85	28.8	30.1	26.5	28.28	28.5	29.4	28.2	27.4
2006	28.2	29.9	29.2	29.46	31.1	30.2	27.1	26.43	27.9	28.3	27.3	26.4
2007	28	30.7	30.9	32.98	30.9	28.7	26.5	26.01	27.1	27.6	26.7	26.7
2008	28.6	28.2	31.1	30.16	31.4	28.5	25.6	25.17	27.3	27.9	26	26.6
2009	27.9	29.1	31.9	29.17	29	31.5	27.5	27.4	28.6	28.3	28.7	27
2010	28.9	29.1	28.9	30.85	30.9	30.2	27.5	27.08	27.8	28.7	28.3	28.3
2011	29.5	30.7	30.9	32.98	31	30	27.4	26.94	26.5	28.7		27.7
2012	29.1	30.3	31.5	30.63	32.1	28	27	27.98	26.6	28.5	29.3	28.2
2013	28.1	30.8	32.2	31.12	30.4	29.7	26	26.57	27.7	28.3	28.5	28.1
2014	29.2	30.4	31	31.37	30.8	31	27.4	26.25	26.5	26.9	28.4	27.1
2015	28.4	31.4	32.7	31.45	29.6	28.4	28.3	29.36	31.9	29.6	28.5	27
Mean	**28.6**	**29.9**	**31**	**30.82**	**30.6**	**29.6**	**26.9**	**27.06**	**27.8**	**28.3**	**28**	**27.3**

Appendix Table 11: Monthly minimum temperature at Alem Tena station

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2000	9.41	9.7	14	15.3	15.2	14.9	14.8	14.5	15.3	15	15	11.1
2001	13.1	14.3	14	14.4	14.9	14.3	14.8	15	14.8	15	8.8	8.73
2002	12.6	12.7	15	15.3	15.8	15.5	14.7	14.5	14.4	14	9.7	12
2003	12.6	12.2	14	14.6	15	15.3	15	15.2	14.6	14	12	12.2
2004	13.1	14.3	15	15.2	15.1	15.2	14.6	14.9	14.8	13	10	8.32
2005	10.5	13.7	15	15.1	15.7	15.8	14.6	15.1	14.9	12	9.8	6.88
2006	11.9	13.6	14	14.9	15.5	15.3	15	15.2	14.6	14	12	12.2
2007	13.3	12.2	13	15.3	16.3	15.4	14.9	14.2	14.1	9	7	6.86
2008	7.86	8.92	9.7	13.5	16	15.1	11.3	11.3	11.3	9.5	8.4	5.54
2009	8.88	12.2	13	13.6	16	14.8	13.5	13.2	13.6	12	7.4	8
2010	11.1	13.2	14	15.3	16.6	15.7	15.1	15.9	13.6	11	9.2	5.11
2011	8.21	10.6	12	16.2	15.2	15.8	15	15	14.5	8.8	9	7.39
2012	7.38	8.92	8.9	15.4	15.6	16	15	14.9	15.3	12	9	8.69
2013	10.1	13	16	16.4	17.1	16.6	15.3	15.3	15.9	12	9	7.57
2014	13.2	14.8	15	15.5	16.5	16.3	16	15	14.9	12	11	7.14
2015	9	12	9	13.9	16.2	16.9	15.7	15.3	14.9	12	12	13.3
Mean	**10.8**	**12.3**	**13**	**15**	**15.8**	**15.6**	**14.7**	**14.7**	**14.5**	**12**	**9.9**	**8.82**

Appendix Table 12: Monthly maximum temperature at Chefedonsa station

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2000	22.1	23.1	24.6	24	24.8	23	20.4	19.4	22.5	22	20.5	20.8
2001	21.3	22.7	22	23.9	23.8	21.8	20.7	20	21.5	22.4	21.7	21.2
2002	21	24.3	23.6	23.8	25.7	24.8	22.6	22	22.3	22.7	22.1	21.1
2003	22.1	24.3	23.7	23.2	25.8	23.7	20.2	20.6	21.2	21.9	21.5	20.4
2004	22.6	22.7	23.4	22.8	26.1	23.3	21.2	21.1	21.8	21.6	21.2	21.5
2005	21.7	24.3	24.5	24.6	23.5	23.2	20.9	21.8	21.9	22.5	21.9	21.6
2006	22.7	24.4	25	24.2	25.3	23.7	21.2	20.7	21.7	22.4	21.4	21
2007	22.8	24.3	25.2	24.2	25.9	23.1	20.9	21.4	22.6	22.2	21.5	21.7
2008	23.3	22.8	24.9	25.2	25.2	24.2	21.7	21.3	23	23.3	22.1	23.4
2009	22.9	26	26.9	26.2	26.8	27.8	22.6	22.6	24.3	22.9	22.7	23.5
2010	24.5	25.6	24.4	26.3	26.2	25.4	22.4	23	23.7	24.6	24	24.4
2011	25.1	26.2	25.4	27.1	26.8	26.3	22.7	22.2	23.3	23.3	23.7	22.7
2012	24.5	25	27.3	25.8	27	26.6	22.4	22.5	24.1	23.7	24.8	24.5
2013	25.5	26.5	27.4	26.9	26.7	25.8	21.9	21.9	24.5	23.4	22.5	22.5
2014	24.2	26	26	25.8	26	26.5	22.9	22.3	22.6	21.5	22.2	22.2
2015	22.9	25.5	25.4	26.2	25.8	26.3	24.6	23.7	24.4	24.3	23	24
Mean	**23.1**	**24.6**	**25**	**25**	**25.7**	**24.7**	**21.8**	**21.7**	**22.8**	**22.8**	**22.3**	**22.3**

Appendix Table 13: Monthly minimum temperature at Chefedonsa station

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2000	7.71	8.74	11	12.2	11.9	10.8	11	11.1	11.7	9.8	8.8	7.37
2001	7.94	9.88	11	11.2	11.3	10.7	10.9	11.5	10.4	9.7	7.9	8.55
2002	9.24	9.16	12	11.4	11.8	11.6	10.7	11	12.8	12	8	9.96
2003	9.47	10.6	13	14.4	14.5	12	11.1	11.4	11.4	9.5	9	7.27
2004	10.6	9.55	11	12.2	10.7	10.9	11.7	11.6	11.7	9.8	9	6.72
2005	9.15	10.9	12	12.3	12.3	11.2	11.7	11.6	11.7	9.8	9	6.72
2006	9.54	11	12	12.1	11.9	11.4	11.7	12	11.1	11	9.2	9.79
2007	9.9	11.1	11	12.4	12.2	11.6	11.9	11.4	11.3	9.4	8	6.56
2008	9.8	9.38	9.9	12.2	12.1	11.3	11.2	11.3	11.1	10	7.9	7
2009	8.85	11	11	11.5	12.2	11.6	11.6	11.7	11.1	9.7	7.8	10.2
2010	9.05	11.6	12	12.5	12.9	11.6	11.5	12	11.3	10	8.4	7.56
2011	8.85	9.09	11	12.5	11.8	11.2	11.9	11.8	11.1	9.5	10	7.32
2012	8.16	8.34	11	12.1	11.5	10.9	11.6	12	11	9.2	8.4	8.41
2013	8.65	9.15	12	12.2	2.26	11.1	11.5	11.3	10.9	10	8.9	6.7
2014	9.06	11.3	12	12.7	12.5	11.7	12	11.3	11.4	10	9	7.42
2015	8.02	11.6	12	12.4	12.6	12	12	11.7	11.2	12	8	7.5
Mean	**9**	**10.2**	**11**	**12.3**	**11.5**	**11.3**	**11.5**	**11.5**	**11.3**	**10**	**8.6**	**7.82**

Appendix Table 14: Monthly relative humidity at Mojo Station

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2000	33	28	34	39	40	51	62	66	56	50	47	43
2001	43	34	43	0	41	49	59	66	56	50	43	49
2002	49	36	45	50	36	46	48	58	54	45	39	54
2003	43	38	45	48	33	47	58	64	58	45	47	46
2004	48	43	34	55	32	50	57	59	55	50	48	50
2005	44	32	47	45	51	49	61	60	58	49	43	35
2006	46	41	43	48	42	47	59	64	57	56	47	57
2007	52	43	37	45	42	53	59	60	60	42	44	40
2008	38	37	23	45	48	48	60	60	56	46	47	42
2009	46	41	41	49	37	40	57	57	52	53	42	59
2010	47	50	52	55	50	50	65	69	64	44	48	41
2011	43	46	50	52	47	45	62	61	57	51	43	52
2012	53	39	50	51	52	64	72	71	64	51	47	45
2013	52	39	47	57	47	49	63	62	54	60	64	51
2014	57	49	47	46	44	52	69	73	65	59	41	35
2015	42	32	49	40	44	50	65	62	57	55	37	40
Mean	**47**	**44**	**45**	**49**	**46**	**52**	**65**	**67**	**60**	**50**	**46**	**47**

Appendix Table 15: Monthly climatic data in Mojo station

Month	Min Temp °C	Max Temp °C	Humidity %	Sun Hours	Wind Km/day	Rad MJ/ m²/day	ETo mm/day
January	9.44	28.99	47	7.9	80	19.2	3.8
February	11.02	29.99	44	7.8	76	20.3	4.12
March	12.5	30.8	45	8.9	83	23	4.74
April	13.26	30.7	49	8.7	84	22.9	4.79
May	13.44	30.98	46	8.8	86	22.5	4.8
June	13.12	29.8	52	8.1	60	21	4.25
July	13.24	26.1	65	7.6	55	20.4	3.87
August	13.1	25.98	67	8	51	21.5	3.96
September	12.4	27.5	60	8.5	56	22.3	4.18
October	10.6	28.8	50	8.6	83	21.7	4.31
November	9.55	28.7	46	7.9	82	19.4	3.92
December	8.3	28.4	47	7.8	84	18.6	3.71
Average	**11.7**	**28.9**	**51.5**	**8.2**	**73**	**21.1**	**4.2**

Appendix Table 16: Rainfall and effective rainfall of the watershed

Monthly rain - untitled

Station Mojo   Eff. rain method USDA S.C. Method

	Rain mm	Eff rain mm
January	11.0	10.8
February	17.2	16.7
March	54.1	49.4
April	59.0	53.4
May	65.0	58.2
June	99.0	83.3
July	283.0	153.3
August	239.0	147.6
September	112.6	92.3
October	27.5	26.3
November	8.8	8.7
December	2.6	2.6
Total	**978.8**	**702.7**

Appendix Table 17: Irrigation water requirement of Tomato

Crop Water Requirements

ETo station: Mojo | Crop: Tomato
Rain station: Mojo | Planting date: 01/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	1	Init	0.60	2.56	25.6	15.6	10.0
Oct	2	Init	0.60	2.59	25.9	7.9	18.0
Oct	3	Deve	0.60	2.54	28.0	6.3	21.7
Nov	1	Deve	0.69	2.87	28.7	4.9	23.8
Nov	2	Deve	0.83	3.39	33.9	2.4	31.5
Nov	3	Deve	0.97	3.84	38.4	1.9	36.6
Dec	1	Mid	1.11	4.26	42.6	1.1	41.5
Dec	2	Mid	1.16	4.31	43.1	0.2	42.9
Dec	3	Mid	1.16	4.35	47.8	1.5	46.3
Jan	1	Mid	1.16	4.38	43.8	3.1	40.8
Jan	2	Mid	1.16	4.42	44.2	4.1	40.0
Jan	3	Late	1.12	4.39	48.3	5.0	43.3
Feb	1	Late	1.00	4.02	40.2	5.2	35.0
Feb	2	Late	0.88	3.64	36.4	5.8	30.6
Feb	3	Late	0.81	3.52	7.0	2.3	7.0
					533.9	**67.2**	**469.0**

Appendix Table18: Irrigation water requirement of Maize

Crop Water Requirements

ETo station: Mojo | Crop: Maize
Rain station: Mojo | Planting date: 01/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	1	Init	0.30	1.28	12.8	15.6	0.0
Oct	2	Init	0.30	1.29	12.9	7.9	5.0
Oct	3	Deve	0.46	1.94	21.3	6.3	15.0
Nov	1	Deve	0.73	3.05	30.5	4.9	25.6
Nov	2	Deve	1.00	4.06	40.6	2.4	38.2
Nov	3	Mid	1.21	4.76	47.6	1.9	45.7
Dec	1	Mid	1.22	4.67	46.7	1.1	45.6
Dec	2	Mid	1.22	4.53	45.3	0.2	45.1
Dec	3	Mid	1.22	4.56	50.2	1.5	48.7
Jan	1	Late	1.14	4.29	42.9	3.1	39.9
Jan	2	Late	0.86	3.26	32.6	4.1	28.4
Jan	3	Late	0.55	2.16	23.7	5.0	18.8
Feb	1	Late	0.36	1.46	2.9	1.0	2.9
					410.1	**55.0**	**359.0**

Appendix Table 19: Irrigation water requirement of Cabbage

Crop Water Requirements

ETo station: Mojo | Crop: Cabbage

Rain station: Mojo | Planting date: 01/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	1	Init	0.70	2.99	29.9	15.6	14.3
Oct	2	Init	0.70	3.02	30.2	7.9	22.3
Oct	3	Init	0.70	2.96	32.6	6.3	26.3
Nov	1	Deve	0.70	2.91	29.1	4.9	24.2
Nov	2	Deve	0.74	3.01	30.1	2.4	27.7
Nov	3	Deve	0.80	3.15	31.5	1.9	29.6
Dec	1	Deve	0.86	3.28	32.8	1.1	31.7
Dec	2	Deve	0.92	3.40	34.0	0.2	33.8
Dec	3	Deve	0.98	3.66	40.3	1.5	38.8
Jan	1	Mid	1.04	3.92	39.2	3.1	36.2
Jan	2	Mid	1.06	4.02	40.2	4.1	36.0
Jan	3	Mid	1.06	4.13	45.4	5.0	40.4
Feb	1	Mid	1.06	4.24	42.4	5.2	37.1
Feb	2	Mid	1.06	4.35	43.5	5.8	37.7
Feb	3	Late	1.06	4.57	36.5	9.0	27.5
Mar	1	Late	1.01	4.59	45.9	13.2	32.7
Mar	2	Late	0.96	4.58	18.3	6.6	10.1
					601.8	**93.7**	**506.4**

Appendix Table 20: Irrigation water requirement of Onion

Crop Water Requirements

ETo station: Mojo | Crop: Onion

Rain station: Mojo | Planting date: 01/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	1	Init	0.70	2.99	29.9	15.6	14.3
Oct	2	Deve	0.72	3.11	31.1	7.9	23.2
Oct	3	Deve	0.86	3.64	40.0	6.3	33.7
Nov	1	Mid	1.01	4.19	41.9	4.9	37.0
Nov	2	Mid	1.06	4.32	43.2	2.4	40.8
Nov	3	Mid	1.06	4.19	41.9	1.9	40.0
Dec	1	Mid	1.06	4.06	40.6	1.1	39.5
Dec	2	Mid	1.06	3.94	39.4	0.2	39.2
Dec	3	Mid	1.06	3.97	43.6	1.5	42.1
Jan	1	Mid	1.06	4.00	40.0	3.1	36.9
Jan	2	Late	1.06	4.02	40.2	4.1	36.1
Jan	3	Late	1.00	3.90	42.9	5.0	38.0
Feb	1	Late	0.92	3.69	36.9	5.2	31.7
Feb	2	Late	0.84	3.47	34.7	5.8	28.9
Feb	3	Late	0.78	3.37	23.6	7.9	14.6
					569.9	**72.8**	**496.0**

Appendix Table 21: Irrigation water requirement of Pepper

Crop Water Requirements

ETo station: Mojo | Crop: Peppers

Rain station: Mojo | Planting date: 01/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	1	Init	0.60	2.56	25.6	15.6	10.0
Oct	2	Init	0.60	2.59	25.9	7.9	18.0
Oct	3	Deve	0.60	2.51	27.6	6.3	21.4
Nov	1	Deve	0.69	2.78	27.8	4.9	22.9
Nov	2	Deve	0.82	3.21	32.1	2.4	29.7
Nov	3	Deve	0.95	3.66	36.6	1.9	34.8
Dec	1	Mid	1.06	3.99	39.9	1.1	38.8
Dec	2	Mid	1.07	3.95	39.5	0.2	39.3
Dec	3	Mid	1.07	3.98	43.8	1.5	42.3
Jan	1	Mid	1.07	4.01	40.1	3.1	37.1
Jan	2	Late	1.04	3.96	39.6	4.1	35.5
Jan	3	Late	0.97	3.76	41.4	5.0	36.4
Feb	1	Late	0.92	3.67	7.3	1.0	7.3
					427.3	**55.0**	**373.4**

Appendix Table 22: Maximum crop height and crop coefficient

Crop	Kc initial	Kc middle	Kc end	Maximum crop height(m)
Maize	0.3	1.2	0.35	2
Onion	0.7	1.05	0.75	0.4
Cabbage	0.7	1.05	0.95	0.4
Pepper	0.6	1.05	0.9	0.7
Tomato	0.6	1.15	0.8	0.6

Appendix Table 23: Stage (days) for selected crop

	Length of growing period (LGP) in days						
Crop type	initial	Dev	Mid	Late	Total	planting date	harvesting date
Maize	20	35	40	30	125	Oct-1	Feb-2
Cabbage	40	60	50	15	165	Oct-1	Mar-1
Tomato	35	40	50	30	155	Oct-1	Mar-5
Onion	15	25	70	40	150	Oct-1	Feb-30
Pepper	30	35	40	20	125	Oct-1	Feb-2

Appendix Table 24: Livestock population of Mojo watershed

Livestock type	Ada'a	Gimbichuu	Lumee	Liban	Total
Cattle	155,741	144,736	130,855	179,800	611,132
Goats	45,003	20,662	43,543	68,200	177,408
Sheep	39,099	61,460	34,060	30,980	165,599
Horse	3,261	9,561	892	2,700	16,414
Donkey	46,083	45,675	29,357	28,585	149,700
Mules	1,229	798	934	3,839	6,800
Camel	0	37	197	0	234
Poultry	561,495	96,299	110,000	87,200	854,994

Appendix Table 25: Population data of Mojo watershed (Source: ECSA, 2007 census)

No	Wereda	Urban	Rural	Urban + Rural
1	Lome	38,742	77,759	116,501
2	Gimbichu	6,327	79,911	86,238
3	Ada’a	100,114	131,273	231,387
4	Liban	2,929	73,837	76,766
Total		**148,112**	**362,780**	**510,892**

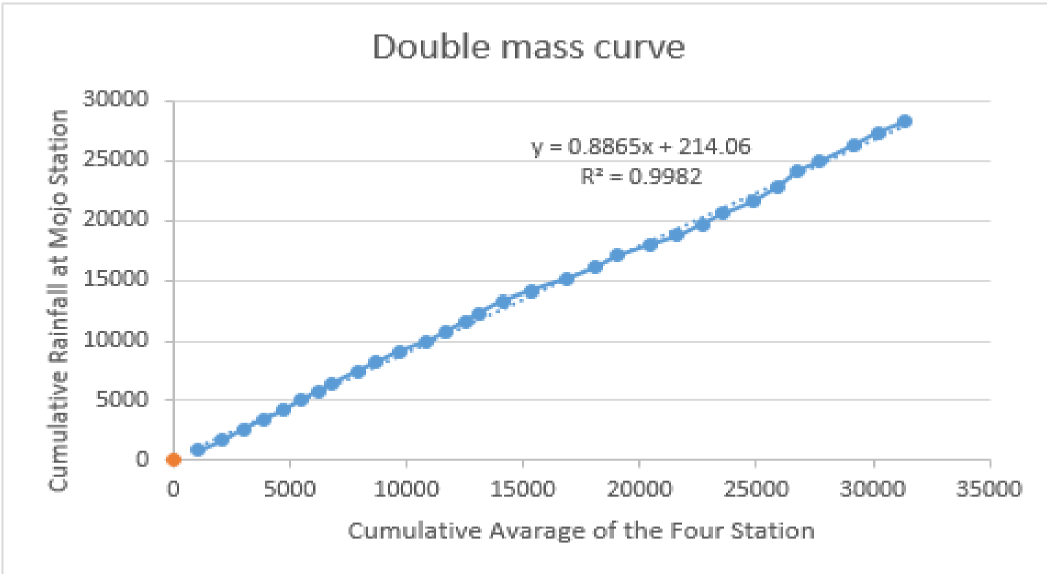
Appendix Table 26: Population monthly water requirement

Population	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rural	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Urban	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Cattle	9.13	9.13	9.13	9.13	9.13	9.13	9.13	9.13	9.13	9.13	9.13	9.13
Sheep	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46
Goat	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46
Horses	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
Mules	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
Donkeys	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
Camels	9.29	9.29	9.29	9.29	9.29	9.29	9.29	9.29	9.29	9.29	9.29	9.29
Poultry	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Appendix Table 27: Summary of monthly water balance for Mojo river watershed

Water balance components	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
Decrease in Soil Moisture	51.9	62.3	23.9	5.97	4.53	2.5	19.4	28.2	101	96.9	27.1	40.5	464.42
Evapotranspiration	-55	-72	-77	-40	-25	-103	-262	-286	-262	-124	-27	-39	-1,372.7
Flow to Groundwater	-9.4	-8.8	-8.8	-9.73	-11	-13	-13.8	-15	-14	-12	-11	-10	-136.39
Increase in Soil Moisture	-5.7	-7.1	-41	-66.3	-95	-62	-134	-68	-1	-3.65	-6	-2.8	-493.12
Interflow	-1.7	-1.6	-1.6	-1.72	-2	-2.2	-2.44	-2.6	-2.5	-2.11	-1.9	-1.9	-24.07
Irrigation	0.26	1.79	8.31	4.08	1.78	0.3	0	0	0	0.04	0.03	0.26	16.85
Precipitation	22	28.2	104	116	140	200	516	510	238	53.4	21.8	15.5	1,964.6
Surface Runoff	-1.9	-2.3	-8.2	-7.86	-12	-23	-124	-167	-59	-8.37	-3.4	-2	-419.7
Sum	0.03	0.06	0.01	-0.03	-0.1	-0.1	-0.25	-0.1	0.16	0.06	0.01	0.02	-0.13

Figure in the Appendix

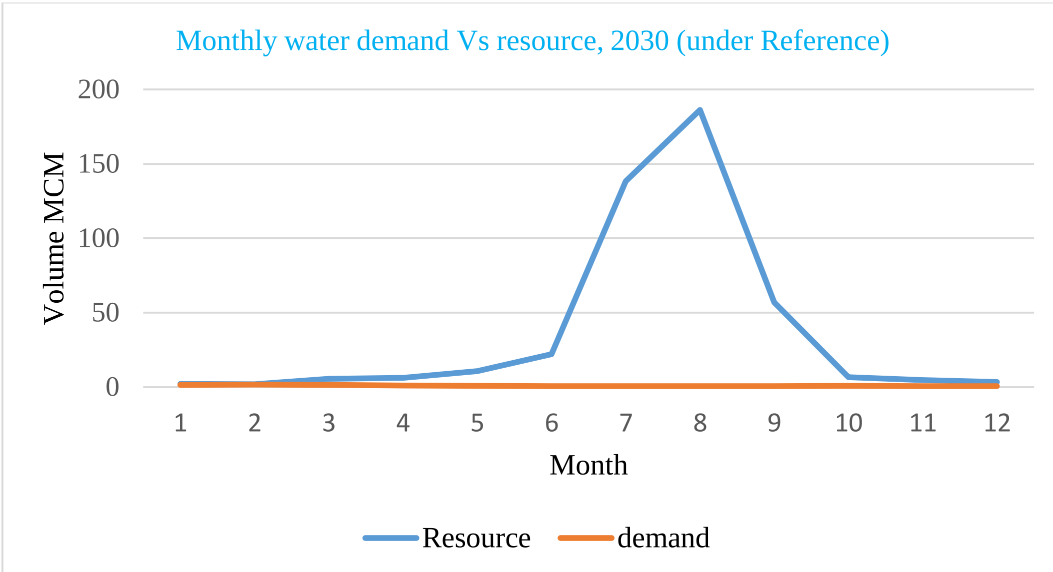


Appendix Figure 1: Double mass curve

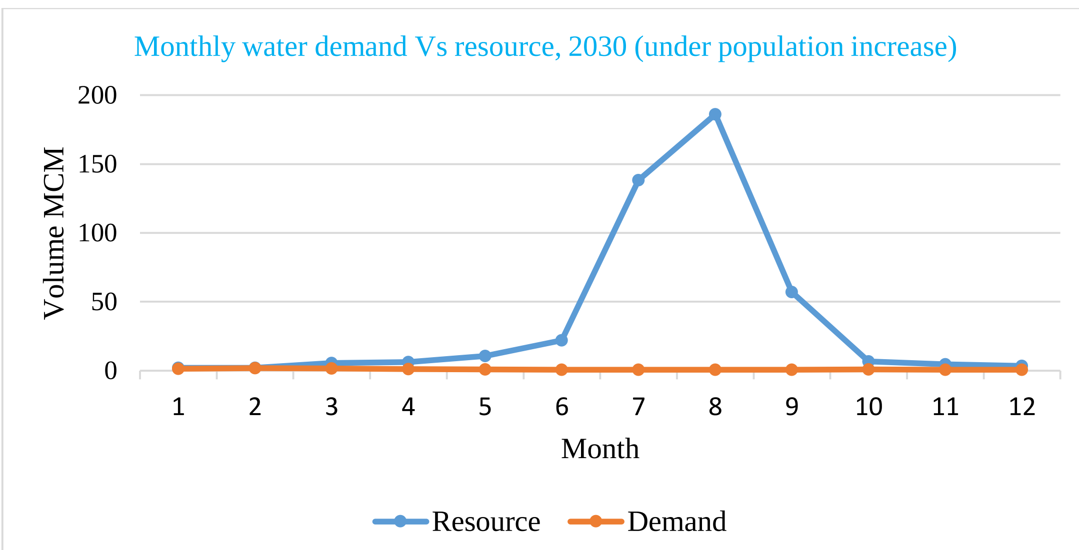
Appendix Figure 2: Mojo River near to Mojo town (Taken on May 24, 2021)

Appendix Figure 3: Irrigation Onion crops near to Mojo town (Taken on May 24, 2021)

Appendix Figure 4: Irrigation for Maize crops near to Mojo town (Taken on May 24, 2021)



Appendix Figure 5: Monthly water demand Vs resource, 2030 under reference scenario



Appendix Figure 6: Monthly water demand Vs resource, 2030 under population increase scenario

Questioners for data collection

1.Which type of method used to water transport for source to command area?

2. Which crops are the dominant in the agricultural farming system in the study area?

3. which type water used for domestic water supply?