



ASSESSMENT OF SURFACE IRRIGATION POTENTIAL IN UPPER WEYIB
WATERSHED, GENALE DAWA BASIN BALE ZONE OROMIYA REGION, ETHIOPIA

M.Sc. THESIS

GETACHEW SHIFERAW ESHETE

HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

MARCH,2021

ASSESSMENT OF SURFACE IRRIGATION POTENTIAL IN UPPER WEYIB
WATERSHED GENALE DAWA BASIN, BALE ZONE OROMIYA REGION, ETHIOPIA

GETACHEW SHIERAW ESHETE

A THESIS SUBMITTED TO THE
FACULTY OF BIO-SYSTEMS AND WATER RESOURCE ENGINEERING
DEPARTMENT OF WATER RESOURCE AND IRRIGATION ENGINEERING

HAWASSA UNIVERSITY INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

HAWASSA UNIVERSITY

HAWASSA, ETHIOPIA

IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE IN WATER RESOURCE AND IRRIGATION
ENGINEERING

(SPECIALIZATION: WATER RESOURCE ENGINEERING AND
MANAGEMENT)

MARCH,2021

SCHOOL OF GRADUATE STUDIES
HAWASSA UNIVERSIT
EXAMINERS' APPROVAL SHEET-2

We, the undersigned, members of the Board of Examiners of the final open defense by Getachew Shiferaw Eshete have read and evaluate his/her thesis entitled “**Assessment of Surface irrigation potential in upper weyib watershed Genale Dawa Basin Bale Zone Oromia Region**” and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree

Tewodros Assefa (PhD)

Name of Major Advisor

Signature

Date

Name of Internal Examiner-I

Signature

Date

Name of Internal Examiner-II

Signature

Date

Name of External examiner

Signature

Date

SGS Approval

Signature

Date

Declaration

I, Getachew Shiferaw declare that this thesis, which I submit to the school of graduate studies of Hawassa university in partial fulfillment of the degree of masters of sciences in water resources engineering and management, is my effort work and all sources of materials used for this thesis have been duly acknowledged. I formally declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

Name: Getachew Shiferaw

Signature: _____

Date: _____

ACKNOWLEDGEMENT

First of all, I would like to thank the almighty GOD for giving me this opportunity and the power to complete this research work successfully. The task could not have been accomplished without his help and protection.

It is right to acknowledge those who contribute to this research, directly and indirectly, such as mentors, instructors, advisors, friends, and family. But, here particularly, I would like to thank and express my deepest heartfelt appreciation to my advisors Dr. Tewodros Assefa and Mr. Teshale Tadesse (MSc) for their close supervision and guidance they offer me from the idea state of this thesis to its final result of what it looks today.

I would like to thank the Ethiopian Meteorological Service Agency (EMSA), Ministry of Water and Energy (MoWE), and Bale zone agricultural and Natural resources offices for providing the necessary data. I would also like to express my genuine gratefulness to my father, mother, brothers, and sisters, for their moral motivation offered me.

LISTS OF ACRONYMS AND ABBREVIATIONS

AHP	Analytical Hierarchy Process
ARS	Agricultural Research Service
BMC	Billion Metric Cube
BMNP	Bale Mountain National Park
CR	Consistency Ratio
CSA	Central Statistical Agency
CWR	Crop Water Requirement
DEM	Digital Elevation Model
ESRI	Environmental Systems Research Institute
EMA	Ethiopian Mapping Agency
ET	Actual Evapotranspiration
ET _c	Crop Evapotranspiration
ECACC	Ethiopian Central Agricultural Census Commission
ET _o	Reference Crop Evapotranspiration
FAO	Food and Agriculture Organization
GIS	Geographical information systems
GDP	Gross Domestic Product
GIWR	Gross Irrigation Water Requirement
HRU	Hydrological Response Unit
IFAD	International Fund for Agricultural Development
IWMI	International Water Management Institute
ICID	International Commission for Irrigation and Drainage
K _c	Crop Coefficient
LULC	land use land cover
MCDM	Multi-criteria Decision Making
MOA	Ministry of Agriculture
MoWIE	Ministry of Water Resources, Irrigation & Electricity
NASA	National Aeronautics and Space Administration
NIWR	Net irrigation water requirement
NMSA	National Meteorological Services Agency

NPCM	Normalizing Pairwise Comparison Matrix
OWWDSE	Oromia Water Works Design and Supervision Enterprise
PCM	Pairwise Comparison Matrix
SPOT	Système Pour l'Observation De La Terre
SRTM	Shuttle Radar Topography Mission
SUFI2	Sequential Uncertainty Fitting Two
SWAT	Soil and water assessment tools
SWAT CUP	Soil and Assessment tool, Calibration and Uncertainty Program
TIN	Triangulated irregular networks
Tmax	Maximum Temperature
Tmin	Minimum Temperature
UN	United nations
UTM	Universal Transverse Mercator
UNESCO	United Nations Educational Scientific and Cultural Organization
USDA	United States Department of Agriculture
UNFAO	Food and Agriculture Organization of the United Nations
WMO	World Meteorological Organization
WGEN	Weather Generator

TABLE OF CONTENTS

ACKNOWLEDGEMENT	i
LISTS OF ACRONYMS AND ABBREVIATIONS	ii
LISTS OF TABLES.....	vii
LISTS OF FIGURES	viii
LISTS OF APPENDICES	ix
ABSTRACT.....	x
1.INTRODUCTION	1
1.1 Background of the Study.....	1
1.2 Statement of the Problem	3
1.3. The Objective of the Study	4
1.3.1 General Objective	4
1.3.2 Specific Objectives	4
1.4 Research Questions	4
1.5 Significance of the Study	4
1.6 Scope of the Study	5
1.7 Thesis Outline	5
2. LITERATURE REVIEW	6
2.1 Definition of Irrigation Potential.....	6
2.2 Need for Irrigation.....	6
2.3 Irrigation Potential in Ethiopia.....	6
2.4 Water Resources.....	8
2.4.1 River Basins.....	8
2.4.2 Lakes and Reservoirs.....	8
2.4.3 Ground Water Resources.....	9
2.5 Land Suitability Evaluation Techniques	9
2.5.1 Slope	10
2.5.2 Soil Type	11
2.2.3 Land Use/Cover.....	12
2.2.4 Distance from Water Source	12

2.6 Assessment of Water Resources	13
2.7 Estimation of Irrigation Water Demand.....	14
2.7.1 Reference Crop Evapotranspiration (ET _o).....	15
2.7.2 Crop evapotranspiration (ET _c)	16
2.7.3 Net and gross irrigation water requirements	16
2.8 GIS Application for Irrigation Potential Assessment.....	17
2.9 Multi-criteria Decision Making (MCDM)	18
2.10 AHP Application for Weighted Overlay Analysis.....	18
2.11 Irrigation Potential Assessment.....	19
3. MATERIALS AND METHODS.....	23
3.1 Description of the Study Area.....	23
3.1.1 Location.....	23
3.1.2 Climate	24
3.1.3 Topography.....	26
3.1.4 Soil.....	26
3.1.5 Water Resources	27
3.2 Data Collection and Analysis.....	28
3.2.1 Data collection.....	28
3.2.1.1 Soil Data	28
3.2.1.2 LULC Data	28
3.2.1.3 Digital Elevation Model (DEM).....	28
3.2.1.4 Climate Data	29
3.2.1.5 Crop data.....	29
3.2.1.6 Stream Flow data	29
3.2.2 Data Processing and Analysis	29
3.2.2.1 Filling missing data.....	29
3.2.2.2 Checking consistency of rainfall data.....	30
3.2.2.3 Land Suitability Analysis.....	31
3.2.2.5 Estimation of water availability using SWAT	38
3.2.2.6 Estimating discharges at un-gauged sites from gauged sites	43

3.2.2.7 Estimation irrigation water demand.....	44
3.3 Determination of irrigation potential	47
4 RESULTS AND DISCUSSION.....	48
4.1 Suitable Land for Surface Irrigation	48
4.1.1 Irrigation Land Suitability Factor Analysis.....	48
4.1.1.1 Slope Suitability.....	48
4.1.1.2 Soil Suitability	49
4.1.1.3 Land Use Land Cover Suitability	54
4.1.1.4 Proximity to Water.....	57
4.1.1.5 Assessing Weights Using AHP for Irrigation Suitability Mapping.....	59
4.2 Water Availability Assessment.....	64
4.2.1 Stream Flow Sensitivity Analysis	65
4.2.2 Model Calibration and Validation.....	66
4.3 Irrigation water demand.....	70
4.4 Irrigation potential.....	74
5 CONCLUSION AND RECOMMENDATIONS.....	76
5.1 Conclusion	76
5.2 Recommendations	77
REFERENCES	78
APPENDICES	86

LISTS OF TABLES

Table 2. 1: Irrigation Potential in the River Basins of Ethiopia	7
Table 2. 2:Water Resource Potential in the River Basins of Ethiopia.....	8
Table 2. 3:Structure of land suitability order and classes (FAO, 1976)	10
Table 3. 1:Major soil types in the Upper Weyib River watershed.....	26
Table 3. 2: Slope suitability classification for surface irrigation.....	32
Table 3. 3:Soil Combination suitability factor rating	32
Table 3. 4: Land use/land covers suitability criteria.....	34
Table 3. 6: Random Consistency Index table (Saaty, 1980).....	37
Table 3. 7: Meteorological data (source: -NMSA).....	40
Table 3. 8: Indices for sensitivity classes	41
Table 4. 1:Slope suitability range of the study area for surface irrigation.....	48
Table 4. 2:Soil texture and their suitability class.....	50
Table 4. 3: Drainage suitability class and their percentage	51
Table 4. 4:Soil depth and their suitability class	52
Table 4. 5: Analysis of soil suitability for irrigation.....	53
Table 4. 6:Soil suitability reclassification result.....	53
Table 4. 7:Confusion matrix of SPOT LULC Classification.....	55
Table 4. 8:Area coverage of land cover/use classes of the study area.....	55
Table 4. 9:Land use/cover suitability reclassification results	56
Table 4. 10:Proximity to water suitable for surface irrigation.....	58
Table 4. 11:Pairwise comparison matrix based on the selected criteria"s for surface irrigation suitability.	60
Table 4. 12: Normalized criteria comparison matrix.....	61
Table 4. 13: Weighting factors	61
Table 4. 14:Final Suitable land for surface irrigation.....	62
Table 4. 15: Overall highly suitable land for surface irrigation in sub-watershed level.....	63
Table 4. 16:Result of sensitive analysis of model parameters in Upper Weyib Watershed	66
Table 4. 17: R ² , ENS, and Pbias values both for calibration and validation	67
Table 4. 18:SWAT's most sensitive streamflow Parameters, final calibrated fitted values, and variation methods (imet) used for analysis.	69

Table 4. 19:Minimum Monthly simulated flow (m ³ /s).	70
Table 4. 20:Monthly crop water demand of selected crops in mm at dry periods.....	71
Table 4. 21:Gross irrigation requirement of dominant crops(m ³ /s)	72
Table 4. 22:Comparing of crop demands and available flows for Dominant crops	73
Table 4. 23:Summary of irrigation potential of the river watershed and their ranking for development possibilities.....	75

LISTS OF FIGURES

Figure 3. 1:Location map of the Upper Weyib watershed.....	23
Figure 3. 2: The annual average maximum and the minimum temperature of the study area ..	24
Figure 3. 3: Mean monthly minimum and maximum temperature profile	25
Figure 3. 4:Soil map of the upper Weyib River watershed	27
Figure 3. 5: Double mass curve of all rainfall station.....	31
Figure 3. 6: Hierarchical organization of criteria	36
Figure 3. 7:Conceptual Frameworks for surface Irrigation assessment of the study area.	47
Figure 4. 1:Reclassified slope class and its suitability map.....	49
Figure 4. 2:Soil texture class and its suitability map.	50
Figure 4. 3:Soil drainage class and its suitability map of the study area.....	51
Figure 4. 4:Soil depth class and its suitability map of the study area.....	52
Figure 4. 5:Land use/cover map of the study area and its suitability map	57
Figure 4. 6:Proximity to water and its suitability map of Upper Weyib River watershed	59
Figure 4. 7:Irrigation land suitability map of the study area	63
Figure 4. 8:Upper Weyib river sub watershed.....	64
Figure 4. 9:Observed and simulated flow for the calibration period (m ³ /s).....	67
Figure 4. 10:Observed and simulated monthly flow for the validation period (2006-2014).....	68

LISTS OF APPENDICES

Appendix 7. 1: Annual rainfall stations used in developing double mass curve	86
Appendix 7. 2: Mean monthly rainfall(mm) stations in the study area	87
Appendix 7. 3: Mean monthly Maximum and minimum temperatures of the study area	87
Appendix 7. 4: Minimum monthly simulated flow (m ³ /s) at sub-watershed obtained from SWAT outputs.	88
Appendix 7. 5: Double mass curve for Dinsho rain gage station	88
Appendix 7. 6: Double mass curve for robe rain gage station.....	89
Appendix 7. 7: Double mass curve for Sinana rain gage station.....	89
<i>Appendix 7. 8: Double mass curve for Agarfa rain gage station</i>	<i>90</i>
Appendix 7. 9: ETo and climatic data Meteorological Station (1987-2017).....	90
Appendix 7. 10: CWR and IWR estimation for pepper.....	91
Appendix 7. 11: CWR and IWR for potato	91
Appendix 7. 12: CWR and IWR estimation for Barley.....	92
Appendix 7. 13: CWR and IWR estimation for Wheat	92

ABSTRACT

Planning and decision-making for new irrigation development projects require the systematic assessment of irrigable land together with available water resources. This study was started with the objectives of assessing the water and land resources potential of the upper Weyib river watershed for irrigation development and generating a geo-referenced map of these resources by using a Geographic information system. Watershed delineation, identification of potentially irrigable land, and estimation of irrigation water requirement and surface water availability of river watershed were the steps followed to evaluate this irrigation potential. GIS was used to map the irrigation potential of the watershed; the ArcSWAT model; was used to estimate the water availability in the watershed; AHP and pairwise comparison was used to land suitability assessment and a CROPWAT model was used to determine the major crop water requirement. To identify potentially irrigable land, irrigation suitability factors such as soil physical properties, slope, land use/ land cover, and distances from the water supply(sources) are taken into account. The irrigation suitability analysis if these factors indicate that 98.59% of soil 75.72% LULC and 41.62% slope in the study area are in the range of highly suitable to marginally suitable for the surface irrigation system. The final results of irrigation land suitability indicate that 14.90% high suitable (S1), 55.08% moderately suitable (S2), 5.62% marginally suitable (S3), whereas 24.38% not suitable (N) for surface irrigation development. After calibration and validation, the observed monthly streamflow values with a coefficient of determination (R) and Nash-Sutcliffe Coefficient (NSE) of 0.81 and 0.77 for the calibration period and 0.77 and 0.76 for the validation period, respectively. The Irrigation water demand of the four major crops which are grown in the study area through the growing season was found to be 1170.1mm. Based on the Model Builder of ArcGIS, the SWAT estimated available water can potentially irrigate an area of 10,564.15ha for highly suitable areas.

Keywords: Upper Weyib River Watershed; irrigation potential; surface water; ArcSWAT; CROPWAT

1.INTRODUCTION

1.1 Background of the Study

Ethiopia depends on rainfed agriculture with limited use of irrigation for agricultural production. It is estimated that more than 90% of the food supply in the country comes from low productivity rainfed smallholder agriculture and hence rainfall is the single most important determinant of food supply and the country's economy (Belete,2006). The major problem related to rainfall-dependent agriculture in the country is the high degree of rainfall variability and unreliability. Due to this variability, crop failures due to dry spells and droughts are frequent. as a consequence, food insecurity often turns into famine with the slightest adverse climatic incident particularly, affecting the livelihoods of the rural poor.

With the need to double food production over the next two decades, water has been recognized as the most important factor for the transformation of low productive rain-fed agriculture into the most effective and efficient irrigated agriculture (FAO, 1996). The utilization of water resources in irrigated agriculture provides supplementary and full-season irrigation to overcome the effects of rainfall variability and unreliability. Hence, the solution for food insecurity could be provided by irrigation development that can lead to security by reducing variation in harvest, as well as the intensification of cropping by producing more than one crop per year.

Ethiopia has a huge potential for water and natural resources that would be used for irrigation. The country is gifted with ample water resources with 12 river basins with an annual runoff volume of 124.5 billion m³ of water and an estimated 2.86 m³ of groundwater potential. Due to this Ethiopia is considered to be the water tower of Africa (Makombe et al., 2011; MoA, 2011a) and about 73.6 million ha (67%) of the country's area is potentially suitable for agriculture (Fasil, 2002).

The development of irrigation and agricultural water management holds significant potential to improve productivity and reduce vulnerability to climatic volatility in any country. Ethiopia receives about 980 billion cubic meters(m³) of rain a year and its agricultural system does not yet get the full benefit from the technologies of water management and irrigation (Seleshi,2010).

The Ethiopia highlands are comprised of land resources, which are potentially suitable for irrigation. Irrigation would provide farmers with sustained livelihoods and improve their general

well-being (Belay and Bewket,2013; Hussain and Hanjira,2004). But the country's irrigable land has been underutilized; and only 4 to 5% of the potential area has been developed for irrigation (Awulachew et al., 2007). Consequently, the agricultural economy of the country is largely based on rainfed cultivation, but while employing 85% of the population, it only contributes 50% to the gross domestic product (Berry, 2003). Finally, increasing agricultural production using irrigation is one of the main drivers to end poverty caused by insufficient output from these rainfed systems.

Surface irrigation offers some benefits for the less skilled and poor farmers. Under such circumstances, more than 90% of the world uses surface irrigation, even if local irrigators have the least knowledge of how to operate and maintain the system (Saymen, 2005). besides, these systems can be developed at the farm level with minimal capital investment. The major capital investment on the surface system is mainly associated with land grading, but if the topography is not too undulating, these costs are not high. Hence, surface irrigation development requires favorable topography and information on land water resources for proper planning (FAO,1996). hence, surface irrigation development favorable topography and information on land and water resources for proper planning (FAO,1995).

The Bale zone has abundant water and land resources, but its agricultural system does not yet fully productive and mainly depends on rainfed agriculture. This resulted from no systematic land suitability assessment, land use planning, and lacking clarity, current land use, and irrigation land suitability description for potential natural resources in the area. Therefore, this study has identified available water in the Upper Weyib River Watershed, suitable land for surface irrigation, and provides maps based on suitability parameters also assesses the irrigation water demand and supply by implementing software's and other materials which are relevant to this study.

Therefore, this study was to assess suitable land for surface irrigation and the irrigation water demand and supply (the gross irrigation requirement) for dominant crops cultivating in the study area also providing maps for a suitable site in terms of suitability parameters also, assess the amount and pattern of stream flow under the current land use land cover soil and slope using Arc GIS 10.3 and, Arc SWAT 2012.

1.2 Statement of the Problem

Agriculture is a mainstay of the Ethiopian economy and Irrigation development in Ethiopia is in its infancy stage and not contributing its share to the growth of the agriculture sector accordingly. It accounts for the employment of 90% of its population, over 50% of the country's gross domestic product (GDP), and over 90% of exchange earnings (ECACC,2002) However, the country has the potential for its development both in terms of large appropriate land and availability of freshwater resources appropriate for irrigation purposes. But currently, limited land is being cultivated under surface irrigated agriculture, and therefore, crop production is predominantly based on rainfed agriculture.

Most of the population lives in the upper Weyib river watershed depending on the agricultural system and favorable climatic conditions limit the productivity of the area. The basic climatic conditions are major consequences of seasonal or annual fluctuations of rainfall. Correspondingly, livelihoods of the upper Weyib river watershed depend on rainfed agriculture, and irrigation is intensive. Due to this seasonal rainfall variability, most of the farmers of the Watershed are engaged in one cropping cultivation system. In this study area, the population is increasing and agriculture is the main source of income. farmers are mainly depending on rainfed agricultural practice. However, the rainfall is not enough to produce sufficient food for the growing population and such problems occur due to a lack of irrigation projects in the area.

To safeguard adequate management and design of particular irrigation, a well-developed and suitable database is quite important. Therefore, it should be able to deal with spatially and temporally varying factors affecting the system. But to build up irrigation schemes in this study area, we need to identify water resource potential and suitable irrigable land resources for surface irrigation in the Upper Weyib Watershed. Hence, assessing surface irrigation in terms of suitable land and available water is a very important option for solving this problem.

Therefore, this study has identified available water in the Upper Weyib River Watershed, suitable land for surface irrigation, and provides maps based on suitability parameters also assesses the irrigation water demand and supply by implementing software's and other materials which are relevant to this study.

1.3. The Objective of the Study

1.3.1 General Objective

- o The main objective of this study was to assess irrigation potential for the Upper Weyib river watershed.

1.3.2 Specific Objectives

The following were the specific objectives of the study:

- o To assess land for surface irrigation;
- o To identify surface water availability;
- o To determine the irrigation water demand for major crops;
- o To estimate and map surface irrigation potential.

1.4 Research Questions

- o What is the area of land suitable for surface irrigation development in the upper Weyib watershed?
- o What is the surface water potential of the upper Weyib watershed?
- o What is the annual irrigation water demand of the major crops in the watershed?
- o Can the available water satisfy the water demand for suitable land?

1.5 Significance of the Study

Ethiopia has huge water and land resource potential for irrigation. But due to a lack of technology and skilled manpower, this potential is not utilized for agricultural production to alleviate poverty and drought. Nowadays, Ethiopia has been affected frequently by drought due to the rising population growth, uneven distribution of spatial and temporal rainfall occurrence, water resources, and land degradation. Therefore, the current production of sufficient food and food security in Ethiopia is impossible unless the agricultural production system shifts to irrigation from rain-fed agriculture. Subsequently, agriculture is an engine to develop an Ethiopian economy to achieve food self-sufficiency and food security.

The future trend of development highly depends on how do we manage sectors and all other resources, these appeals to knowing total surface water and land resource potential for irrigation in the Upper Weyib river watershed of Genale Dawa basin. After knowing the available water

and irrigable area in this watershed, it helps planners and decision-makers to proceed with any physical structures to store or divert sufficient water for agriculture purposes. So that the population can be profitable by producing yields two or three times per year this leads to, the development of the Ethiopian economy.

1.6 Scope of the Study

The scope of the study mainly focuses on water available, irrigation demand, and land suitability without considering the chemical property of the soil type and water quality. So, the present work only investigates soil physical property, land use/cover, distances from the river, and land slope for determining land suitability for surface irrigation. And also assess available water for surface irrigation to compare with irrigation water demand for the selected crops.

1.7 Thesis Outline

This research work was explained in five chapters. Chapter one gives a general introduction to the study with its background of the study, statement of the problem, objectives of the research, significance and study scope, and layout of the thesis. Chapter two describes the reviewed literature related to the study on the concept of irrigation suitability, potential, and status of irrigated land and water resources, an overview of the GIS, and remote sensing is discussed in this chapter. Chapter three gives a brief description of the study area and data availability, material, and methodology. It also gives an overview of the stages gone through during the study.

In chapter four, the result and discussion of the study are presented. It includes factors that used for suitability analysis like land cover/use, soil data, river proximity, and slope assessment, sensitivity analysis, calibration and validation of SWAT model, and crop water requirements for certain crops mainly grown in the study area were presented. Lastly, the results of the discussion obtained are presented. Finally, in chapter five summary and conclusion are given. Under these chapter references that are used for this study, appendixes that are used for more information are shown.

2. LITERATURE REVIEW

2.1 Definition of Irrigation Potential

Irrigation potential is the cumulative suitability of the soil, slope, irrigable land, and suitability or capacity of water available for irrigation on the given watershed without affecting the crop growth (FAO, 1997). Hence environmental and social factors are also taken into consideration in the assessment of irrigation potential to guarantee sustainable use of the available physical resource, land, and water plays a great role in the assessment of planning of sustainable food production in the country. Surface irrigation is the method that allows the flowing water on the soil surface by gravitational force.

According to (FAO, 1986) surface irrigation is the process of diverting water from the river and applying, to the irrigable land and properly use for agricultural production by evaluating land characteristics. FAO (1997) Irrigation potential is the sustainability of available water resources, the suitability of soil and slope for irrigation, and availability of irrigable land from the watershed and conducted on physical irrigation potential with a combination of water resource availability match with gross water requirement, area of soils suitable for irrigation, and available water resources by basin. If these all parameters are fulfilled in the watershed, is potentially irrigable for surface irrigation.

2.2 Need for Irrigation

Irrigation is the process of applying water to the command area in consideration to be necessary when the rainfall is short or uneven (erratic) distribution in the time of crop growth. It is important to satisfy the crop requirement for sustaining crop production. Irrigation can be applied in supplemental or full depending on the adequacy of rainfall. Moreover, the need to sustain a double cropping system in the dry season and assuring of growing high-value crops are among the factors that necessitate irrigation (FAO, 1992).

2.3 Irrigation Potential in Ethiopia

Agriculture is the dominant sector of the Ethiopian economy and its performance is the major determinant of the overall GDP growth rate. Ethiopia has a considerable land resource for agriculture. About 73.6 million ha (67%) of the country's area is potentially suitable for

agriculture (Fasil, 2002) and the Ethiopian agricultural sector has a proven potential to increase food supplies faster than the growth of the population (Davidson, 1992).

The estimates of the irrigation potential of Ethiopia vary from one source to the other, due to a lack of standard or agreed criteria for estimating irrigation potential in the country. The earlier report, for example from the World Bank (1973), showed the irrigation potential at the lowest of 1.0 and 1.5 million hectares, and the highest of 4.3 million hectares. There have also been different estimates of the irrigation potential in Ethiopia. According to the Ministry of Agriculture (1986), the total irrigable land in the country measures 2.3 million hectares. The International Fund for Agricultural Development (IFAD, 1987), on the other hand, gives a figure of 2.8 million ha. A total of 3.7 million ha had been identified as potentially irrigable land by MoWR (2002). Currently, the MoWR (Ministry of Water Resources) has identified 560 irrigation potential sites on the major river basins. The total potential irrigable land in Ethiopia is estimated to be around 3.7 million hectares were shown in Table 2.1 below.

Table 2. 1: Irrigation Potential in the River Basins of Ethiopia

Basin	Catchment Area (km ²)	Irrigation potentials (Ha)
Abbay	199,812	815,581
Tekeze	89,000	83,368
Baro-Akobo	74,100	1,019,523
Omo-Ghibe	78,200	67,928
Rift Valley	52,740	139,300
Awash	112,700	134,121
Genale Dawa	171,050	1,074,720
Wabi Shebele	200,214	237,905
Denakil	74,000	158,776
Ogaden	77,100	-
Ayisha	2,200	-
Total	1,136,816	3,731,222

Source: IWMI Working paper 123: Water Resources and Irrigation Development in Ethiopia

Ethiopia, indeed, has significant irrigation potential assessed both from available land and water resources potential, irrespective of the lack of accurate estimates of potentially irrigable land and developed area under irrigation

2.4 Water Resources

2.4.1 River Basins

Ethiopia possesses a substantial amount of water resources that could play a significant role in the Socio-economic development of the country. All of Ethiopia's major rivers originate in the highlands and flow outward in many directions through deep gorges. Based on the drainage condition the country's total area is divided into 12 major basins, namely, (Abbay, Wabishabele, Awash, Tekeze, Baro-Akobo, Mereb, Rift-Valley Lakes, General Dawa, Omo-Ghibe, Danakil, Ogden, and Aysha) with total mean annual flow 124.5 BMC (MoWIE 2010).

Table 2. 2: Water Resource Potential in the River Basins of Ethiopia

River basin	Area (km ²)	Runoff (Bm ³)	Estimated Groundwater Potential (Bm ³)
Abbay	199,812	54.80	1.80
Tekeze	89,000	8.20	0.20
Baro-Akobo	74,100	23.60	0.28
Omo-Ghibe	78,200	17.90	0.42
Rift valley	52,740	5.60	0.10
Awash	112,700	4.60	0.14
Genale Dawa	171,050	5.88	0.14
Wabi Shebelle	200,214	3.15	0.07
Danakil	74,000	0.86	0
Ogaden	77,100	0	0
Ayisha	2,200	0	0
Total	1,136,816	124.5	2.86

Source: MoWR (2010); UN-Water (2008); Abbay River Basin Master Plan (1999)

2.4.2 Lakes and Reservoirs

Ethiopia has 11 fresh and 9 saline lakes, 4 crater lakes, and over 12 major swamps or wetlands. The majority of the lakes are found in the Rift Valley Basin. The total surface area of these natural and artificial lakes in Ethiopia is about 7,500 km². The estimated storage capacity of these major lakes is about 95.46 BCM (IWMI, 2007).

2.4.3 Ground Water Resources

Groundwater, the water beneath the surface, is recharged as part of rainfall and surface water bodies that infiltrates and percolate deep into the soil. Factors such as climate, topographic features, geology, land use, and land cover affect the rate of groundwater recharge. As compared to surface water resources, Ethiopia has a lower groundwater potential. However, by a standard of many countries, the total exploitable groundwater potential is high. Based on the scanty knowledge available on groundwater resources, the potential is estimated to be about 2.86BMC (Billion metric cubes) annually rechargeable resources; which provide a little higher value (MoWIE, 2010).

2.5 Land Suitability Evaluation Techniques

Land suitability is the fitness of a given type of land for a defined use, or suitability is a measure of how well the qualities of a land unit match the requirements of a particular form of land use. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defining uses (Meron, 2007).

Structure of the Suitability Classification:

Determining suitable land for a particular use is a complex process involving multiple decisions that may relate to biophysical, socio-economic, and institutional/organizational aspects. A structured and consistent approach to land suitability analysis is therefore essential. The systemic classification of the suitability of irrigation land adopts the following tiers of classification.

Land Suitability Orders

According to FAO (1976), Land Suitability orders indicate whether the land is assessed as suitable or not suitable for use under consideration. The two orders are represented as S and N respectively.

Order S (suitable): It implies land expected to yield benefits that justify the inputs, without unacceptable risk of damage to land resources.

Order N (not suitable): Land which has qualities that appears to preclude sustained use of the kind under consideration.

Table 2. 3:Structure of land suitability order and classes (FAO, 1976)

Order	Class	Description
Suitable (S)	S1 (Highly suitable)	Land having no, or insignificant limitations to the given type of use
	S2(Moderately suitable)	Land having minor limitations to the given type of use
	S3 (Marginally suitable)	Land having moderate limitations to the given type of use
Non-suitable (N)	N (unsuitable)	Land having severe limitations that preclude the given type of use

Land evaluation is the process of the assessment of land performance when using the land for a specified purpose. The assessment requires implementation and understanding of the survey and studies of landforms, soil, climate, vegetation, and other aspects to compare favorable kinds of land use in terms applicable to the objective of the evaluation. (FAO, 1976) Land evaluation is primarily the analysis of data about the land –its soils, climate, and vegetation in terms of realistic alternatives for improving the use of that land. For irrigation, land suitability analysis, particular attention is given to the physical properties of the soil, to the distance from available water sources, and the terrain conditions about methods of irrigation considered (FAO, 2007).Land evaluation parameter used to address the suitability of the selected irrigation method such as surface and sprinkler irrigation method were soil depth, soil texture, electric conductivity, pH, drainage, and slope) factors and rated based on (FAO, 1976, and 1983; Sys et al., 1991). In addition to these factors, land cover/land use types are considered as limiting factors in evaluating the suitability of land for irrigation (Haile, 2007).

2.5.1 Slope

The slope is the inclination or gradient of a surface and is commonly expressed in percentage. The slope is important for soil formation and management because it influences runoff, drainage, erosion, and choice of irrigation types. The slope gradient of the land has a great influence on the selection of irrigation methods. According to FAO standard guidelines for the evaluation of slope gradient, slopes that are less than 2%, are very suitable for surface irrigation. Slope measures the rate of change of elevation in the direction of steepest descent; the slope is

how gravity induces the flow of water and other materials, so it is of greater significance in the gradational process of landscape evolution and soil development (FAO, 1999).

2.5.2 Soil Type

The assessment of soils for irrigation involves using physical properties that are permanent that cannot be changed or modified. Such physical properties include drainage, texture, and depth (Fasina et al, 2008). The soil is a major factor in the suitability of land for sustained irrigation (FAO, 1997). Accordingly, some soils are considered not suitable for surface irrigation and could be suitable for sprinkler irrigation or micro-irrigation and selected land utilization types (Kebede, 2010). Therefore, the type of soil is the major determinant factor for applying the amount of water to the crop root zone.

Soil Texture: Texture refers to the relative proportion of sand, silt, and clay in a mass of soil. The proportion of sand, silt, and clay are used to determine the textural class 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 classified by the fractions of each soil separate (sand, silt, and clay) present 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 texture is very important for hydrologic soil group determination.

Soil Depth: Depth is the dimension from the soil surface to bedrock, hardpan, and water table to specified soil depth. Soil depth refers to the thickness of the soil materials. Besides, 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.

Soil Drainage: Soil drainage is a natural process by which water moves across though and out of the soil because of the force of gravity. The drainage condition of a land development the unit commenced concerning specific land utilization type and texture. Adequate soil drainage is essential to ensure sustained productivity and to allow efficiency in farming operations. The suitability of land decrease when drainage condition comes under problem.

According to FAO (1997) evaluation techniques used for evaluation of permeability of the soil properties of the land, soil drainage area can be classified as well-drained, moderately well-drained, imperfectly drained, poorly drained, and very poorly drained.

2.2.3 Land Use/Cover

According to Jaruntorn, et al. (2004) matching existing land cover/use with topographic and soil characteristics to evaluate land suitability for irrigation with land suitability classes, presents possible lands for new agricultural production. Land cover and land use are often used interchangeably. However, they are quite different. Water, ice, bare rock, or sand surfaces also count as land cover. However, the definition of land use establishes a direct link between land cover and the actions of people in their environment. Thus, land use can be defined as a series of activities undertaken to produce one or more goods or services. Given land use may take place on one, or more than one, pieces of land, and several land uses may occur on the same piece of land. Definitions of land cover or land use in this way provide a basis for identifying the possible land suitability for irrigation with precise and quantitative economic evaluation.

2.2.4 Distance from Water Source

It is important to make sure that there will be no lack of irrigation water. If water is in short supply during some part of the irrigation season, crop production will suffer, returns will decline and part of the scheme's investment will lay idle FAO, (2001). Therefore, water supply (water quantity and seasonality) is an important factor to evaluate the land suitability for irrigation according to the volume of water during the year which is available FAO, (1985). Computing the amount of water that is available for surface irrigation and locate the exact location to be economical addressed to transport from the source to the command area. Surface irrigation water sources should be above the command area to irrigate the entire area by gravity through surface irrigation. It is also desirable that the location of water preferably near the command area to minimize the length of the conveyance structure to be economical. Therefore, distance from water sources to command area, nearness to rivers, is useful to reduce the conveyance system (irrigation canal length), evaporation losses, and thereby developing the irrigation system to be economical

2.6 Assessment of Water Resources

Several hydrologic models are widely used for the assessment of the water resource. Rainfall-runoff models have broadly been used in hydrology over the last century for several applications, and play an important role in optimal planning and management of water resources in catchments (O'Loughlin *et al.*, 1999; Munyaneza, O., *et al.*, 2013). Oyebande (2001) reported that the main challenge associated with applying a successfully rainfall-runoff model lies in the lack of monitoring data, mainly rainfall spatial distribution over the catchment area, since rainfall is the primary input in any hydrological model. Another potential problem is having no reliable flow data that can lead to reliable calibration and validation of catchment parameters.

Those models include SCS-CN (NEH, 1985), HEC-1, HEC-HMS (HEC 1990, 2001), SWAT (Arnold *et al.*, 1996), the MIKE BASIN (Supiah and Normala, 2002), WatBal (Water Balance Model) (Loucks, 2006; Mugatsia, 2010), WatBal is lumped conceptual model which consists of two major components. The first one calculates the potential evapotranspiration using the Priestley Taylor method and the other component calculates the water balance of the basin (Kaczmarek, 1993). The WEAP model simulates the natural hydrological processes (e.g., rainfall, evapotranspiration, runoff, and infiltration) to enable assessment of the availability of water within a catchment (basin) (Sieber *et al.*, 2005), etc.

The Soil Conservation Service Curve Number (SCS-CN) is used to predict runoff, which links rainfall response to soils, land use, and antecedent moisture condition (AMC), and it is widely applicable in predicting event-based runoff volume (SCS, 1972; NRCS, 2004; Teka, 2014). The SCS-CN is one of the most enduring methods for estimating the volume of direct surface runoff in the ungauged catchment (watershed) and is developed from an empirical study of runoff in small

catchments (Kousari, M.R., *et al.*, 2010). Besides, the model has been widely used with success, providing consistently useful results (Soulis *et al.*, 2009; D'Asaro and Grillone, 2010). 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; Das *et al.*, 2004), has a comprehensive the structure that models all hydrologic processes in the watershed over long periods of time (Neitsch *et al.*, 2002b). The model has also been applied in the many basins for example:

Githui *et al.* (2009) used the SWAT model to simulate stream flow in Western Kenya. Sang (2005) also applied the SWAT model in the Nyando Basin in Kenya and 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 (Yates, 2005). Besides, 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.*, 2005b).

Soil and Water Assessment Tool (SWAT) is a physically-based continuous-event hydrologic model developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over long periods (Arnold *et al.*, 1998, 2000; Neitsch *et al.*, 2001). SWAT was applied for watershed delineation. And it is embodied in ArcGIS that can integrate various readily available geospatial data to accurately represent the characteristics of the watershed.

SWAT uses Hydrological Response Units (HRUs) to describe the spatial heterogeneity in terms of land use, soil types, and slope within a watershed as a physical-based model. To simulate hydrological processes in a watershed, SWAT divides the watershed into sub-watersheds based upon drainage areas of the tributaries. The sub-watersheds are further divided into smaller spatial modeling units known as HRUs, depending on land use land cover, soil, and slope characteristics. One of the main advantages of SWAT is that it can be used to model watersheds with less monitoring data. For simulation, SWAT needs a digital elevation model; land uses a land cover map, soil data, and climate data of the study area that is used to model watersheds with less monitoring data.

2.7 Estimation of Irrigation Water Demand

Water demand is the quantity of water regardless of its source required by a crop. In other words, it is diversified patterns of crops in a given period for its normal growth under

field conditions at a place (Awulachew *et al.*, 2007). In other words, the Irrigation water requirement is the amount of water that is needed by the crop on the optimal growth condition without water deficiency and it is expressed the net water requirement for irrigation (Juwono *et al.*, 2018). The most important of computed irrigation water demand is that knowledge of the total quantity of water required from its sowing time up to harvest. Under the same condition, different crops require a different amount of water and the quantities of water used by a particular crop are different in the entire life span (initial, development, mid-season, late-season stage) of the crop period (Mamenie, 2017). Initially, during seeding, sprouting, and early growth, a crop uses water at a relatively slow rate. The rate will increase with the growth of crop reaching the maximum in most crops as it approaches flowering and then declines towards maturity (MoA, 2011).

2.7.1 Reference Crop Evapotranspiration (ET_o)

The evapotranspiration rate from a reference surface is known as Reference Crop Evapotranspiration. The reference surface is a hypothetical grass reference crop with specific characteristics. ET_o expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors. The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development, and management practices. The only factors affecting ET_o are climatic parameters. The FAO Penman-Monteith method is recommended as the sole method to determine ET_o.

Suat (2003) International Commission for Irrigation and Drainage (ICID) and the Food and Agriculture Organization of the United Nations (UNFAO) expert consultation highly recommend the Penman-Monteith method for estimation of evapotranspiration than other methods, because this method is used as the standard method and encompasses both physical and aerodynamic parameters. Besides, with this method, a process has been developed to calculate the missing climatic data. Moreover, the Penman glide path in both arid and humid regions has been showing very accurate and logical in both ASCE and European research studies. This method has been selected because it provides values that are very consistent with actual crop water use data worldwide, as it has been demonstrated through many years of evaluations reported in the scientific literature.

$$ET_o = \frac{0408 * \Delta * (R_n - G) + \gamma * \frac{900}{T + 273} * u_2(e_s - e_a)}{\Delta + \gamma * (1 + 0.34u_2)} \quad 2.1$$

Where:

ET_o =Reference evapotranspiration [mm /day]

R_n =Net radiation at the crop surface [MJ/ m² per day]

G =Soil heat flux density (MJ/m² per day)

T =Mean daily air temperature at 2 m height (°C)

u_2 =Wind speed at 2 m height (m/sec)

e_s =Saturation vapour pressure (kPa)

e_a =Actual vapour pressure (kPa)

$e_s - e_a$ = Saturation vapour pressure deficit (kPa)

Δ = Slope of saturation vapor pressure curve at temperature T (kPa/°C)

γ = Psychrometric constant (kPa/°C)

2.7.2 Crop evapotranspiration (ETc)

Crop Evapotranspiration under standard condition (ETc) is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions and achieving full production under the given climatic conditions. Crop evapotranspiration can be calculated from climatic data and by integrating directly the crop resistance, albedo, and air resistance factors in the Penman-Monteith approach. As there is still a considerable lack of information for different crops, the Penman-Monteith method is used for the estimation of the standard reference crop to determine its evapotranspiration rate.

2.7.3 Net and gross irrigation water requirements

The Net Irrigation Requirement (NIR) is the water quantity required for the growth of the crop. It is the amount of water necessary to reach the field capacity of the soil. The total amount of water applied through irrigation is termed as gross irrigation water requirement. Gross irrigation requirements include net irrigation requirement plus losses in water application and others. CropWat is a practical tool to carry out standard calculations for

reference evapotranspiration, crop water requirements, and crop irrigation requirements, and more specifically the design and management of irrigation schemes (Berhane *et al.*, 2015).

2.8 GIS Application for Irrigation Potential Assessment

GIS is a tool that allows users to create users' interactive queries, analyze spatial information, and edit data (Nazir *et al.*, 2019). GIS has been an increasingly important means for understanding and dealing with the persuasive problem of water and related resource management in the world.

The integrated application of GIS and MCE helps land-use planners to improve decision making processes (Malczewski, 1999). GIS-based MCE found to be a favorable tool to identify potential land limitation to growing different crops (Murayama, 2010). One of the most advantages of this tool is the possibility of adjusting a standardized FAO land suitability framework for soil, slope, land use/land cover, and river proximity relative to irrigation potential assessment. For agronomic, environmental, and economic reasons, the need for specialized information about agricultural practices is expected to rapidly increase (Begue *et al.*, 2018). Accurate mapping of the distribution of irrigated land using remote sensing data at a regional scale can facilitate an improved understanding of patterns of water uses and food production (Chance *et al.*, 2017). Yet, studies that have used remote sensing to map irrigated lands remain relatively infrequent (Ozdogan *et al.*, 2010).

The main application in GIS is mapping where things are and editing tasks as well as for map-based query and analysis (Nazir *et al.*, 2019). A map is the most common view for users to work with geographic information. It's the primary application in any GIS to work with geographic information. The map represents geographic information as a collection of layers and other elements in a map view. GIS can integrate Remote Sensing and different data sets to create a a broad overview of the potential irrigable area. While the remotely sensed image of an area gives a true representation of an area based on land use/cover/use, grid interpolated climate data can serve many purposes and used as a climatic database where meteorological data from gauging networks are not adequate.

An application example in the continental United States, irrigation mapping methodology that relies on remotely sensed inputs from the Moderate Resolution Imaging Spectro radiometer

(MODIS) instrument, globally extensive ancillary sources of gridded climate and agricultural data and on an advanced image classification algorithm. The methodology involves four steps, first, climate-based indices of surface moisture status and a map of cultivated areas to generate a potential irrigation index. Second, identify remotely-sensed temporal and spectral signatures that are associated with the presence of irrigation. Thirdly, combine the climate-based potential irrigation index, remotely sensed indices, and learning samples within a decision tree supervised classification tool to make a binary irrigated/non-irrigated map. Finally, apply a tree-based regression algorithm to derive the fraction of irrigated area within each pixel that has been identified as irrigated (Ozdogan and Gutman, 2008).

2.9 Multi-criteria Decision Making (MCDM)

The Analytic Hierarchy Process (AHP), introduced by Saaty (1980), is an effective tool for dealing with complex decision making and may aid the decision-maker to set priorities and make the best decision. By reducing complex decisions to a series of pairwise comparisons, and then synthesizing the results, the AHP helps to capture both subjective and objective aspects of a decision. Besides, the AHP incorporates a useful technique for checking the consistency of the decision-makers evaluations, thus reducing the bias in the decision-making process.

The AHP method calculates the required weights associated with the respective criterion map layers with the help of a preference matrix, in which all relevant criteria identified are compared against each other based on preference factors. The weights can then be aggregated. GIS-based AHP has gained popularity because of its capacity to integrate a large quantity of heterogeneous data, and because obtaining the required weights can be relatively straightforward, even for a large number of criteria. It has been applied to a variety of decision-making problems (Chen et al., 2010 cited in Feizizadeh and Blaschke, 2011).

2.10 AHP Application for Weighted Overlay Analysis

A weighted overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create integrated analysis (Malczewski, 1999). The purpose of weighting in land suitability analysis for irrigation is to determine the importance of each factor relative to other factors that affect land for irrigation. To prioritize the influence of the factor

values, weighted overlay analysis uses an evaluation scale from 1 (represents the least suitable factor) to 9 (represents the most suitable factor) (Saaty, 1980).

Weighted overlay accepts integer raster as input, such as a raster of land cover, soil type, and Euclidean (the straight line from the center of the source cell to the center of the surrounding cells) distance output to find suitable land for irrigation.

AHP is a powerful and flexible decision-making process to help people set priorities and make the best decision when both quantitative and qualitative aspects of decision need to be considered (Weerakoon, 2014). AHP involves structuring multiple-choice criteria into a hierarchy, assessing the relative importance for each criterion, determining an overall ranking of the alternatives, and completely aggregating various facets of the decision problem into a single objective function (Saaty, 2000). By organizing and assessing alternatives against a hierarchy of multifaceted objectives, AHP drastically reduces the complex decision cycle (Anonymous, 2015).

According to Shen et al. (2015) the procedure used to establish the weights using the AHP method includes; - a) structure hierarchy, b) construct pairwise comparison matrix, c) calculating the weights (the priority eigenvector), and d) consistency evaluation.

2.11 Irrigation Potential Assessment

In the past, several studies have been made to assess the irrigation potential and water resources by using GIS as a tool. Some of them are presented in this section

(1987) conducted a study to assess land and water resources potential for irrigation in Africa based on river basins of countries. It was one of the first GIS-based studies of its kind at a continental level. It proposed a natural resource-based approach to assess irrigation potential. Its main limitations were in the sensitivity of criteria for defining land suitability for irrigation and in water allocation scenarios needed for computation of irrigation potential.

FAO (1997) studied the irrigation potential of Africa taking into consideration the above limitations. It concentrated mainly on quantitative assessment based on physical criteria (land and water) but relied heavily on information collected from the countries. A river basin approach had been used to insure consistency at river and basin levels. Geographic Information System

(GIS) facilities were extensively used for this purpose. In this study, a physical approach to irrigation potential was understood as setting the global limit for irrigation development.

Meron (2007) carried out similar work on surface irrigation suitability analysis of the southern Abay basin by implementing GIS techniques. This study considered soil, slope, and land cover /use factors to find suitable land for irrigation concerning the location of the available water resource, and to determine the combined influence of these factors for irrigation suitability analysis, weighted overlay analysis was used in Arc-GIS. Land unit is obtained by the overlaying of selected theme layers, which has unique information of land qualities for which the suitability is based on the selected theme layers.

Kebede (2010) conducted a study on GIS-based surface irrigation potential assessment of river catchments for irrigation development in Dale Woreda, Sidama zone, SNNP. In this study irrigation suitability factors such as soil type, slope, land use/cover, and distance from water supply (sources) were taken into account and weighted overlay analysis of these factors has been accomplishing to identify potentially irrigable land. The irrigation suitability analysis of these factors indicates that 86% of soil and 58.5% slope in the study area in the range of highly suitable to marginally suitable for the surface irrigation system. In terms of land cover/use, 87.1% of land cover/use is highly suitable whereas 12.9% were restricted from irrigation development.

Dagnenet (2008) conducted a study on the assessment of irrigation land suitability and development of the map for the Fogera catchment using GIS in South Gonder. Based on stoniness, soil salinity, soil alkalinity, soil depth, and groundwater quality it was concluded that 72 percent of the study area was potentially suitable for irrigation, and 28 percent was classified as unsuitable (N) due to drainage limitation, flood hazard, texture, and slope factors. Of the potentially suitable land, 1 percent was highly suitable (S1), 28 percent was moderately suitable (S2), and 43 percent is marginally suitable (S3).

Abraham et al. (2015) conducted a study on GIS-based land suitability evaluation for main irrigated vegetables in the Seams dam, northern Ethiopia. In this study, the area was classified into six land mapping units and samples were taken from the representative sites of these land mapping units. The parametric evaluation system and Inverse Distance Weighted (IDW)

interpolation provided in Arc GIS 10.1 software were used to perform the land suitability classification. The result of the study depicted that the study area was moderately suitable for any irrigated vegetable purposes. Soil texture was the only limiting factor and the cause for the area to be moderately suitable (S2).

Girma (2015) assess 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 evaluation of slope, LULC, major soil physical properties such as texture and depth, drainage, PH, etc. besides surface water resources of the sub basin for surface irrigation development. Suitability of the area's slope, soil, land use land cover and surface water resources were evaluated and geo-referenced map of each the parameter was presented on Arc GIS. Overall suitability map of the area of the intended the irrigation system was produced using the suitability model developed on Arc GIS. In this model weighted overlay analysis, the high value of percent influence was given for slope, since it is the main determinant factor in the evaluation of the given area of surface irrigation development. The result of the suitability model revealed that about 45.72% (135519.18 ha) of lands in the sub-basin were in the range of highly suitable to marginally suitable for surface irrigation development due to the combined effect of slope, soil, and land use land cover suitability. 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. Accordingly; Amana, Rebu, Kulit, Nano, Walga, and Darge river catchments have a total potential irrigable area of 41.32 % (122488.2 ha) together in the sub-basin through surface irrigation system. The current study considered slope, land use land cover, surface water availability and some soil physical properties only.

Tibebe (2013) conducted a study on Runoff estimation and water management for the Holetta River in Ethiopia. In his study to estimate the irrigation water demand for each crop, evapotranspiration, effective rainfall, crop type data, area coverage, and soil data were fitted in the CROPWAT model. Then, the CROPWAT model calculated the irrigation water

requirement (mm/month) for each crop. Based on the result, the total irrigation water demand was 0.305, 0.575, 0.995, 0.865 and 0.332 MCM for January, February, March, April and May, respectively.

Negash (2004) conducted a study on GIS-based irrigation suitability analysis in the Abaya Chamo Basin. As the author indicates a crop water requirement for selected crops was evaluated using CROPWAT 4.3 tool as an input of climate, soil, and crop data of the area under consideration was provided. It uses monthly data to estimate evapotranspiration. Monthly rainfall magnitude was converted into daily values each month through interpolation. In this study reference evapotranspiration (ET_o) was mainly estimated by Penman-Monteith and Hargreaves method if all meteorological data was available, and only temperature data was available respectively. The cropping pattern was selected to fit with the local cropping calendar and the respective crop coefficient for the initial, mid and late seasons were identified based on the FAO guidelines. The intermediate K_c values were linearly interpolated between the pre-identified K_c values for different stages. Thus the evapotranspiration demand of the crop was determined as $ET_c = ET_o \times K_c$ mm/period. Effective rainfall was determined with the aid of the SCS method option in the program and deducted from the ET_c value. Finally, the crop water requirement was estimated to take care of the rainy seasons as $CWR = ET_c - P_{eff}$ and the net irrigation requirement was estimated as, $NIWR = CWR \times A_{crop}$ mm/period

3. MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

The study was conducted in Oromia regional state, in Bale zone, which is located in the south-eastern part of Oromia Regional State, Bale Zone and far apart about 425 kilometers from Addis Ababa. The watershed is situated in the Genale Dawa Basin at the upper parts of the Weyib Sub-basin and located at 6° 52' 21" N and 7°26' 55' 'N latitude and 39°35' 24' 'and 40°05'46" E longitudes with an elevation of 4264m to the 2302-meter range. The area of the watershed covers about 998.95 km² including Bale Mountains National Park (BMNP) at the upper part of the watershed. This watershed is located as shown in Figure 3.1 below.

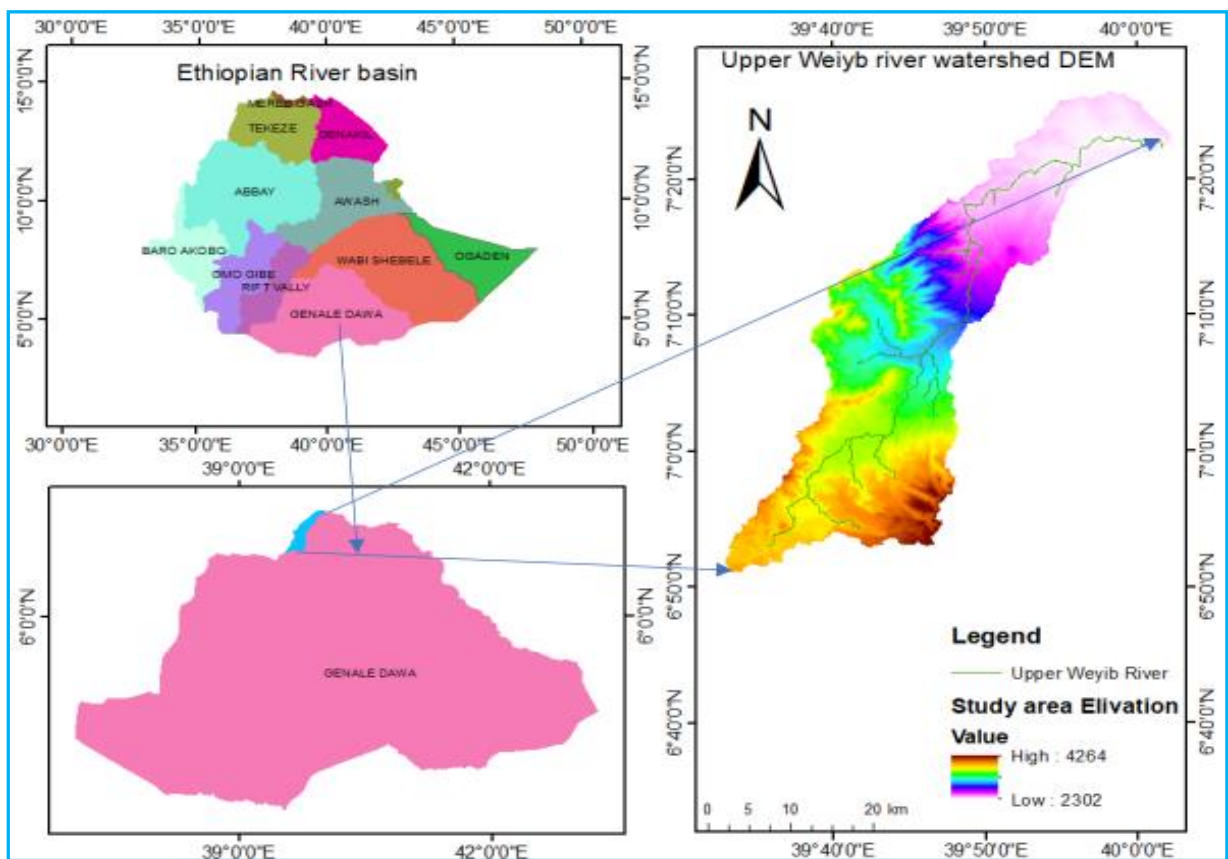


Figure 3. 1:Location map of the Upper Weyib watershed

3.1.2 Climate

The climate of Ethiopia is very much the reflection of its diversified topography and its location in the tropics. According to the definition given by the World Meteorological Organization (WMO), Climate is defined as the synthesis of weather conditions in a given area characterized by long-term statistics (mean, variance, probabilities of extremes, etc) of the meteorological elements in an area (NEDECO, 1998). The WMO usually accepts 30 years of statical data series to define climate. The meteorological/climatic elements include rainfall, temperature, wind, radiation, humidity, and sunshine hours.

The climate of the Upper Weyib watershed is in the range of frost (Wurch) at the uppermost part near the Bale Mountains national park to the humid highlands of the Bale Mountains. Rainfall during the year occurs in distinctly different seasons. The rainfall pattern is bimodal type, which divides the year into two main seasons: a main rainy season Kiremt (July to October) and a short rainy season Belg (March to May). The bimodal type of rainfall pattern is generally characterized by a double peak rainfall pattern with a small peak in April and a maximum peak in August (MoWIE, 2007). Based on meteorological data from Robe, Sinana, Agarfa, and Dinsho stations the average annual rainfall distribution is 1001.85mm and generally, the temperature and rainfall pattern in all stations follows similar trends. The average annual maximum and minimum temperature in the watershed area is about 24⁰c and 4.3⁰c at Agarfa and Dinsho Station respectively, as shown in Figure 3.2 below.

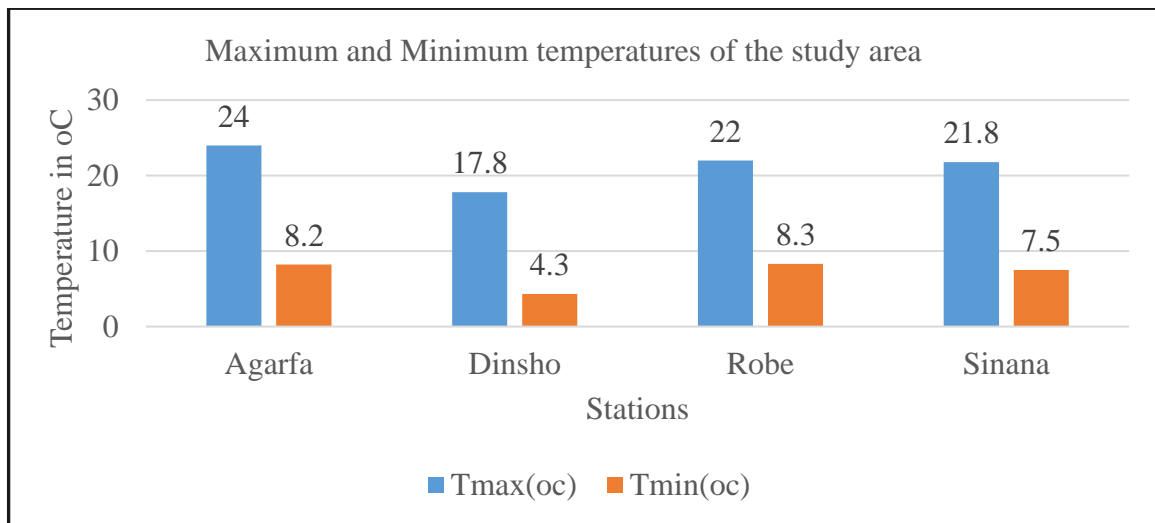


Figure 3. 2: The annual average maximum and the minimum temperature of the study area

Temperature:

The mean monthly minimum and maximum temperatures recorded for four metrological stations in the Upper Weyib river watershed are presented in Figure 3.3 respectively. The mean monthly temperature was calculated as the average of the maximum and minimum temperatures. Generally, the month of March had the highest temperature with a reading of 22.6°C while December's extremely lowest temperature with a reading of 4.80°C.

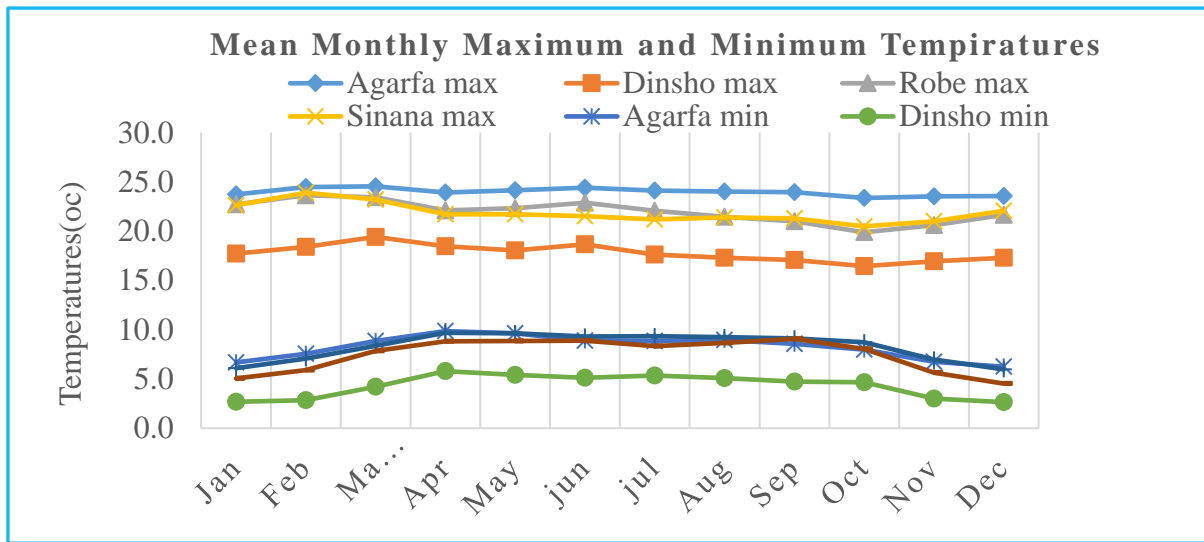


Figure 3. 3: Mean monthly minimum and maximum temperature profile

Relative Humidity:

Relative humidity was one input parameter in ET_c calculation. The thirty-one years (1987-2017) average daily relative humidity taking from Robe metrological station was found to be 66.9%.

Wind Speed:

Wind characteristics such as wind velocity. The frequency and direction of winds are important regarding the selection of irrigation methods, the rate of transpiration of crops. The average wind was observed as 1.6m/s or 138km/day.

Sunshine Hours:

The maximum average monthly sunshine hour in the Robe metrological station was found to be 9.0 hours, which occurred in February, whereas the minimum sunshine hour was 5.7 hours occurred in October with an annual average of 7.4 hours.

3.1.3 Topography

The topography is the most determinant factor influencing surface irrigation practice. Land classification factors were evaluated by the topographical qualities slope gradient. The elevation of the study area is extending from 2302 to 4264 meters above the mean sea level. As shown in Figure 3.1, The maximum elevation of the Upper Weyib Watershed is located in the southwestern part of the watershed, and also the minimum elevation of this watershed is located in the northeastern part of this watershed.

3.1.4 Soil

There are five major soil groups in the Upper Weyib river watershed, Eutric cambisol, chromic luvisol, lithic leptosols, haplic luvisol, and Eutric vertisols. There are several soil physical parameters to determine soil suitability analysis, but mainly there are three soil physical properties to evaluate soil suitability in the watershed. These are soil texture, soil depth, and soil drainage properties each data was taken accordingly to FAO standards. The physical properties of these soil groups were used for irrigation suitability analysis. The major soil types and their area coverage of each soil type in the study area are summarized in Table 3.1 and Figure 3.4.

Table 3. 1:Major soil types in the Upper Weyib River watershed

No	Soil type	Soil Map Unit	Coverage (ha)	Area (%)
1	Eutric Cambisol	CMe	12,242	12.25
2	Lithic Leptosol	LPq	1,401	1.40
3	Chromic Luvisol	LVx	59,340	59.40
4	Haplic Luvisol	LVh	1,630	1.63
5	Eutric Vertisol	VRe	25,282	25.31
Total			99,895	100

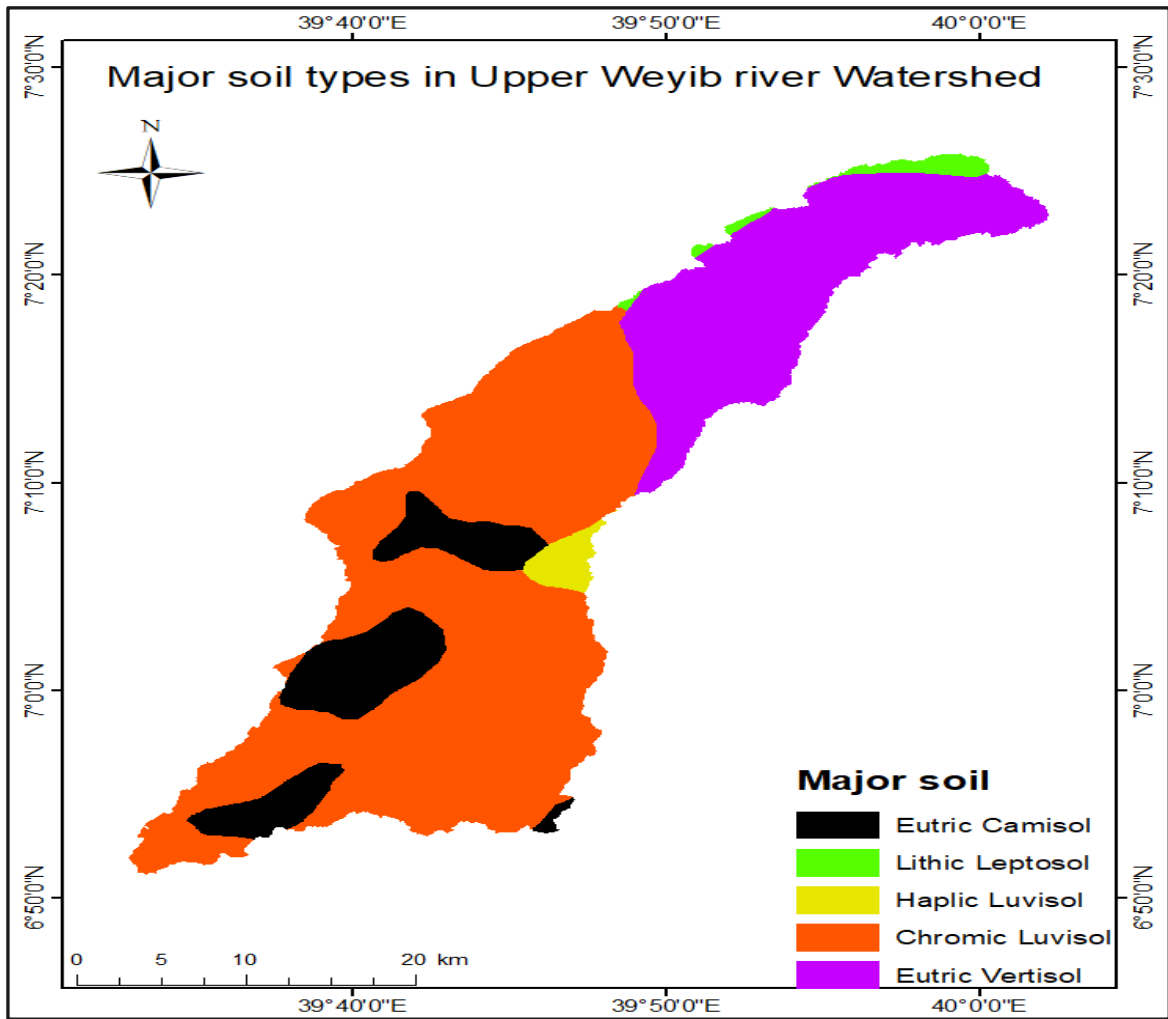


Figure 3. 4: Soil map of the upper Weyib River watershed

3.1.5 Water Resources

Investigations of water resources should be considered an integral part of the land resources evaluation process (FAO, 1985). The quality and quantity of the water supply are equally as important as land and other factors to the success of an irrigation project (Meron, 2007). It is important to make sure that there will be no lack of irrigation water. If water is in short supply during some part of the irrigation season, crop production will suffer, returns will decline and part of the scheme’s investment will lay idle FAO, (2001). Therefore, water supply (water quantity and seasonality) is an important factor to evaluate the land suitability for irrigation according to the volume of water during the year which is available FAO, (1985). Computing the amount of water that is available for surface irrigation and locate the exact location to be

economical addressed to transport from the source to the command area. Surface irrigation water sources should be above the command area to irrigate the entire area by gravity through surface irrigation. It is also desirable that the location of water preferably near the command area to minimize the length of the conveyance structure to be economical. Therefore, distance from water sources to command area, nearness to rivers, is useful to reduce the conveyance system (irrigation canal length), evaporation losses, and thereby developing the irrigation system to be economical.

3.2 Data Collection and Analysis

3.2.1 Data collection

3.2.1.1 Soil Data

Soil data was collected from the GIS and remote sensing department and the ministry of water, irrigation, and electricity. This data has been used to soil suitability analysis for surface irrigation. General information of soil in the study watershed is classified based on the revised FAO/UNESCO-ISWC (1998) classified system. The soil data were extracted from the 1:250,000 scale of the soil map developed by (MoWE, 2007). The basic physical properties of major soil types in the watershed were mainly obtained from a digital soil map from the ministry of water and energy produced between the year 2004 and 2007; soil and terrain database for North-Eastern Africa. In addition to these sources, some soil properties were estimated based on available soil parameters and they were used as input data for soil suitability analysis for irrigation.

3.2.1.2 LULC Data

SPOT5 satellite images, with acquisition dates between November 2015 and December 2016 that included three bands (1, 2 & 3) and with a spatial resolution of 1.5m, were obtained from the Ethiopian Mapping Agency. They were used to classify the land cover of the study area.

3.2.1.3 Digital Elevation Model (DEM)

SRTM-DEM (shuffle radar topographic mission digital elevation model data) were obtained from the Ethiopian ministry of water and energy GIS department of 30*30 and was used as input

data in ArcGIS to delineate watershed and to derive slope maps of the study area for surface irrigation suitability analysis.

3.2.1.4 Climate Data

Climate data such as precipitation, temperature, wind speed, sunshine was collected from the National meteorological service agency (NMSA). These data were used to quantify the crop water requirement of some selected crops using cropwat8.0 software. This software uses the Climate data (Mean daily hours of sunshine, (hours/day), Mean monthly wind speed (km/day), Monthly precipitation (mm), Mean monthly maximum and minimum temperatures, per month (°C), mean monthly precipitation (mm), and agronomic data as an input data for estimation of irrigation water demand.

3.2.1.5 Crop data

Agronomic data, the data was collected from the zonal Agriculture and Natural Resource Office and Agronomic data include types of crop, cropping pattern (planting date, growth length, (early stage, medium stage development stage, and late-stage) in days.

3.2.1.6 Stream Flow data

The streamflow, daily data of the watershed at Denbel gauging station was found from the hydrology department of the MoWE, this data(discharge/streamflow) has been employed in Arc SWAT model sensitivity, testing, and verification analysis.

3.2.2 Data Processing and Analysis

3.2.2.1 Filling missing data

Missing rainfall data analysis was conducted for each station to fill the missing rainfall data from the neighboring rain gauge stations having complete data set. In this study area, missing data in four considered stations i.e., Robe, Agarfa, sinana, and Dinsho gauge station were executed by using the normal ratio method which was recommended to estimate missing data in the region where annual rainfall among stations differed by more than 10% (Dingman, 2002).

Normal ratio method:

$$P_x = \frac{1}{m} \sum_{i=1}^m \left(\frac{N_x}{N_i} \right) * P_i \quad 3.1$$

Where: P_x = missing annual rainfall at station x

m = number of neighboring stations

P_1, P_2, P_m = annual rainfall at neighboring station 1, 2, and m respectively

N_1, N_2, N_m = normal annual precipitation at station 1, 2, and m respectively

3.2.2.2 Checking consistency of rainfall data

Consistencies of rainfall data are checked by the method of double mass curve analysis. A plot of accumulated rainfall data at the site of interest against the accumulated average at the surrounding stations is generally used to check the consistency of streamflow/rainfall data. To prepare the streamflow and rainfall data for further application, their consistency was checked using this method. Each station was also checked for consistency of rainfall series by using a double mass curve.

$$P_x' = P_x \frac{M'}{M} \quad 3.2$$

Where : P_x' = corrected precipitation at the station x (mm)

P_x = original recorded precipitation at the station x (mm)

M' = Corrected slope of the double mass curve(%)

M = original slope of the double mass curve(%)

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. To check the degree of consistency, Nemec (1973) provided the following value of the coefficient of correlation as follows:

$R = 1$: direct linear correlation,

$0.6 \leq R < 1$: good direct correlation,

$-0.6 < R < 0$: insufficient – reciprocal correlation,

$-1 < R < 0.6$: good reciprocal correlation and

$R = -1$: reciprocal linear correlation.

The double mass curve to check the consistency of rainfall data was described in Figure 3.5 below.

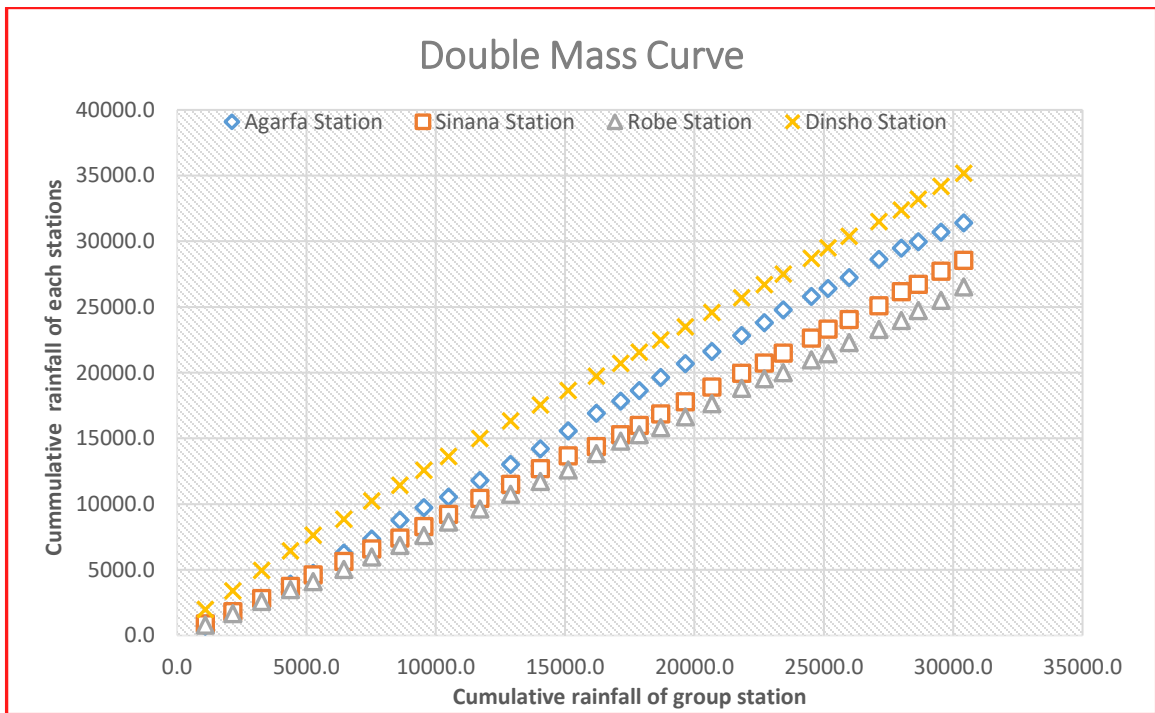


Figure 3. 5: Double mass curve of all rainfall station

3.2.2.3 Land Suitability Analysis

Slope Suitability Analysis:

The slope has been considered as one of the evaluation parameters in surface land suitability analysis. The slope of the study area was derived from DEM 30m by using the ArcGIS10.3 spatial analysis tool. The analysis tool produced a raster layer of continuous slope digital map. Then, a reclassified digital map of slope in % based was produced. The slope derived from the DEM was classified based on the classification system of (FAO, 1996) using the “Reclassification” tool into four suitability classes S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable), and N (marginally not suitable) for surface irrigation, whereas they represent the range of 0-2%, 2-5%, 5-8% and >8% respectively. Finally, the slope suitability map was developed and data layers were prepared for a further overlay for land suitability analysis for surface irrigation. The slope suitability class for surface irrigation was shown in Table 3.2 below.

Table 3. 2: Slope suitability classification for surface irrigation

No	Slope (%)	Factor rating
1	0 – 2	S1
2	2 – 5	S2
3	5 – 8	S3
4	> 8	N

The classified raster data layers were then converted to feature(vector) data layers for the overlaying analysis. Using data management tools in the Arc Toolbox, the generalization of feature (vector) data layers was performed to make a clearer slope suitability map.

Soil Suitability Analysis:

Physical soil properties are the most dominant factors that determine the land suitability for irrigation. Those soil properties are including soil depth, soil texture, and soil drainage. Soil drainage, texture, and soil depth were extracted from the soil map for the suitability rating. The soil map was redefined into four classes specifying its suitability for surface irrigation. First preparing soil feature layers of each physical soil parameters; soil texture, soil drainage and soil depth then, the feature layers were converted into raster layer using the conversion tool “To Raster”. The soil vector layer was converted into a raster layer using conversion tools- to raster-feature to raster in the Arc GIS. The rasterized soil map of the study area was then reclassified based on texture, depth, and drainage classes. Finally, a soil suitability map of each soil physical parameter was developed with the factor rating of S1, S2, S3, and N through reclassified the raster layers based on the FAO soil classification guideline. The factor of rating for each selected soil physical parameter was shown below.

Table 3. 3:Soil Combination 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	Coarse Sand	< 50	Very poor	N

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

(Source: FAO guideline for land evaluation (1991) modified by the OWWDSE land evaluation team based on practical observation (2010).

Image classification: There are two approaches to extract spectral information: supervised and unsupervised classification (Richards, 1986). Unsupervised classification is the method in which image pixels are assigned to spectral classes without the user having previous knowledge about the study area whereas, supervised classification is a method that involves the selection of areas in the image, which statically characterize the categories of interest. The SPOT image was conducted to understand the general land cover classes of the study area. Based on the results from classification and information from the topographic map of the study area, sample training sites were selected to collect geographic coordinates. By using supervised classification with the Maximum Likelihood method, seven land cover classes were classified for the study area except for towns, which were not separable and they were classified by masking using their polygon layers.

Accuracy of Image Classification: Accuracy of image classification the accuracy is essentially a measure of how many ground truth pixels were classified correctly. When looking at the land cover map, it is important to remember that no map is a perfect representation of reality. There are always errors in maps and we need to keep in mind how accurate they are, and whether that level of accuracy is sufficient for the ways we want to use the map information (Awotwi, 2009). Based on the 1.5-meter resolution of the SPOT5 data used to create the map, it is important to keep in mind that the map will be most accurate for viewing geographic patterns over larger areas. The result of an accuracy assessment provides us with an overall accuracy of the map based on an average of the accuracies for each class on the map.

$$\text{Overall accuracy} = \frac{\text{No of the pixels correctly classified}}{\text{Total no of pixel}} * 100 \quad 3.3$$

Kappa is used to measure the agreement or accuracy between the remote sensing derived classification map and the reference data as indicated by the major diagonals and the chance agreement, which is indicated by the row and column totals (Jensen, 2003).

The Kappa factor is given by the formula (Jensen, 2003):

$$\text{kappa}(K) = \frac{P_o - P_e}{1 - P_e} \quad 3.4$$

Where P_o is the proportion of correctly classified cases

P_e = is the proportion of correctly classified cases expected by chance

The producer's accuracy is the total number of correct pixels in a category divided by the total number of pixels of that category as derived from the reference data (column total). This statistic indicates the probability of a reference pixel being correctly classified and is a measure of omission error. The producer's accuracy gives how well a certain area can be classified (Jensen, 2003). User's accuracy is when the total number of correct pixels in a category is divided by the total number of pixels that were classified in that category (row total), the result is a measure of commission error. The user's accuracy or reliability is the probability that a pixel classified on the map represents that category on the ground (Jensen, 2003).

Land Use Land Cover Suitability Assessment: Land use/land cover is a factor that is used to evaluate land suitability for irrigation. The land use/land cover of the study area has been obtained by performing a supervised classification of the SPOT5 image. The major land use of the Watershed was classified as cultivated dominantly, shrub and plantations, grassland/pasture, Urban area, wetland, and forest (dense).

Table 3. 4: Land use/land covers suitability criteria

Suitability category	Designation	Description of land cover types
S1	Highly suitable	Cultivated–dominantly, moderately Grassland–open, bushed, shrubbed Bushland – open, riparian
S2	Moderately suitable	Woodland–open, riparian Bushland - dense
S3	Marginally suitable	Forest-open Cultivated – Irrigation, a state far
N	Marginally not suitable	Woodland–dense Bamboo Urban area

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

Distance from Water Supply Source: Available irrigable land close to the water supply (the Upper Weyib River) was identified by creating Euclidian distance along the river to a specified distance using the buffer icon in the analysis tool and clip to the specified study area. Euclidean distance is the straight-line distance between two points on a plane, also known as ‘distance as the flow flies. This tool was used when creating the irrigation land suitability map (ESRI, 2016). The buffer zone or distance created around the river is provided as a linear distance and the area covered in between two buffer lines was clipped using the editing tool and the shapefile features class were created by making a union of each clipped buffer polygons. The clipped feature class was converted to raster using the conversion tool land reclassified into suitability class based on its distance to the water source used “Reclassified tool”. The reclassified land distance was used for weighting overlay for further analysis together with other factors.

Approaches used to develop suitability map

MCE in a GIS environment is the best technique to evaluate different factors for a specific objective. It is concerned with how to combine the information from several criteria to form a single index of evaluation.

The purpose of weighting in land suitability analysis for irrigation is to the importance of each factor relative to other factors that affect land for irrigation suitability and making on the suitability of land mapping unit (Bagheri et al., 2012). In pairwise comparison, each factor was matched head-to-head (one to one) with each other and a comparison matrix was prepared to express the relative importance. A scale of importance is broken down from a value of 1 to 9 (Table 3.5), the highest value 9 corresponds to absolute importance and a reciprocal of all scaled ratio was entered in the transpose position. These pairwise comparisons are then analyzed to produce a set of weights that sum to 1. The factors and their result weight were used as input for the MCE model for weighted linear combination. The procedure by which the weights are produced follows the judgment developed by Saaty under the AHP with a weighted linear combination applying a weight to each followed by a summation of the results to yield a suitability map.

Analytical Hierarchy Process (AHP)

The AHP is a mathematical method that may be applied to resolve highly complex decision making problems involving multiple scenarios, criteria, and factors (Saaty, 1980). The AHP is

a powerful and flexible decision-making process to help people set priorities and make the best the decision when both quantitative and qualitative aspects of decisions need to be considered.

The procedure used to establish the weights using the AHP method includes several steps:-

Structure a hierarchy

The relationship between objectives and their attributes has a hierarchy structure (Malczewski, 1999). At the highest level, one can differentiate the objectives and at lower, the attributes can be disintegrated Figure 3.6.

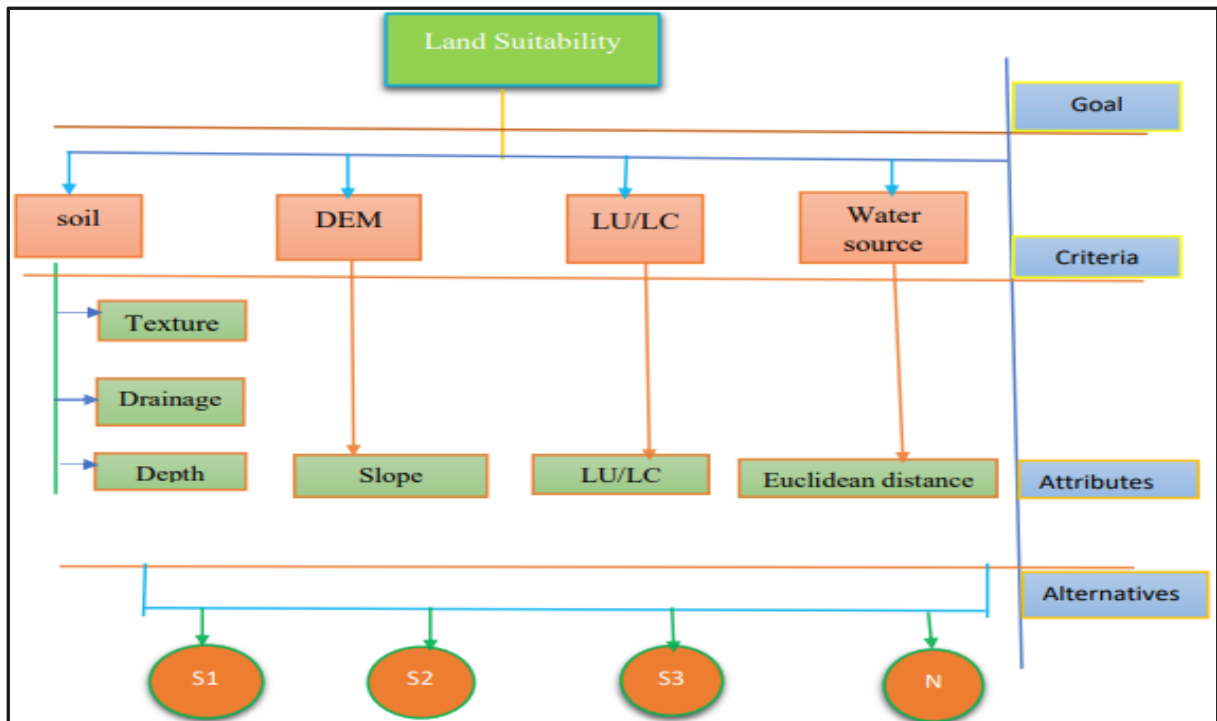


Figure 3. 6: Hierarchical organization of criteria

Construct pairwise comparison matrix

In Saaty (1980) technique, the weight of this nature can be derived by the principal eigenvector of square reciprocal matrixes of pairwise comparisons between the criteria. The comparisons concern the relative importance of the criteria involved in determining suitability for the standard objective, Ratings on a 9 points continuous scale (Ayla et al., 2016).

The weights of the individual criteria are calculated. First, normalized comparison matrix is created each value in the matrix is divided by the sum of its column. To get the weights of the

individual criteria, the mean of each row of this second matrix is determined. These weights are already determined and their sum is 1.

Evaluate consistency of pairwise comparisons:

The AHP also provides mathematical measures to determine the consistency of the judgment matrix. The weights derived from a pairwise comparison matrix must be consistent. According to Saaty (1980) to ensure the consistency of the pairwise comparison matrix, the consistency judgment must be checked for the appropriate value of n by CR. The CR coefficients should be less than 0.1, that indicating the overall consistency of the pairwise comparison matrix. A consistency ratio (CR) of 0.10 or less indicates a reasonable level of consistency. If the CR is >0.1, the comparison matrix should be revised.

$$CI = \frac{\lambda_{max}-n}{n-1} \tag{3.5}$$

$$CR = \frac{CI}{RI} \tag{3.6}$$

Where CI is the consistency index, n is the number of criteria, λ_{max} is the largest Eigenvalue of the matrix. The RI is the average of resulting consistency.

Table 3. 5: Random Consistency Index table (Saaty, 1980)

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.42	1.45	1.49	1.51	1.48	1.56	1.57	1.58

Source: Ayla et al (2016) AHP and GIS-based land suitability analysis for Cihanbeyli Count
 Creating weighted analysis in spatial analysis tool sets are used to find suitable lands for surface irrigation. After the individual suitability was assessed, the irrigation suitability factors which were considered to do the weighting slope factor, soil factor, land use/land cover factor and proximity to river factor as input to find the most suitable site for surface irrigation. Selected raster layers were overlaid by identifying their cell values to the same scale, giving a weight value to individual criterion and integrating the weight cell values. The cell values of each raster layer are also multiplied by their weight value (Ayla et al., 2016).

$$LS = \sum_1^n WiXi \tag{3.7}$$

Where LS indicates the total land suitability score, Wi indicates the weight of the selected land suitability criteria, xi indicates the assigned sub-criteria score of i land suitability criteria and n

denotes the total number of land capability criteria. Basically, in weighted total overlay the cell values of the rating of suitability class) are multiplied by criteria weights. The resulting cell values were added to produce the final suitability map.

3.2.2.5 Estimation of water availability using SWAT

Watershed Delineation:

The first step in creating the SWAT model input is the delineation of the watershed from a DEM. Before going in hand with spatial input data i.e., the soil map, land use/cover map, and DEM were projected into the same projection called UTM zone 37N, which is a projection parameter for Ethiopia. The SWAT model provides three spatial levels: the watershed, the sub-watershed, and the hydrologic response unit. The largest spatial level, the watershed, refers to the entire area being represented by the model. To delineate watershed and generate data using Arc SWAT the following steps were adopted.

Load the DEM/importing DEM data: The DEM of the watershed was projected to the UTM coordinate system using Arc Catalog in ArcGIS10.3 and import to Arc SWAT to start automatic watershed delineation. The DEM projection setup was done.

Computing flow direction and accumulation flow direction for individual DEM cells were created using flow direction and accumulation tool in Arc SWAT. Arc SWAT computes flow directions for individual DEM cells based on these directions and streams were created using the defined stream threshold area in hectares. Using creates streams and outlets tool drives the stream network point.

Creating watershed outlets: an outlet, or pour point, is the point at which water flows out of an area. This is the lowest point along the boundary of the watershed. By using the outlet selection tool in Arc SWAT, the watershed outlet was defined. Using the add point sources to each sub-watershed tool outlet and inlet definitions of the sub-watersheds were edited manually.

Delineation of main and sub-watersheds: the main watershed was delineated by using a watershed delineator tool in Arc SWAT based on an automatic procedure using the watershed outlet in the step above. Sub-watershed was created by defined additional drainage outlets. Finally, the watershed parameters were calculated and the number of outlets and sub-watershed was derived.

Several criteria can be used for choosing the right model. These criteria are mainly dependent on the use of the model. Furthermore, some criteria are also user-dependent such as personal preference; computer operating system; input/output management and structure, etc. (Cunderlic,2003) suggested four criteria for the selection of models. These are (1) required model outputs for the needed purpose, (2) different hydrological processes that are required to be modeled for the desired purpose, (3) availability of input data, and (4) price. Depending upon the above selection criteria for this research Soil and Water Assessment Tool (SWAT) for the assessment of surface water availability was selected because:

1. SWAT is public or open-source domain software actively supported by USDA (United States Department of Agriculture)-ARS (Agricultural Research Service) at the Grassland, Soil and Water Research Laboratory in Temple, Texas, USA
2. SWAT is a river basin scale, a continuous-time, spatially distributed model developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds with varying soils, land use, and management conditions over long periods (Neitsch et al., 2005).
3. SWAT can analyze both small and large watersheds by subdividing the area into homogenous parts. As a physically-based model, SWAT uses hydrologic response units (HRUs) to describe spatial heterogeneity in terms of land use land cover, soil type, and slope within the watershed. The SWAT system is embedded within a geographic information system (GIS) that can integrate various spatial environmental data including soil, land cover, and topographic features (Lenhart et al., 2002).

The SWAT model (Arnold et al 1998) is a semi-physically based model for evaluating land management practices, discharge, sediment transport, and nutrient cycling. SWAT simulates the hydrologic cycle for each Hydrologic Response Unit (HRU) based on the following water balance Equation (3.1).

$$SW_t = SW_{t-1} + (R_t - Q_t - E_t - S_t - G_t) \quad 3.9$$

where SW_t is the final soil water content at time t , SW_{t-1} is the soil water content at time $t-1$, R is the precipitation, Q is the surface runoff, E is the actual evapotranspiration, S_t is the percolation and bypass exiting the soil profile bottom, and G_t is the return flow (Bhunya et al,2010).

Weather Data Definition:

All meteorological stations were having both temperature and precipitation data, but only Robe stations were synoptic stations (having all types of climatic data) used for generating remaining weather data for others (weather generator stations). After loading the WXGEN parameter and location table, the daily meteorological data (daily precipitation, daily minimum, and maximum air temperature) with the missing data filled with a missing data identifier of NA and including the corresponding location table prepared according to the SWAT format were loaded into the model. SWAT takes data of each climatic variable from the nearest weather station measured from the meteorological stations. The meteorological stations of the study area are described in Table 3.7 below.

Table 3. 6: Meteorological data (source: -NMSA)

S No	Station	Latitude (^o N)	Longitude (^o E)	Elevation(masl)	Period of record
1	Agarfa	7 ^o 16'1.2"	39 ^o 49'1.2"	2550	1987-2017
2	Sinana	7 ^o 4'1.2"	40 ^o 13'1.2"	2400	1987-2019
3	Robe	7 ^o 7'58.8"	40 ^o 03'00"	2480	1987-2019
4	Dinsho	7 ^o 06'00"	39 ^o 46'1.2"	3072	1987-2018

SWAT Model Simulation, Sensitivity Analysis, Calibration and Validation

After loading all the data that are required by the SWAT model, it is necessary to run the model and read the simulated output. It was adjusted the model to simulate for 28 years (1987- 2014) years of data. The result of the simulation cannot be directly used for further analysis. Instead, the ability of the model to sufficiently predict the streamflow should be evaluated through sensitivity analysis, model calibration, and model validation (White and Chaubey,2005).

a. Sensitivity Analysis

Sensitivity analysis is the process of identifying the model parameters that exert the highest influence on model calibration or model predictions. Sensitivity analysis describes how the model output varies over a range of a given input variable. Some researchers argue that sensitivity analysis and calibration are difficult with a large number of parameters. It is necessary to identify key sensitive parameters and the sensitive parameter precision required for calibration.

Model parameters that have higher sensitivity must be selected with care since small variations in their values can cause large variations in model output, and therefore it is important to safeguard that the parameter value is the best possible estimate. Model parameters that have low sensitivity do not require as much examination in their selection since small changes in their values do not cause large changes in model output. Model sensitivity classes were shown in Table 3.8 below.

Table 3. 7: Indices for sensitivity classes

Class	Index (I)	Sensitivity
I.	$I=1$	Very high
II.	$0.2 < I < 1$	High
III.	$0.05 < I < 0.2$	Medium
IV.	$0.00 < I < 0.05$	Small to negligible

b. Calibration

Calibration is an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty. Model calibration is performed by carefully selecting values for model input parameters (within their respective uncertainty ranges) by comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions. Calibration was done with the predefined parameters that have been identified as the most sensitive parameters. The parameter values are then adjusted to more closely match the model behavior to that of the watershed. The process of adjustment can be done “manually” or using computer-based “automatic” methods. In this study, the calibration process was done by observed streamflow data using automatic calibration from January 1,1989-December 31,2005.

After calibration, checking the R², NSE, and Pbias values and calibrate at least until the minimum recommended values were embraced by the model that is $R^2 > 0.6$, $NSE > 0.5$, and $pbias < \pm 25$ (Santhi et al., 2001).

c. Validation

Validation is the final step for steam flow. Model validation is the process of demonstrating that a given site-specific model is capable of making sufficiently accurate simulations, while, “sufficiently accurate” can vary based on project goals (Refsgaard, 1997). The validation procedure involves running a model through parameters that were determined during the

calibration process and comparing the predictions to observed data not used in the calibration. In this study, the validation period occurs from January 1, 2006-December 31, 2014

Model Performance Efficiency

Two methods for goodness-of-fit measures of model predictions were used during the calibration and validation periods, these numerical model performance measures are coefficient of regression (R^2 coefficient), the Nash-Sutcliffe simulation efficiency (NSE), and Relative Volume Error (RVE) Nash and Sutcliffe (1970). The range of values for R^2 is 1.0 (best) to 0.0 (poor). The R^2 coefficient measures the fraction of the variation in the measured data that is replicated in the simulated model results. A value of 0.0 for R^2 means that none of the variances in the measured data is replicated by the model predictions. On the other hand, a value of 1.0 indicates that all of the variances in the measured data are replicated by the model predictions. Hence, for evaluation of the performance of the model, efficiency criteria were used. Such as Nash Sutcliffe efficiency (NSE), Coefficient of determination (R^2), and Relative Volume Error.

a. Nash-Sutcliffe efficiency, NSE

According to (Moriasi et al., 2007) recommended for monthly time steps that NSE values between 0.75 and 1 are very good and NSE-value between 0.65 and 0.75 are good. The efficiency, NSE proposed by Nash and Sutcliffe (1970) is defined as one minus the sum of the absolute squared differences between the predicted and observed values normalized by the variance of the observed values during the period under investigation.

$$NSE = 1 - \frac{\sum(Q-P_i)^2}{\sum_{i=1}^n(Q_i-Q)^2} \quad 3.10$$

Where Q_i is observed flow at i^{th} period P_i is simulated flow at the i^{th} period and Q is the mean of the observed flow.

b. Coefficient of Determination, R^2

The coefficient of determination R^2 expressed as the squared ratio between the covariance and the multiplied standard deviations of the observed and predicted values and also defined as the squared value of the coefficient of correlation.

$$R^2 = \left[\frac{[\sum_{i=1}^n(Q_s - Q_{sm})(Q_o - Q_{om})]^2}{[\sum_{i=1}^n(Q_s - Q_{sm})]^2 [\sum_{i=1}^n(Q_o - Q_{om})]^2} \right] \quad 3.11$$

Where Q_o =Observed discharge (m³/s)
 Q_s =Simulated discharge (m³/s)
 Q_{om} =Mean of observed discharge (m³/s)
 Q_{sm} =Mean of simulated discharge (m³/s) and n is the number of observations
 Q_{om} =Mean of observed discharge (m³/s)

R^2 is indicated how the simulated data correlates to the observed values of data. The range of R^2 extends from 0 (unacceptable) to 1. If the simulation is accurate, R^2 is equal to one. An efficiency of R^2 is equal to zero indicates that the model predictions are as accurate as the mean of the observed data. (Krause, Boyle, & Base, 2005). According to (Moriasi et al., 2007) recommended monthly time steps that R^2 values between 0.75 and 1 are very good and R^2 -value between 0.65 and 0.75 is good.

c. Percent bias (PBIAS)

The percent bias (Pbias) describes the tendency of the simulated data to be greater or smaller than observed data, expressed as a percentage. Positive values indicate model underestimation, and negative values indicate model overestimation. This test is recommended due to its ability to reveal and poor performance of the model. (Gupta et al, 1999) and calculated by equation next.

$$Pbias = \frac{\sum_{i=0}^n (Q_{ob} - Q_{sim})}{\sum_{i=0}^n (Q_{ob})} * 100 \quad 3.12$$

Where RVE = Relative Volume Error (%).

Q_{ob} = Observed flow (m³/s)

Q_{sim} = Simulated flow (m³/s) and n is the number of observations.

3.2.2.6 Estimating discharges at un-gauged sites from gauged sites

The rainfall data analysis results, together with discharges from gauged sites, were used to estimate the streamflow at the un-gauged sites in the study area. Since only irrigation potential of perennial rivers were considered in this study, a long-term average of streamflow at gauged sites and mean monthly areal rainfall of the sites were used to estimate the discharges at ungauged sites. This was performed by applying the runoff coefficient of the gauged sites to ungauged sites (FAO, 1997; Goldsmith, 2000 and DFID, 2004)

According to Goldsmith (2000) and DFID (2004), to estimate mean monthly runoff volume of ungauged sites from gauged sites, catchment characteristics such as land cover, soil type, and catchment slope ranges should be similar, and distances between the gauged and ungauged river catchments should not be more than 50km and a minimum of 10 years mean monthly river flow at the gauged sites should be available. Based on these criteria, the gauged and ungauged river catchments soil, slope, and land cover maps were derived using FAO (1997) digital soil map of East Africa, DEM, and SPOT5 satellite image, respectively.

$$Q_{\text{ungauged}} = \left(\frac{DA_{\text{ungauged}}}{DA_{\text{gauged}}} \right)^n * Q_{\text{gauged}} \dots \dots \dots 3.13$$

Where: Q_{ungauged} = Discharge at the site of interest (m³/s).

DA ungauged = Discharge area at the site of interest (m²).

DA gauged = Drainage area at the gauged site (m²).

Q_{gauged} = discharge at gauged site (m³/s) and n = exponent b/n 0.6 and 1

If the DA ungauged should be 20% of the DA gauged ($0.6 \leq DA_{\text{ungauged}} / DA_{\text{gauge}} \leq 1.2$), n value equal to 1 unless n equal to 0.6. The streamflow calculated using the above equation for ungauged sites was used to estimate either adequacy for the potential irrigable sites.

3.2.2.7 Estimation irrigation water demand

Reference evapotranspiration, effective rainfall, crop pattern data, and soil data were used for CROPWAT model analysis. It is a decision-support computer program developed by the FAO to calculate reference evapotranspiration (ET_o), crop water requirement (CWR), irrigation scheduling and irrigation water requirement (IR) using rainfall, soil, crop and climate data. The major crops identified from the Zonal Agricultural and natural resource offices were used in the calculation of crop water requirements. First, monthly maximum and minimum temperature, relative humidity, sunshine hour, and wind speed data were fitted in CROPWAT 8.0 model. Then, the model calculated crop evapotranspiration values based on the FAO Penman-Monteith equation. Methodologies for crop water requirements have been developed to predict the amounts of water needed to obtain optimal crop yields based on climatological data, crop coefficients, and to some extent by taking into account the influence of other factors on CWR.

The panel of experts recommended the adoption of the Penman-Monteith method as a standard in estimating ETo and is considered as the more accurate method to calculate ETo. CROPWAT 8.0 software allows the user to either enter measured ETo values or input data on temperature, humidity, wind speed, and sunshine hours which allows CROPWAT to calculate ETo using the penman-Monteith formula.

The crop water use can be determined by multiplying the reference ETo by a crop coefficient (Kc). The crop coefficient adjusts the calculated reference ETo to obtain the crop evapotranspiration. The values of ETc and CWR (Crop Water Requirements) are identical, whereby ETc refers to the amount of water lost through Evapotranspiration and CWR refers to the amount of water that is needed to compensate for the loss. ETc can be calculated directly from ETo and Kc.

$$ETc = ETo * Kc \quad 3.14$$

Where ETc=crop evapotranspiration

ETo = Reference Evapotranspiration and

Kc = crop coefficient

ETo is the rate of evaporation from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground and with no shortage of water and expresses the evaporative demand of the atmosphere at a specific location and time of the a year and does not consider crop and soil factors. Kc is the crop coefficient during the initial, mid and development stages. Different crops will have a different crop coefficient and resulting in water use. Kc data can be obtained from FAO references, guidelines, and from different kinds of literature for each of the proposed crops. The values of Kc are varying with the crop types, their stage of growth, growing season, and the prevailing weather condition. ETc was calculated using CROPWAT version 8.0 and Kc values present the relationship between reference ETo and crop evapotranspiration.

Net irrigation water requirement 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 required certain amounts of water. Thus, CWR includes ET, losses during the application of water needed for these purposes (salam *et al.*,2019).

$$\text{NIR} = \text{ETc} - \text{peff} \quad 3.15$$

Where, NIR=the net irrigation requirement of crops

ETc = crop Evapotranspiration

P_{ef} = effective rainfall.

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 31 years is used and the data on the monthly basis was given in CROPWAT for calculating effective rainfall. Rainfall data from 1987-2017 was taken to calculate effective rainfall and USDA Soil The 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 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;

$$\text{GIWR} = \frac{\text{NIR}}{\text{E}} \quad 3.16$$

Where, GIWR = the gross irrigation requirement of crops and

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.

3.3 Determination of irrigation potential

Assessing the study area, by collecting available data from different ministers and agencies such as the Ministry of Water, Irrigation and Electricity, Ministry of Agriculture and Natural Resource, and Ethiopian National Meteorological Agencies. After collecting, the necessary data for the research and then filling of missed data and quality checking have been done carefully. An Arc SWAT model for estimating surface water potential at the outlet of the watershed and GIS software for determining land suitability analysis for surface irrigation considering slope /topography, soil physical properties, distances from the source, and land use land cover were implemented. In addition to this CROPWAT 8 method of the study has been summarized below the following conceptual framework Figure (3.7). the software was used to determine the crop and irrigation water demand for wheat, potato, pepper, and Barley crops in the watershed.

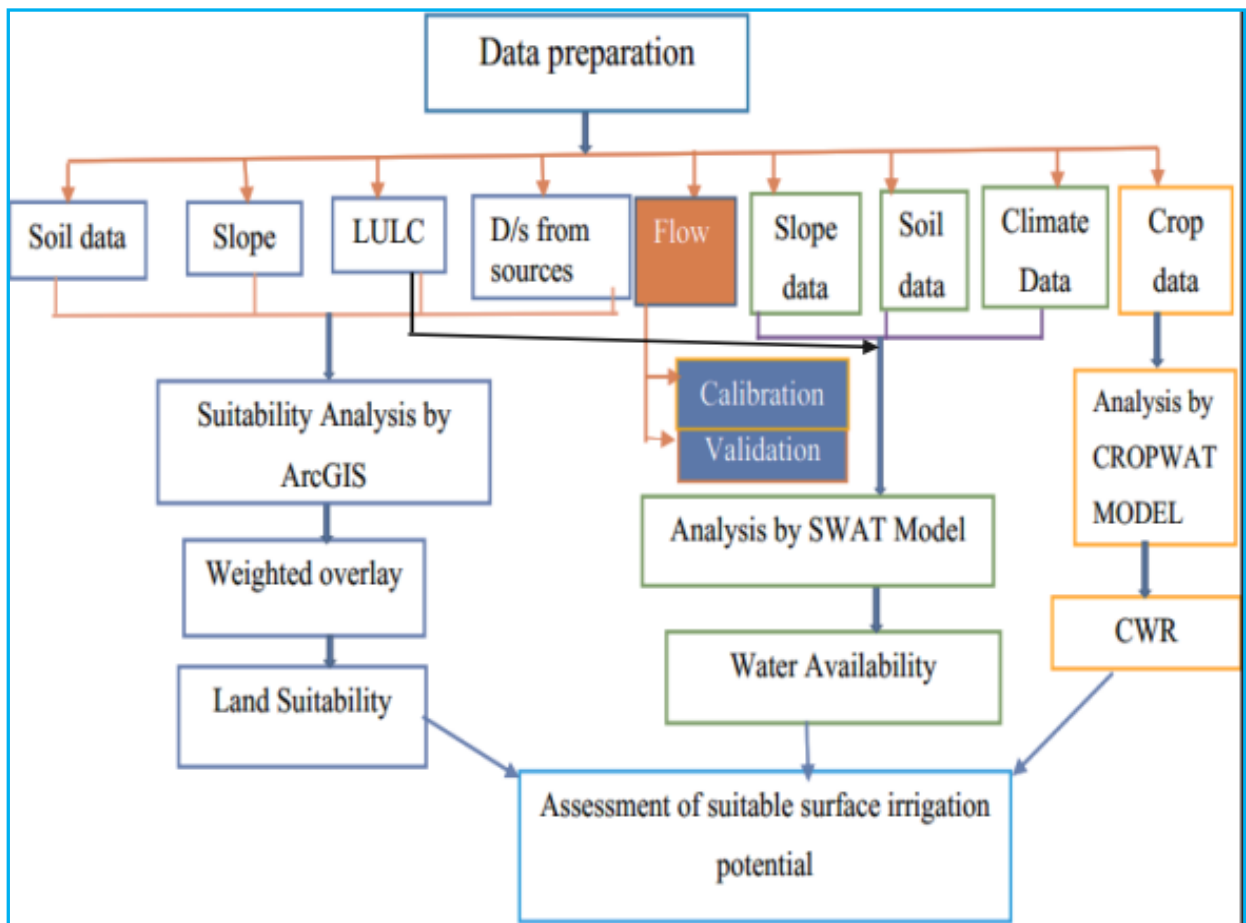


Figure 3. 7:Conceptual Frameworks for surface Irrigation assessment of the study area.

4 RESULTS AND DISCUSSION

4.1 Suitable Land for Surface Irrigation

4.1.1 Irrigation Land Suitability Factor Analysis

The analysis results of surface irrigation suitability evaluation factors are presented in the following sections.

4.1.1.1 Slope Suitability

According to FAO guidelines, the slope map of the watershed was classified into four suitability classes. The classification was based on the suitability of the slope for the development of the surface irrigation method. The classes are highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N) classes. The slope suitability map of the watershed and area coverage of each suitability class was described in Table (4.1) and Figure (4.1) below.

Table 4. 1: Slope suitability range of the study area for surface irrigation

No	Slope (%)	Coverage (ha)	Area (%)	Suitability Class	Suitability Class Name
1	0-2	5,227.36	5.23	S1	Highly Suitable
2	2-5	20,486.13	20.51	S2	Moderately Suitable
3	5-8	15,858.67	15.88	S3	Marginally Suitable
4	>8	58,322.77	58.38	N	Marginally not Suitable

The slope analysis indicates that about 41.62% (covering an area of 41,572.16ha) of the study area was covered with less than 8% slope class where this land is classified under highly suitable to marginally suitable for surface irrigation. 58.38% (covering an area of 58,322.77ha), of the watershed area, has a slope of greater than 8%, which is permanently not suitable for irrigation. According to (FAO,1999) suitability classification for surface irrigation, most of the area of the Upper Weyib river watershed was found to be not suitable for surface irrigation in terms of its work efficiency and cost for land leveling, canal construction, and cost for the pumping system.

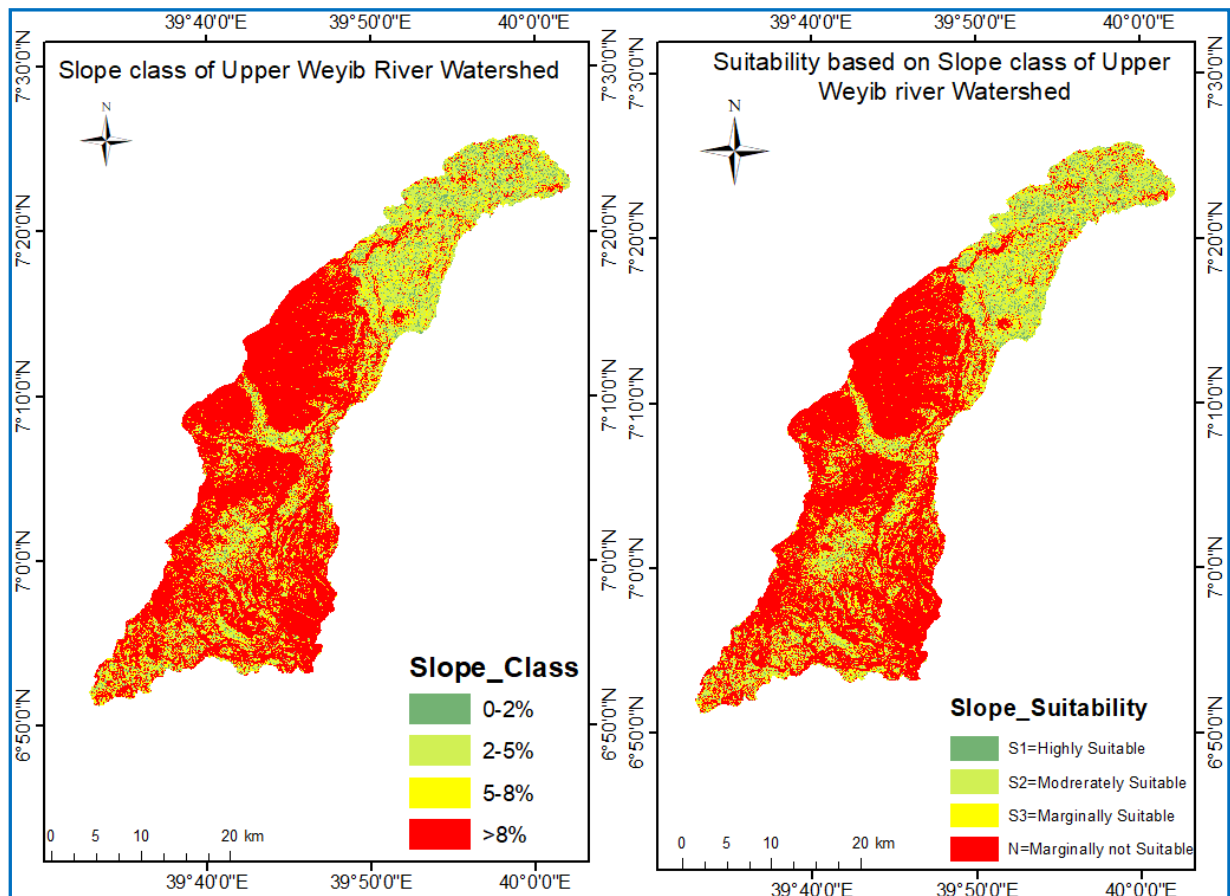


Figure 4. 1:Reclassified slope class and its suitability map

4.1.1.2 Soil Suitability

There are several soil physical parameters to determine soil suitability analysis, but only three soil physical properties to evaluate soil suitability in this watershed. These are soil texture, soil depth, and soil drainage properties each data was taken accordingly to FAO standards. The physical properties of these soil groups were used for land suitability analysis for surface irrigation.

a. Texture Suitability of soil

According to (FAO,1999) guidelines for soil evaluation, the soil texture of the study area was classified into loam, clay loam, sandy clay loam, and light clay, and their distribution in the study area was mapped in Figure 4.2 and Table 4.2. Soil texture classes such as light clay, and loam soil were classified as highly suitable (S1) and sandy clay loam and clay loam was classified as moderately suitable S2. Based on the (FAO, 1999) evaluation criteria, 86.34% of

the total area of the Upper Weyib river watershed had been highly suitable and 13.66% are moderately suitable (S2 by using the criteria of soil texture).

Table 4. 2: Soil texture and their suitability class

No	Soil Texture	Coverage		Soil Texture Suitability	Coverage	
		ha	%		ha	%
1	L	59,340	59.40	S1	86,252	86.34
2	C (light)	26,912	26.94			
4	SCL	12,242	12.25	S2	13,643	13.66
5	CL	1401	1.40			

Generally, the soils of the study were dominated by fine soil texture classes such as light clay, loam, and medium texture class clay loam, sandy clay loam soil texture.

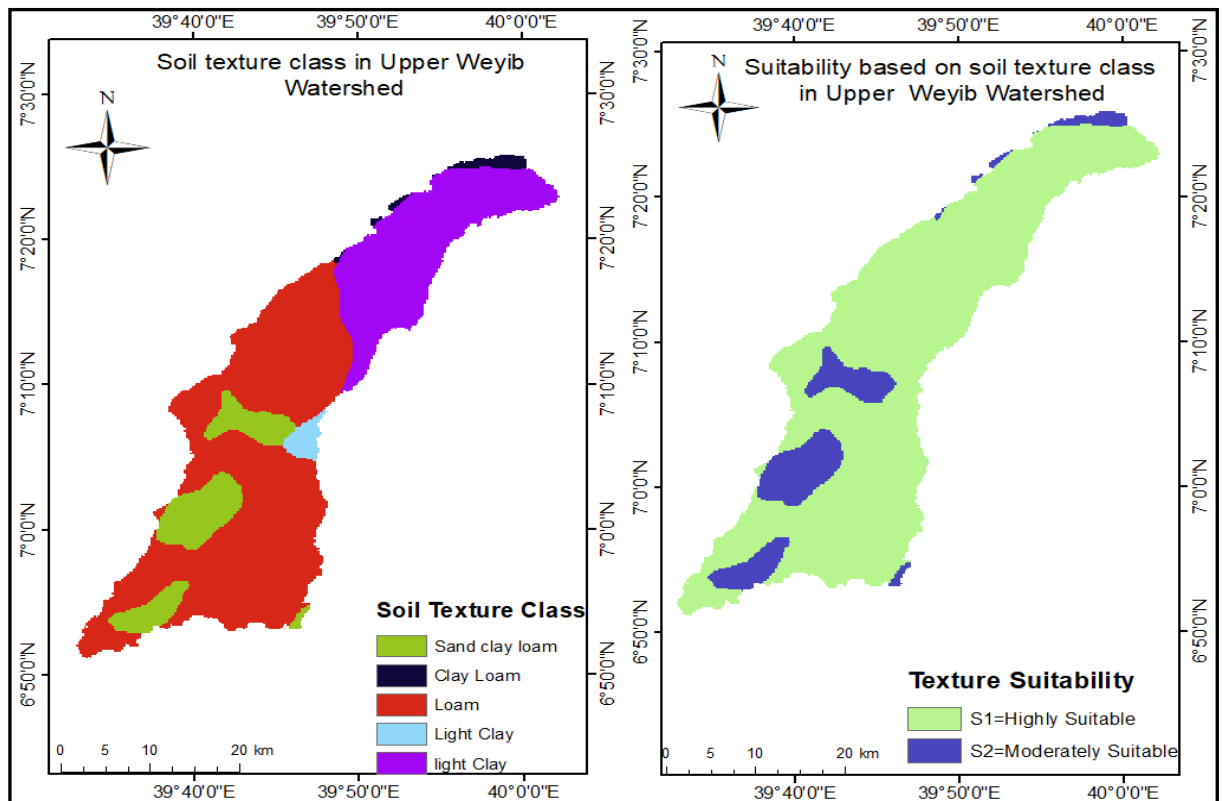


Figure 4. 2: Soil texture class and its suitability map.

b. Soil Drainage Suitability

According to (FAO, 1999) standard guidelines, soil drainage of a specified area can be divided into three classes. These are well-drained, imperfectly drained, and poorly drained soil (Table 4.3).

Table 4. 3: Drainage suitability class and their percentage

No	Soil drainage	Coverage	Area (%)	Drainage Suitability Class
		Area (ha)		
1	Well	86,023	86.11	S1
2	Imperfectly	1,630	1.63	S3
3	Poor	12,242	12.25	N

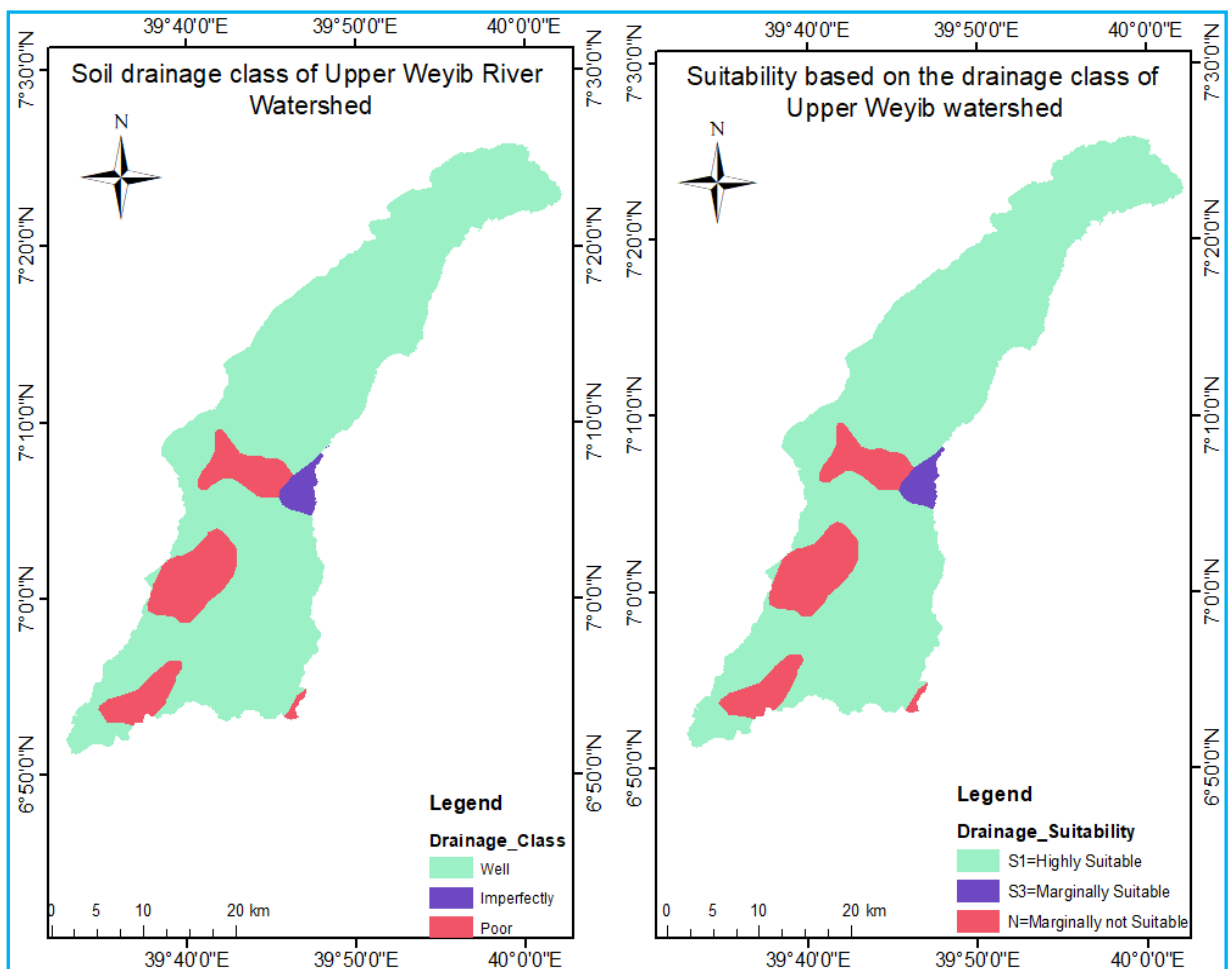


Figure 4. 3: Soil drainage class and its suitability map of the study area

The final drainage class and its suitability map were developed accordingly as shown in Figure 4.3. The result in Figure 4.3 on the right-hand side and Table 4.3 below revealed that the drainage suitability map of the area shows the well-drained area which covers a higher percentage area of 86.11 % which indicates a well, highly suitable class, 1.63% of the area covered by the imperfectly, marginally suitable class and poor class which occupies 12.25 % that was marginally not suitable for surface irrigation.

c. Soil depth suitability

The soil depth of the study area was ranging from less than 0.30meter to even greater than 1.2 meters. Resulted from the soil depth reclassification class and its suitability map of the study area was developed in Table 4.4 and Figure 4.4 with S1 and N suitability classes.

Table 4. 4:Soil depth and their suitability class

No	Soil Depth	Coverage Ha	Area (%)	Soil depth suitability
1	>120cm	98,494	98.6	S1
2	<30cm	1,401	1.40	N

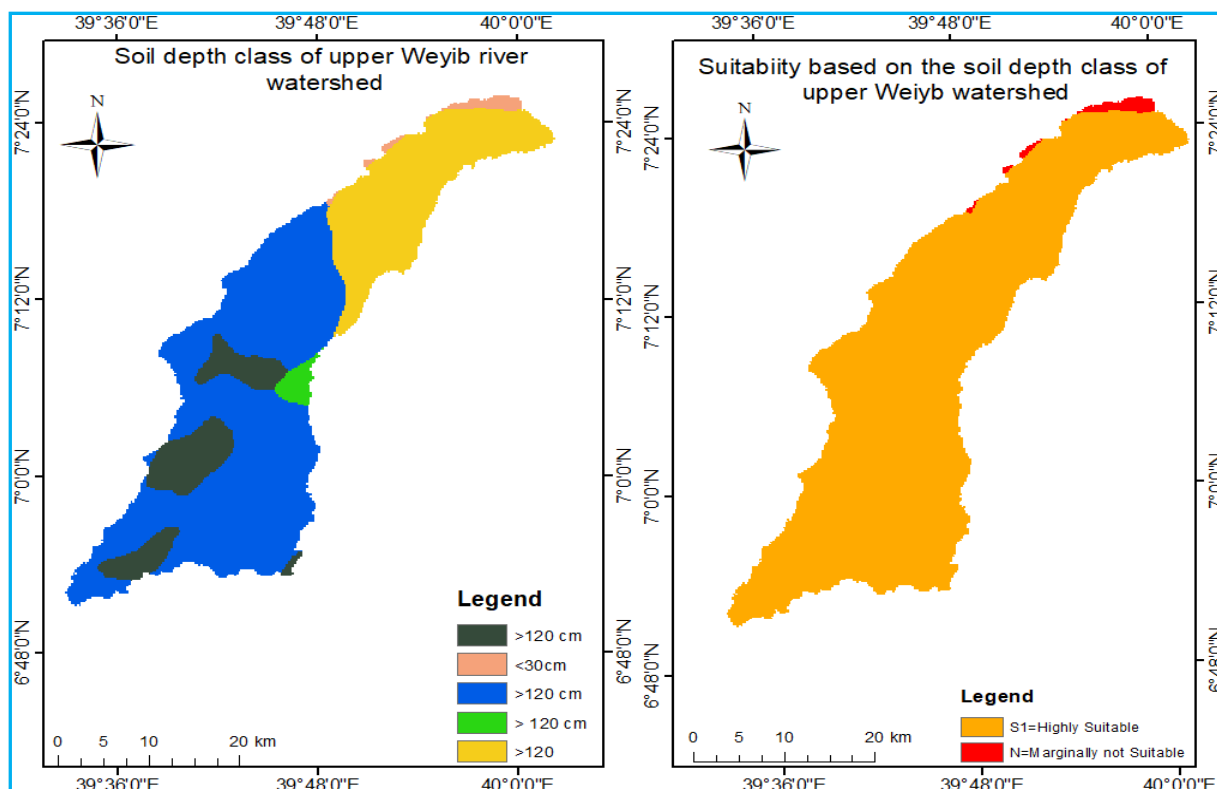


Figure 4. 4:Soil depth class and its suitability map of the study area

Soil having soil depth greater than 1.2m was classified as S1 (highly suitable) for irrigation and covered most of the study area 98,494 ha (about 98.60%) and less than 0.30m was classified as N (Marginally not a suitable class which covers an area of 1401 ha (1.40%). The final evaluation of Soil suitability for irrigation indicating soil texture, depth, and drainage after reclassification is tabulated in Table 4.5.

Table 4. 5: Analysis of soil suitability for irrigation

No	Soil Type	Soil Map Unit	Texture	Depth (cm)	Drainage	Text Suit.	Depth Suit.	Dra Suit.	Soil Suit.	Area ha	Area %
1	Eutric Cambisol	CMe	SCL	>120	P	S2	S1	N	S3	12,242	12.25
2	Lithic leptosol	LPq	CL	<30	W	S2	N	S1	N	1,401	1.40
3	Chromic Luvisol	LVx	L	>120	W	S1	S1	S1	S1	59,340	59.40
4	Haplic Luvisol	LVh	C(light)	>120	I	S1	S1	S3	S2	1,630	1.63
5	Eutric vertisol	VRe	C(light)	>120	W	S1	S1	S1	S1	25,282	25.31

Finally, the soil suitability analysis indicates that the study area could be generally classified into four suitability classes; S1(Highly Suitable), S2 (Moderately suitability), and N (Marginally not suitable) for agricultural crop production through application technology (Table 4.7)

Table 4. 6:Soil suitability reclassification result

No	Suitability Class	Coverage (ha)	Coverage (%)	Soil Type
1	S1 (Highly Suitable)	84,622	84.71	Chromic Luvisol, Eutric vertisol
2	S2 (moderately Highly Suitable)	1,630	1.63	Haplic Luvisol
3	S3(Marginally suitable)	12,242	12.25	Eutric Cambisol
4	N (Marginally not Suitable)	1,401	1.4	Lithic leptosol
Total		99,895	100	

Soil types having soil texture light clay and Loam soil depth greater than 1.2m, and well soil drainage was classified as highly suitable (S1). It covered 84,622ha, (84.71%) of the total area coverage of the watershed. The second suitability class is moderately suitable classes (S2). It covered the area of 1630 ha, (1.63%) in the study area and is comprised of soil type having soil

texture light clay, with a soil depth of greater than 1.2 m and imperfectly soil drainage. These soil types are limited by their imperfect drainage condition while the other factors are optimum for surface irrigation. Soil types having sandy clay loam soil texture, with soil depth greater than 120 cm and poor drainage was classified as S3 (marginally suitable) and it covered 12,242ha (12.25%) of the total area coverage of the study area. They were limited by poor soil drainage (Eutric Cambisol) and the final soil suitability class was marginally not suitable (Lithic leptosol)) they there were limited by shallow soil depth while other factors were optimum for surface irrigation.

In general, the majority of soils of the Upper Weyib river watershed were found to be suitable for surface irrigation. Whereas the limiting factor in most soil types of the study area was limited soil depth condition which required intensive improvement as well as soil and water conservation practices. However, S2 could be transferred to S1 through the drainage improvement practice or by using the most appropriate irrigation methods such as sprinkler and drip irrigation on these soils.

4.1.1.3 Land Use Land Cover Suitability

Land use/cover evaluation from SPOT5 image by supervised classification, seven land use land cover were identified. These classes include Mixed forest, Wetland land, Agricultural land, Built-up area, Shrubland land, Pastureland, and Plantation/wooded land. all land cover/use classes were classified with high accuracy except pasture land which interfered with cultivated and shrublands., of all land cover classifications, the wetland was classified with a high accuracy level. The land cover/use of the study area was classified with an overall accuracy of 90.40% and a Kappa coefficient of 0.86. The Kappa coefficient of 0.86 of the land cover classification in the study area represents a strong agreement according to Rahman et.al (2007).

Table 4. 7:Confusion matrix of SPOT LULC Classification

Classified Data	Forest	Wetland	Agriculture	Builtup	Shrubland	pasture land	plantation	Total
Forest	70	0	0	0	0	0	0	70
Wetland	1	8	0	0	0	0	0	9
Agriculture	0	0	288	1	10	32	3	334
Builtup	0	0	0	8	0	0	0	8
Shrubland	0	0	0	0	74	0	0	74
Pasture land	0	0	5	0	5	78	0	88
Plantation	0	0	0	0	0	0	11	11
Column Total	71	8	293	9	89	110	14	594

Overall accuracay= $537 \times 100 / 594 = 90.40$, Kappa Coefficient= $0.8558 = 0.86$.The supervised image classification result of the study area was described in detail in table 4. 9 below'

Table 4. 8:Area coverage of land cover/use classes of the study area

No	Land Cover	Area (ha)	Area (%)
1	Agriculture	47304.29	47.40
2	Built up	712.68	0.71
3	Mixeg high Forest	8967.64	8.99
4	Grassland open	12973.80	13.00
5	Woodland open	2448.01	2.45
6	Wooded shrubland	12829.17	12.85
7	Wetland	1336.69	1.34
8	Park	13229.83	13.26

The land-use type was reclassified into four suitability classes, highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and marginally not suitable (N) (Figure 4.5) and Table4.10).

Table 4. 9:Land use/cover suitability reclassification results

No	Coverage (ha)	Coverage (%)	Land use/Cover	Suitability
1	61071.52	61.20	Agriculture/grassland-open	S1
2	2388.34	2.39	Woodland-open	S2
3	12106.71	12.13	Forest open	S3
4	10994.38	11.02	Mixed high Forest/Wetland/Builtup	N
5	13229.83	13.26	park	
Total		100		

Land use/cover classes of cultivated and open grassland were classified as highly suitable for irrigation with the assumption that these land cover classes could be irrigated without or with the limited cost for land clearing and farm preparation. It covered 61.20% of the study area. According to the agricultural practice, a commonly grown woodland open area was classified as the second suitable area next to cultivation. On the land use/cover suitability classification Forest open were classified as lands marginally suitable for irrigation. This is due to their work efficiency, the cost for land clearing, and land preparation for irrigation, whereas mixed high forest, the built-up area, and wetland were classified as lands not suitable for irrigation. Those land cover classes were 11.02 % of the total land cover of the study area they are restricted to use for irrigation

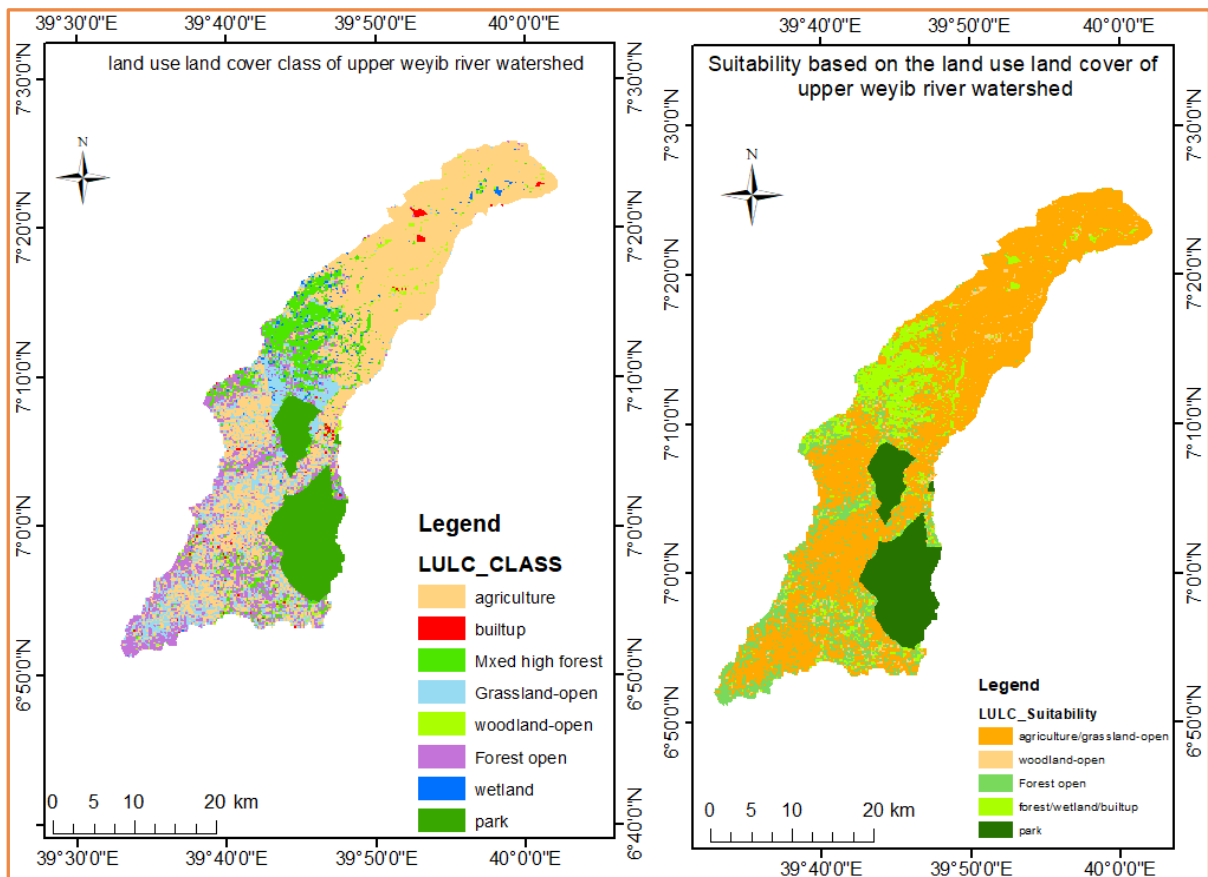


Figure 4. 5: Land use/cover map of the study area and its suitability map

4.1.1.4 Proximity to Water

Irrigated areas should be located as close as possible to rivers (putting into consideration a buffer zone for the protection of water resources. Based on the main factors that were considered in distance suitability classification were; power and capacity of the pumping engine, the cost for the high-power pumping engines, and cost for construction and maintenance of canals and water lost from canal especially for small scale and medium scale irrigation, the command area was reclassified into four equal suitability class; S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable) and N (not suitable). Because of these factors' irrigation suitability is decreased as distance increase away from the water source river.

To identify irrigable land close to the water supply (rivers), straight-line (Euclidean) distance from watershed main river points was calculated. Spatial proximities to water sources were computed using the spatial overlay of respective GIS layers. Influences of distance parameters

on agricultural land suitability, Table 4.11, were estimated using the clipped feature class was converted to raster using the conversion tool and reclassified into suitability class based on its distance to the water source used “Reclassified tool “and shown in Figure 4.6. Then, the reclassified distance was used for weighted overlay analysis together with other factors.

Table 4. 10: Proximity to water suitable for surface irrigation.

Proximity to water (km)	Area coverage		Proximity suitability
	ha	%	
0-2.28	61955.29	62.11	S1
2.28-4.56	28989.85	29.06	S2
4.56-6.84	7875.74	7.89	S3
6.64-9.12	936.42	0.94	N

The result of proximity to water suitable for surface irrigation revealed that about 62.11 %, 29.06%, 7.89 %, and 0.94 % area of the study was covered by highly suitable, moderately, marginally suitable, and not suitable respectively. The closeness to water suitable for surface irrigation suitability map of the watershed is shown in Figure 4.6.

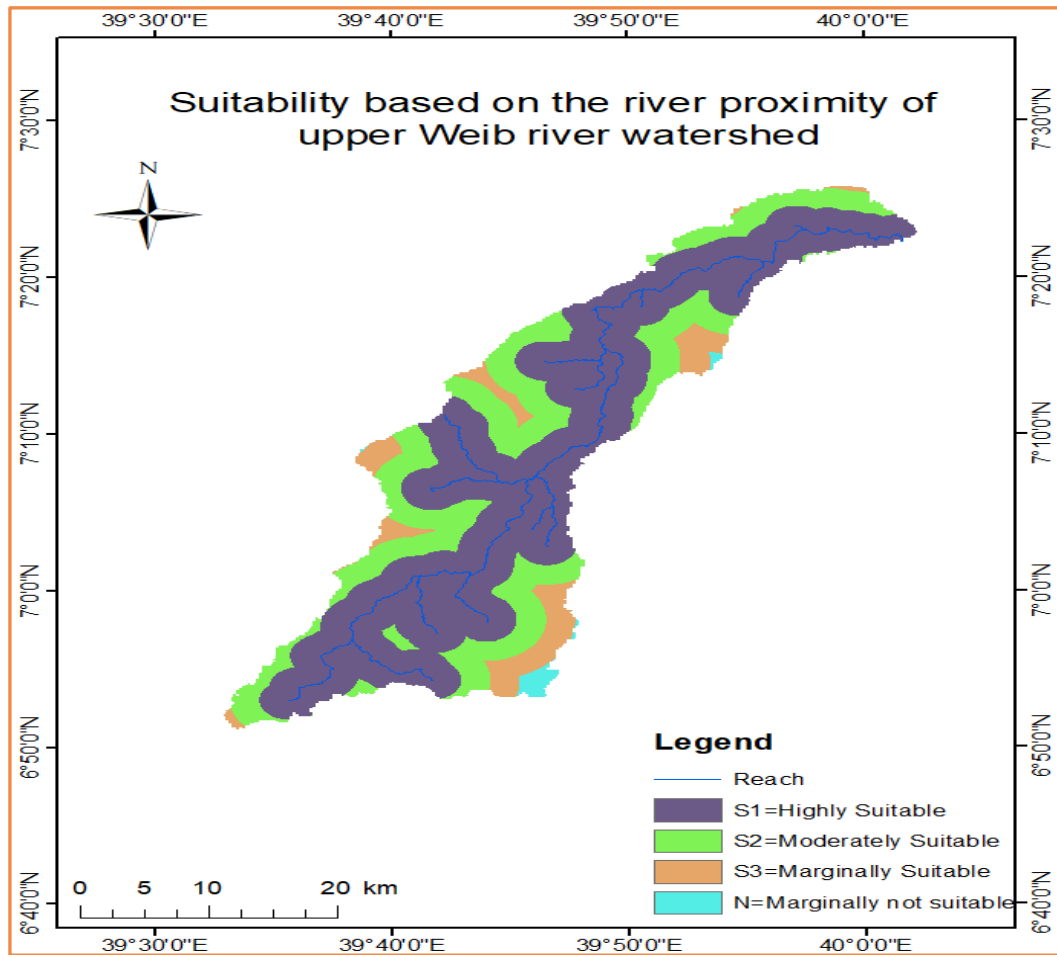


Figure 4. 6: Proximity to water and its suitability map of Upper Weyib River watershed

4.1.1.5 Assessing Weights Using AHP for Irrigation Suitability Mapping

Not all selecting factors are equally important for suitability analysis. Comparisons are needed to identify the importance of each factor with the others. For instance, how much is the effect of slope important relative to soil depth or other factors on land suitability? Hence, in this case, a comparison is among factors. The pairwise comparison matrix and overall weights of the factors selected for the study are shown in Table 4.11 and were constructed first. The six factors are listed in the six columns and rows. The row factors were compared with the factors in the columns or their significance to irrigation, and then using scoring of Saaty (1980) Table 3.6, the pairwise comparison matrix Table 4.11 was prepared. These for example, in Tale 4.11 the “slope” factor is far more important for determining the suitability of land than the factor “land use” in the column. Conversely, “land use” in the row of Table 4.11 is far less important than

the slope in the column. Assigning of factors was made based on studies in the Upper Weyib river watershed and surface irrigation suitability factors.

The results in Table 4.11 show that the factor “slope” is the most important factor since its values are greater than 1 in its row followed by “river proximity” and “soil depth”. The weights of each calculated by using pairwise techniques are listed in Table 4.13 were, the greater the value the more important the factor. In this land suitability analysis, the consistency ratio (CR) is 0.028 which indicates that the comparisons of land characteristics were consistent and that the relative weights were appropriately chosen.

Table 4. 11: Pairwise comparison matrix based on the selected criteria’s for surface irrigation suitability.

Factors	Soil depth	Soil texture	Soil drainage	Land use	Slope	River proximity
Soil depth	1	2	2	7	1/2	1/2
Soil texture	1/2	1	1	3	1/3	1/2
Soil drainage	1/2	1	1	3	1/3	1/3
Land use	1/7	1/3	1/3	1	1/7	1/7
Slope	2	3	3	7	1	3
River prox.	2	2	3	7	1/3	1
	6.1429	9.3333	10.3333	28.0000	2.6429	5.4762

Normalize the matrix

Normalizing the matrix means add the columns of the matrix and then divide each element in every column by the sum of that column.

Table 4. 12: Normalized criteria comparison matrix

Factors	Soil depth	Soil texture	Soil drainage	Land use	Slope	River prox.	Criteria Weight
Soil depth	0.1628	0.2143	0.1935	0.2500	0.189 2	0.091 3	0.1835
Soil texture	0.0814	0.1071	0.0968	0.1071	0.126 1	0.091 3	0.1016
Soil drainage	0.0814	0.1071	0.0968	0.1071	0.126 1	0.060 9	0.0966
Land use	0.0233	0.0357	0.0323	0.0357	0.054 1	0.026 1	0.0345
Slope	0.3256	0.3214	0.2903	0.2500	0.378 4	0.547 8	0.3523
River prox.	0.3256	0.2143	0.2903	0.2500	0.126 1	0.182 6	0.2315
sum	1	1	1	1	1	1	

To get the weight of factors average each row in the normalized matrix and the weight percentage was calculated by the average of each row by 100. Potential irrigable areas by the intended irrigation method were obtained using the irrigation suitability analysis model developed on Arc GIS. The suitability model involved weighting of values of data sets such as soil, slope, land use land cover, and proximity from the water source. Rasterized and reclassified suitability maps of each parameter were used as input for the overlay analysis tool. As elaborated below in Table 4.13 overall suitable areas for surface irrigation development in the Watershed were identified with their area coverage.

Table 4. 13: Weighting factors

Factors	Criteria Weight	Criteria Weight (%)
Soil depth	0.1835	18
Soil texture	0.1016	10
Soil drainage	0.0966	10
Land use	0.0345	4
slope	0.3523	35
River prox.	0.2315	23
λ_{max}	6.18	
CR	0.028	

Finally, the potentially irrigable land was identified based on the specified suitable criteria by creating irrigation suitability model analysis which involved weighting of values of all data sets

such as soil texture, drainage, depth, slope, land use/cover, and distance from the water supply. The final result of this suitability analysis was identified as shown in Table 4.14. From the total area coverage of the study area 14.90% (14800.10ha) was classified as high suitable (S1), 55.08% (54715.74ha) moderately suitable (S2), 5.62% (5581.15ha) marginally suitable (S3), whereas 11.09% (11017.02ha) not suitable (N) for surface irrigation development (Figure 4.7) which accounted as irrigation restriction area (Built-up area, forest, wetland, and Bale Mountains National Park).

Table 4. 14:Final Suitable land for surface irrigation

S. No.	Coverage (ha)	Coverage (%)	Suitability Class
1	14800.10	14.90	S1 (Highly Suitable)
2	54715.74	55.08	S2 (Moderately Suitable)
3	5581.15	5.62	S3 (Marginally Suitable)
4	11017.02	11.09	N (Marginally Not Suitable)
5	13229.83	13.26	BMNP (irrigation constraint area)

Bale Mountain National Park (BMNP) is located at the upper part of the study area which was covered 13229.83ha of land area. This area was not suitable totally for surface irrigation because such area was restricted for irrigation developmental purposes.

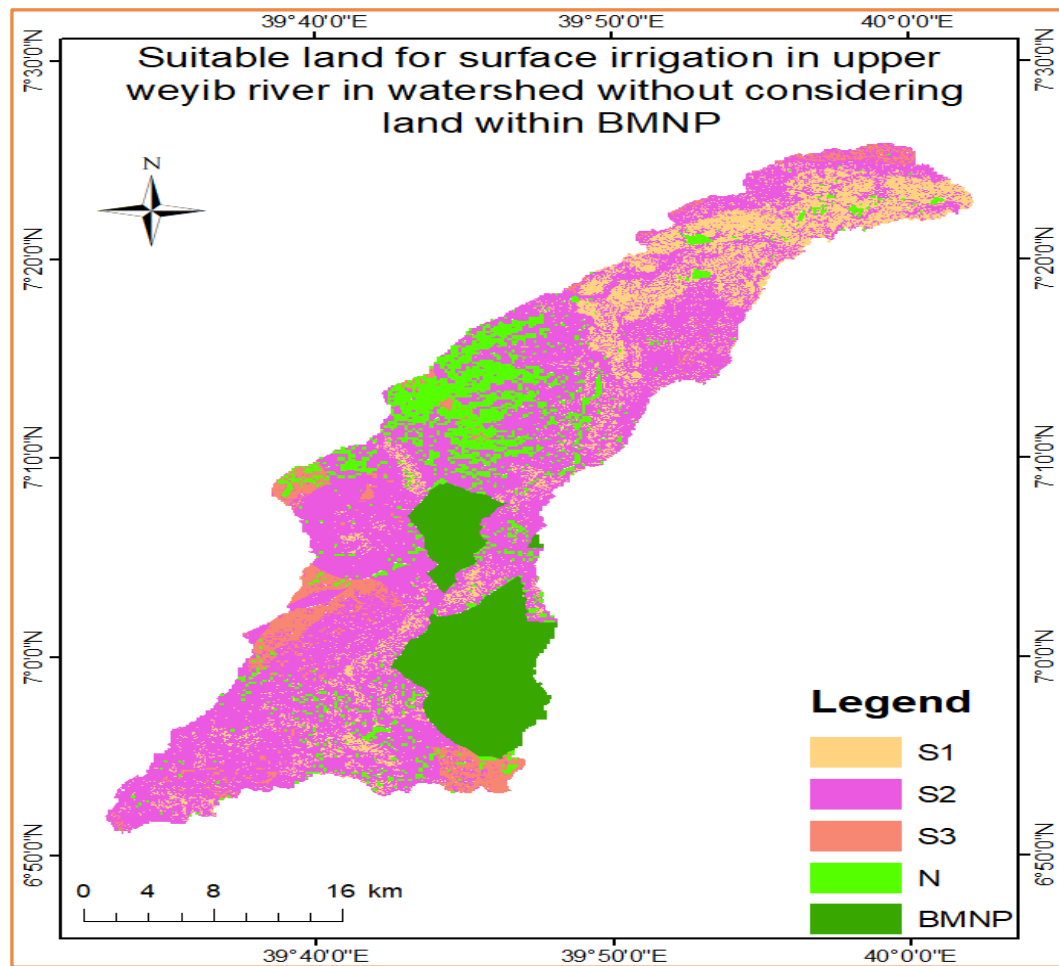


Figure 4. 7: Irrigation land suitability map of the study area

Table 4. 15: Overall highly suitable land for surface irrigation in sub-watershed level.

Sub-watershed	Suitability class	Suitability rate	Area(ha)
Sub-watershed 1	Highly suitable	S1	1833.99
Sub-watershed 2	Highly suitable	S1	2750.40
Sub-watershed 3	Highly suitable	S1	5401.99
Sub-watershed 4	Highly suitable	S1	1075.35
Sub-watershed 5	Highly suitable	S1	1714.48
Sub-watershed 6	Highly suitable	S1	2023.92

4.2 Water Availability Assessment

Watershed delineation:

The watershed delineation showed that there were six sub-watersheds in the study area. Sub watershed 5 and sub watershed 6 are the major ones. The others such as sub-watershed 1, sub watershed 2, sub watershed 3, and sub watershed 4 are sub-watersheds of the upper weyib river watershed each covering area of 4283.99 ha, 6090.06ha, 17624.92 ha,15976.39,34122 ha, and 21797.20ha, respectively. Figure 4. 8 below show the sub-watershed of the upper Weyib river watershed.

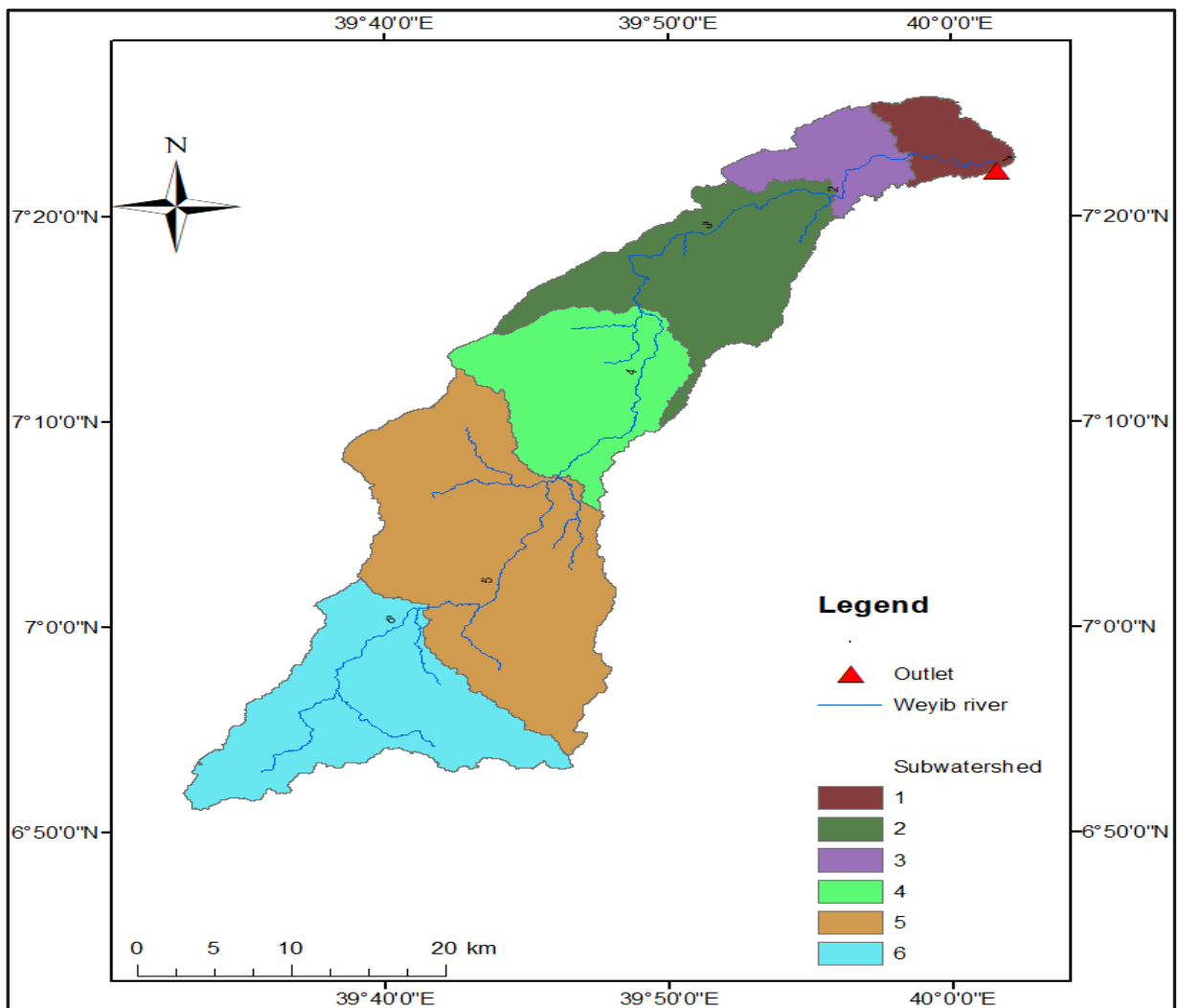


Figure 4. 8:Upper Weyib river sub watershed

4.2.1 Stream Flow Sensitivity Analysis

Sensitivity analysis was carried out to identify which model parameter is most significant or sensitive. Flow sensitivity analysis was carried out for a period of 28 years, which includes two years of warm-up period (from January 1, 1987, to December 31, 1988). About 350, simulations have been done by SWAT sensitivity analysis at the watershed of sub-watershed no 1. Where the outlet of the watershed found in flow calibration with the output of 14 parameters was reported as sensitive in different degrees of sensitivity for flow. Among these 14 parameters, most of the parameters were grouped under a high sensitivity to medium sensitivity range.

T_stat provides a measure of sensitivity (large in absolute values are more sensitive) to the model whereas the P_values determined the significance of sensitivity. When the value of P close to zero indicates a higher significance. According to (Shiferaw E. 2014) the degrees of sensitivity were ranged from $0 < \text{mean relative sensitivity} < 0.05$ means small; $0.05 < \text{mean} < 0.6$ means medium; $0.6 < \text{mean} < 1$ means High and $\text{mean} \geq 1$ means very high.

The most sensitive parameters have an effect when changed ranging from high to small and will be used for flow calibration. The result of SWAT sensitivity analysis revealed that 14 parameters are sensitive to the swat model among 27 hydrological sensitivity parameters and the most sensitive parameters were identified in the rank order at (Table 4.16) in the hydrological process of the watershed. The next table indicates the best-fitted values of the model parameters that occurred from the SWAT CUP sensitivity analysis of the output.

Table 4. 16:Result of sensitive analysis of model parameters in Upper Weyib Watershed

No	Parameter Name	Description	T_stat value	P_value	Sensitivity
1	ALPHA_BF	Base flow alpha factor(days)	-13.67	0.00	1
i2	SOL_AWC	Available water capacity of the soil layers	5.432	0.00	2
3	GW_Delay	Ground water delay in(days)	3.776	0.0002	3
4	CN2	SCS_CN for moisture condition II	-2.98	0.0031	4
5	GW_REVAP	Ground water evaporation coefficient (unitless)	2.06	0.041	5
6	OV_N	Manning's "n" value for overland flow.	-1.275	0.203	6
7	GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur(mm)	1.035	0.301	7
8	SLSUBBSN	Average slope length	-1.007	0.315	8
9	REVAPMN	Threshold depth of water in the shallow aquifer required for evaporation to occur(mm)	-0.789	0.430	9
10	ESCO	Soil evaporation composition factors (unitless)	-0.778	0.437	10
11	CH_N2	Manning's "n" value for the main channel	0.609	0.543	11
12	CH_K2	Effective channel hydraulic conductivity(mm/H)	-0.482	0.630	12
13	SOL_BD	Moist bulk density	0.236	0.813	13
14	CANMAX	Maximum canopy storage	0.228	0.820	14

4.2.2 Model Calibration and Validation

Flow calibration was done for 19 years (from January 1, 1987, to December 31, 2005) which includes two years for model initialization (warm-up). Therefore, the model performance in calibration was considered from 1989 to 2005. This period was chosen because of its continuous time series data with less missed data. While conducting calibration auto-calibration was done. Auto -calibration allows the model to change the parameters until both observed and simulated flow data will be in the acceptable range automatically. After each simulation, the model

goodness-of-fit was evaluated and the model performance after adjusting all the parameters R², NSE, and PBIAS were presented in Table 4.17. Since the acceptable ranges of parameters R², NSE, and Pbias are R² > 0.6, NSE > 0.5, and Pbias ±25% respectively (Santhi et al., 2001). Therefore, it is confirmed that all the values obtained are in the acceptable range and the legend in the graph represents the observed and best estimations or simulated values. The calibration period of the observed and simulated flows is shown in Figure 4.9, the model mostly overestimated and underestimated for some part of the year in a calibration period

Table 4. 17: R², ENS, and Pbias values both for calibration and validation

Model performance measure parameter	Calibration Values (1989-2005)	Validation Values (2006-2014)
R ²	0.81	0.77
ENS	0.77	0.76
Pbias	16.5	-1.4

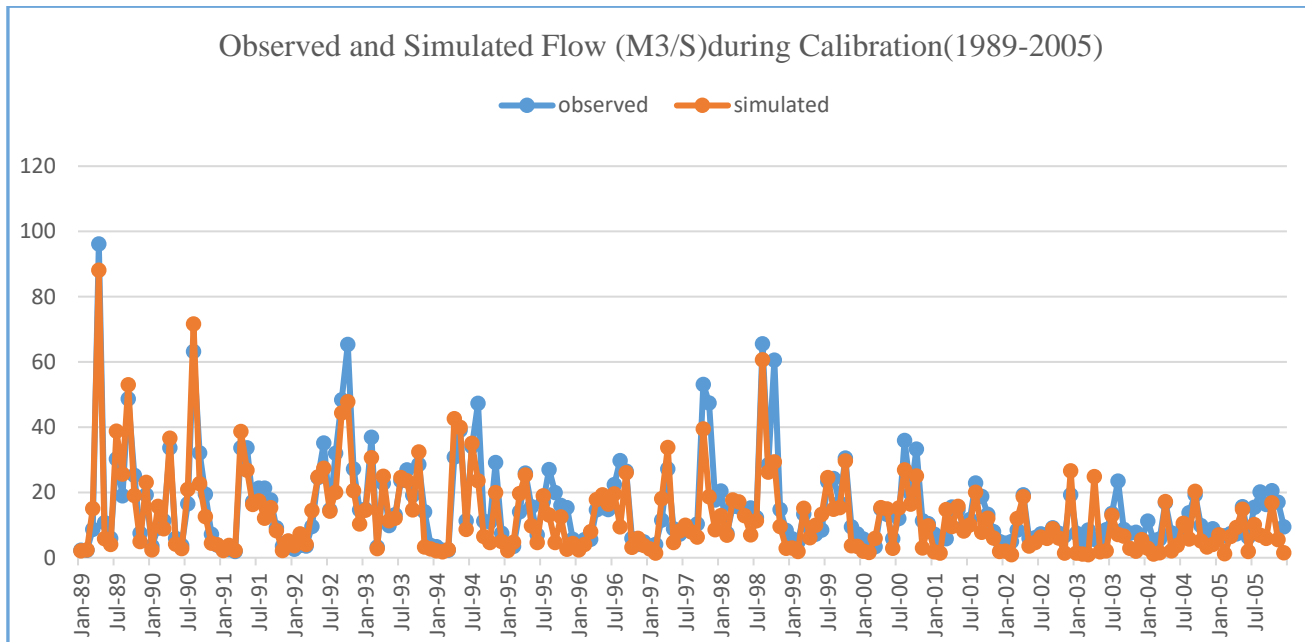


Figure 4. 9:Observed and simulated flow for the calibration period (m3 /s)

Flow validation of the model for the watershed was carried out from January 1, 2006, to December 31, 2014, without further adjustment of the parameters. The objective functions that

were used for evaluation like the coefficient of determination, Nash Sutcliff efficiency, and Pbias were in the acceptable range for the validation time of the model in the monthly time step and the R2, NSE, and Pbias indicates in Table 4.18.

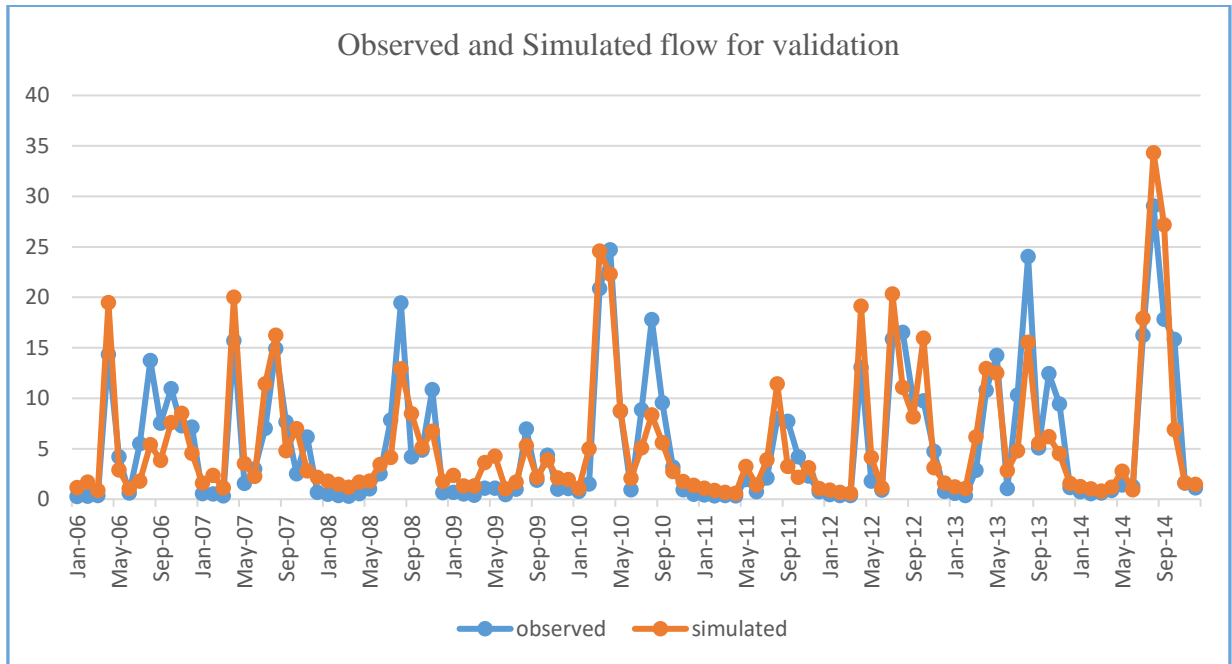


Figure 4. 10: Observed and simulated monthly flow for the validation period (2006-2014)

The validation period of the observed and simulated flow in monthly estimation was underestimated in some of the years in January to February 2014 only. Whereas, the model shows mostly overestimated on April, July, August, and October of the year 2006, 2007, 2012, and 2014.

Table 4. 18:SWAT’s most sensitive streamflow Parameters, final calibrated fitted values, and variation methods (imet) used for analysis.

Parameter	Sensitivity Rank	Default Lower and Upper Bounds	Calibrated Value	Imet
ALPHA_BF: -Base flow alpha-factor(days)	1	-0.03 to 0.35	-0.02	V
SOL_AWC: -Available water capacity of the soil layers	2	-0.90 to 0.5	-0.78	R
GW_Delay: -Groundwater delay in(days)	3	0 to 31	13.77	V
CN2: -SCS_CN for moisture condition II	4	± 0.25	0.08	R
GW_REVAP: -Groundwater evaporation coefficient (unitless)	5	0.02 to 0.20	0.12	R
OV_N: -Manning's "n" value for overland flow.	6	0.01 to 0.09	0.07	V
GWQMN: -Threshold depth of water in the shallow aquifer required for return flow to occur(mm)	7	0.03 to 0.30	0.26	V
SLSUBBSN: -Average slope length	8	0.0 to 150	95.78	R
REVAPMN: -Threshold depth of water in the shallow aquifer required for evaporation to occur(mm)	9	0.0 to 500	406.43	R
ESCO: -Soil evaporation composition factors (unitless)	10	0.50 to 0.60	0.55	R
CH_N2: -Manning's "n" value for the main channel	11	0.0 to 1.0	0.46	R
CH_K2: -Effective channel hydraulic conductivity(mm/H)	12	0.0 to 130	10.58	R
SOL_BD: -Moist bulk density	13	0.90 to 2.2	1.58	R
CANMAX: -Maximum canopy storage	14	0.0 to 100	0.71	R

After successful sensitive analysis, calibration, and validation Water availability assessment was analyzed from the simulated value of streamflow, implementing through the Arc SWAT model in each sub-watershed. The water availability assessment is understanding the potential of irrigation water supply in each sub-watershed obtained from the SWAT simulated outputs and comparing it with the irrigation water demand for dominant crops of the watershed. Water yield simulation results for the period (1989–2014) for the gauged Watershed river showed that the average annual water flow of sub-watershed 2 was the highest, followed by sub-watershed 1 and sub-watershed 3. The average annual water yield of sub-watershed 5 was very small and followed sub-watershed 4. The mean monthly predicted water yield during the dry period phase

(November to March), important to irrigate the selected crops, followed the same trend as the annual water yield (Table 4.19).

Table 4. 19:Minimum Monthly simulated flow (m3/s).

Month	subwat1	Subwat2	Subwat3	Subwat4	Subwat5	Subwat6
Jan	0.70	2.90	1.00	2.63	5.61	2.70
Feb	0.57	2.36	0.81	2.14	4.56	2.14
March	0.57	2.34	0.81	2.12	4.52	1.95
April	1.30	5.36	1.85	4.86	10.38	4.50
May	1.22	5.00	1.73	4.54	9.69	4.02
June	1.07	4.42	1.53	4.01	8.56	3.66
July	1.40	5.76	1.99	5.22	11.16	5.00
Aug	1.80	7.42	2.56	6.73	14.37	5.99
Sept	1.81	7.45	2.57	6.75	14.42	6.03
Octo	1.89	7.77	2.69	7.04	15.04	6.33
Nov	1.38	5.67	1.96	5.14	10.98	4.75
Dec	1.06	4.34	1.50	3.93	8.40	3.79

4.3 Irrigation water demand

To evaluate the surface irrigation potential of the watershed knowing of the water demand by selected crops are essential. Determination of irrigation water requirement of the four selected crops (barley, wheat, potato, and pepper) in terms of water availability in the potential irrigable lands Robe climatic station was selected to calculate irrigation water requirement of the identified irrigable area, because of having complete climatic records and can represent the whole area of the Watershed. Within the study area, different crops have different crop water requirements. From the selected crops such as, barley, wheat, potato, and pepper potato has needed the highest crop water demand which recorded 330.2mm/growing period and Wheat has the minimum water requirement was evaluated 253.8mm/growing period Table 4.20.

Table 4. 20:Monthly crop water demand of selected crops in mm at dry periods

Months	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
Types of crops													
Wheat	0	9.7	72.4	114.8	56.9	0	0	0	0	0	0	0	253.8
Potato	12.5	81.6	116.8	102	17.3	0	0	0	0	0	0	0	330.2
Barley	0	26.8	112.5	114.8	32.4	0	0	0	0	0	0	0	286.5
Pepper	19.4	66.3	104.5	98.5	10.9	0	0	0	0	0	0	0	299.6

Gross irrigation water requirement of wheat, Potato, Barley, and Pepper at the identified potential irrigable site covers 55%,23%,15%, and 7% of the highly suitable total irrigable area respectively under surface irrigation methods were estimated using climatic data for CROPWAT 8.0 model which are presented in Appendix Table 7.8,7.9,7.10 and 7.11. The following Table 4.21 presents monthly gross irrigation water requirements of the dominant crops of Wheat, Potato, Barley, and Pepper. These results give a general overview of monthly water demands for four crops of the full growth stage of Wheat, Potato, Barley, and Peppers that should be abstracted from the sub-watershed during the local cropping period. Tables 4.21 gross irrigation requirement of dominant crops(m³/s).

Table 4. 21:Gross irrigation requirement of dominant crops(m3/s)

sub-watershed	Area (ha)	Crop types	Months											
			Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Sub-watershed 1	1833.99	Wheat		0.08	0.58	0.92	0.46	0.00						
		Potato	0.03	0.18	0.25	0.22	0.04							
		Barley		0.09	0.37	0.37	0.12							
		pepper	0.02	0.07	0.11	0.10	0.01							
		Total	0.05	0.41	1.31	1.62	0.63	0.00						
Sub-watershed 2	2750.4	Wheat		0.12	0.87	1.38	0.69	0.00						
		Potato	0.26	1.77	2.54	2.23	0.39							
		Barley		0.13	0.55	0.56	0.18							
		pepper	0.03	0.10	0.16	0.15	0.02							
		Total	0.29	2.12	4.13	4.32	1.28	0.00						
Sub-watershed 3	5401.99	Wheat		0.24	1.72	2.71	1.36	0.00						
		Potato	0.08	0.52	0.75	0.66	0.12							
		Barley		0.26	1.08	1.10	0.35							
		pepper	0.06	0.20	0.32	0.30	0.03							
		Total	0.13	1.22	3.86	4.76	1.86	0.00						
Sub-watershed 4	1075.35	Wheat		0.05	0.38	0.60	0.30	0.00						
		Potato	0.02	0.10	0.15	0.13	0.02							
		Barley		0.05	0.21	0.22	0.07							
		pepper	0.01	0.04	0.06	0.06	0.01							
		Total	0.03	0.25	0.81	1.01	0.40	0.00						
Sub-watershed 5	1714.48	Wheat		0.08	0.54	0.86	0.43	0.00						
		Potato	0.02	0.17	0.24	0.21	0.04							
		Barley		0.08	0.34	0.35	0.11							
		pepper	0.02	0.06	0.10	0.09	0.01							
		Total	0.04	0.39	1.23	1.51	0.59	0.00						
Sub-watershed 6	2023.92	Wheat		0.09	0.64	1.02	0.51	0.00						
		Potato	0.03	0.20	0.28	0.25	0.04							
		Barley		0.10	0.40	0.41	0.13							
		pepper	0.02	0.07	0.12	0.11	0.01							
		Total	0.05	0.46	1.45	1.79	0.70	0.00						

Table 4. 22:Comparing of crop demands and available flows for Dominant crops

Sun watershed	Area (ha)	Flow\$GIR(m3/s)		Months												
				Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
Sub-watershed 1	1833.99	Available flow		1.38	1.06	0.7	0.57	0.57	1.3	1.22	1.07	1.4	1.8	1.81	1.89	
		GIR m3/s	Wheat		0.08	0.58	0.92	0.46	0.00							
			Potato	0.03	0.18	0.25	0.22	0.04								
			Barley		0.09	0.37	0.37	0.12								
			Pepper	0.02	0.07	0.11	0.10	0.01								
		Total	0.05	0.41	1.31	1.62	0.63	0.00								
Available flow		5.67	4.34	2.9	2.36	2.34	5.36	5	4.42	5.76	7.42	7.45	7.77			
Sub-watershed 2	2750.4	GIR m3/s	Wheat		0.12	0.87	1.38	0.69	0.00							
			Potato	0.26	1.77	2.54	2.23	0.39								
			Barley		0.13	0.55	0.56	0.18								
			Pepper	0.03	0.10	0.16	0.15	0.02								
		Total	0.29	2.12	4.13	4.32	1.28	0.00								
		Available flow		1.96	1.5	1	0.81	0.81	1.85	1.73	1.53	1.99	2.56	2.57	2.69	
Sub-watershed 3	5401.99	GIR m3/s	Wheat		0.24	1.72	2.71	1.36	0.00							
			Potato	0.08	0.52	0.75	0.66	0.12								
			Barley		0.26	1.08	1.10	0.35								
			pepper	0.06	0.20	0.32	0.30	0.03								
		Total	0.13	1.22	3.86	4.76	1.86	0.00								
		Available flow		5.14	3.93	2.63	2.14	2.12	4.86	4.54	4.01	5.22	6.73	6.75	7.04	
Sub-watershed 4	1075.35	GIR m3/s	Wheat		0.05	0.38	0.60	0.30	0.00							
			Potato	0.02	0.10	0.15	0.13	0.02								
			Barley		0.05	0.21	0.22	0.07								
			pepper	0.01	0.04	0.06	0.06	0.01								
		Total	0.03	0.25	0.81	1.01	0.40	0.00								
		Available flow		10.98	8.4	5.61	4.56	4.52	10.38	9.69	8.56	11.16	14.37	14.42	15.04	
Sub-watershed 5	1714.48	GIR m3/s	Wheat		0.08	0.54	0.86	0.43	0.00							
			Potato	0.02	0.17	0.24	0.21	0.04								
			Barley		0.08	0.34	0.35	0.11								
			pepper	0.02	0.06	0.10	0.09	0.01								
		Total	0.04	0.39	1.23	1.51	0.59	0.00								
		Available flow		4.75	3.79	2.7	2.14	1.95	4.5	4.02	3.66	5	5.99	6.03	6.33	
Sub-watershed 6	2023.92		Wheat		0.09	0.64	1.02	0.51	0.00							
			Potato	0.03	0.20	0.28	0.25	0.04								
			Barley		0.10	0.40	0.41	0.13								
			pepper	0.02	0.07	0.12	0.11	0.01								
		Total	0.05	0.46	1.45	1.79	0.70	0.00								

4.4 Irrigation potential

The irrigation potential of the river watershed in the study area was obtained by comparing irrigation requirements of the identified land suitable for surface irrigation and the available mean monthly flows in the river watershed based on the method suggested by FAO (1997). Tables 4.22 present the gross irrigation demand of the four crops commonly grown in the study area (Wheat, Potato, Barley, and Pepper and the available mean monthly flows of the corresponding river watershed. Results of these analyses revealed that monthly irrigation requirements of the four crops are less than the available minimum monthly water yield at each sub-watershed while the minimum monthly flows of rivers are slightly greater than the irrigation water requirements of the four crops at their corresponding command area. But in sub-watersheds 1, the irrigation water demand of the crop is more than the available flow in January and February. Similarly, the irrigation water demand of the four crops in sub-watershed 3 exceeds the available flow in January, February, and March. As a result, the critical command areas were calculated according to (Micheal, 2008) to grow these crops. From Table 4.22 the minimum available flow in February in sub-watershed 1 is 0.57 m³/s whereas the water requirement of the four crops in February is 0.46 l/s/ha (0.00046m³/s /ha) giving a critical command area (that can be reliably irrigated using the available flows in sub-watershed river) of 1239 ha.

Similarly, the critical command area for sub-watershed 3 was found at 1761ha. As a result, the irrigation potential of subwatershed 1 and sub-watersheds 3 are 1239 ha and 1761ha, respectively. However, for the other watersheds, since their minimum monthly flows are greater than the irrigation water demand of the four crops, the identified potential irrigable area was taken as their irrigation potential (IFAD, 1987; MoWR, 2002). Therefore, the irrigation potential of the river watershed in the study area is obtained and ranked (Table 4.23).

Table 4. 23:Summary of irrigation potential of the river watershed and their ranking for development possibilities.

Subwatershed	Irrigation potential (ha)	Rank
subwatershed 1	1239	5
subwatershed 2	2750.4	1
subwatershed 3	1761	3
subwatershed 4	1075.35	6
sub watershed 5	1714.48	4
Sub watershed 6	2023.92	2

Therefore, the total irrigation potential of the Upper Weyib river watershed (the study area) is found to be 10564.15 which accounts for 10.58% of the total land area of the study area.

5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The assessment of Surface Irrigation Potential study was conducted for the upper Weyib River watershed Genale Dawa Basin which is located in the Bale Zone of Oromia regional state. Watershed delineation, identification of potentially irrigable land, and estimation of irrigation water demand and surface water availability of river watershed were the steps followed to evaluate this irrigation potential. The total area coverage of the watershed obtained through watershed delineation is 99,895 ha. It had been carried out to evaluate and estimate suitable irrigable land and irrigation potential of the upper Weyib River in the study area and develop a final land suitability map.

- ✚ After effective model calibration and validation, minimum monthly water yield at each reach above sub-watershed which important for crop production during the dry period was assessed, the result of monthly water yield at each subwatershed was presented in Table 4.20.
- ✚ The main irrigation suitability factors undertaken during the study were based on the physical factor such as slope, soil texture, soil drainage, soil depth, land use/land cover and distance from the water sources indicates, 41.62% of slope, 98.6% of soil depth, 92.83% distance from the water source of the study area, 87.71% soil drainages and 100% of soil texture were identified in the range of highly suitable(S1) to marginal suitable(S3) for surface irrigation development. but, when all the above physical suitable area determination factors were weighted together using weighted overlay in ArcGIS 10.3 software: 14.90% highly suitable(S1), 55.08% moderately suitable(S2), 5.62 % marginally suitable(S3), and 11.09 % non-suitable(N) and 13.32% of LULC was covered by Bale Mountain National Park located at the upper part of the watershed where this area not suitable for surface irrigation because such area was restricted for agricultural development purposes. In general, 75.72% of the land is highly suitable to marginally suitable whereas 24.38% were restricted from irrigation development.
- ✚ The Irrigation water demand of the four major crops which are grown in the study area through the growing season was found to be 1170.1mm.

- ✚ The total irrigation potential of the Upper Weyib river watershed (the study area) is found to be 10564.15 ha which accounts for 10.58 % of the total land area of the study area
- ✚ Results of analyses revealed that monthly irrigation water demand at the dry periods for the four crops are less than the available minimum monthly water yields at each sub-watershed except at the dry month of January, February, and March at the sub-watershed and January and February, at subwatershed 3.

5.2 Recommendations

Generally, based on the conclusion of the study, the following recommendations were made:

- ✚ Irrigation suitability constraints such as water quality, environmental, economic, and social terms should be assessed in addition to those parameters (slope, soil, land use/cover, and distance from a water source) included in this study to evaluate land suitability for irrigation.
- ✚ The analysis shows that the available water supply (streamflow) was less than irrigation water demand. So, constructions of different storage structures are recommended increasing surface irrigation potential.
- ✚ The land-use policy must take account of land suitability with the expected future needs and the possibility of meeting demands. The critical importance of land for specified uses should be known as either physical or economic suitability.
- ✚ Surface irrigation potential analysis result shows that only 10564.15 ha of the study the area was suitable for surface irrigation. Further research is recommended to increase irrigable land by considering other irrigation methods.

REFERENCES

- Abraham, G. (2015). Irrigation Potential Assessment. *MSc thesis. Arba Minch University, Ethiopia*, P 50-68.
- Arnold, J.G., R. Srinivasan, R. R. Muttiah, and J. R. Williams. (1998). Large area hydrologic modeling, and assessment part I: model development. *J. Am. Water Resource. Assoc.* 34 (1), 73-89.
- Arnold, J.G.; Srinivasan, R.; Muttiah, R.S.; Williams, J.R. (1998). Large Area Hydrologic Modeling and Assessment Part I Model Development. *Wiley Online Library: Hoboken, NJ, USA*.
- Asawa, G. (2008). Irrigation and Water Resources Engineering 1st edition, new age international publishers. *New Delhi, India*.
- Awotwi A. (2009.). Detection of land use and Land Cover Change in Accra, Ghana, between 1985 and 2003 using Land sat Imagery. Masterís of Science Thesis in Geoinformatics. Division of Geoinformatics. *Royal Institute of Technology (KTH) Stockholm, Sweden*.
- Awulachew Seleshi Bekele, Teklu Erkossa and Regassa E. Namara, editors. (2010). Irrigation potential in Ethiopia Constraints and opportunities for enhancing the system. *IWMI (International Water Management Institute)*.
- Belete, B. (2006). across systems, comparative assessment of Hare Community managed irrigation schemes performance. *MSc thesis, Arba Minch University*.
- Bhunya, P.K.; Jain, S.; Singh, P.; Mishra, S. (2010). A simple conceptual model of sediment yield. *Water Res. Manag* 24, 1697–1716. [CrossRef].
- Campbell, J. (1984). Introductory Cartography. *Englewood Cliffs, NJ: Prentice_Hall*.
- Chow VT, Maidment DR, Mays LW. (1988). Applied Hydrology. McGraw-Hill: New York 572p.
- CSA (Central Statistical Agency of Ethiopia). (2016). Statistical Abstract of Ethiopia. *Central Statistical Agency, Addis Addis Ababa: Ethiopia*.

- Cunderlik. (2003). Hydrologic Models for Inverse Climate Change Impact Modeling.
- D'Asaro F, Grillone G. ((2010).). Runoff Curve Number method in Sicily: CN determination and analysis of the Initial abstraction ratio. *Proceedings of the 4th Federal Interagency Hydrologic Modeling Conference, Las Vegas, Nevada (USA) 06/27/2010-07/01/2010.*
- Dagnenet Siltan. (2008). GIS-based Irrigation Land Suitability Assessment and Mapping: The Case of Fogera Catchment, South Gondar. *M.Sc.Thesis. Haramaya University, Haramaya, Ethiopia, P 172-175.*
- Daniel Teka. (2014.). Multi-scale analysis of surface runoff and water harvesting dams in a semi arid region: a case study in Tigray (Ethiopia). . *Ph.D. thesis, Earth and Life Institute Centre de recherche sur la Terre et le climat Georges Lemaître, Université catholique de Louvain, Belgium.*
- Das, S.N. Tripathi, M.P. Shrivastava, P.K. (2004). Hydrological Modeling of a Small Watershed Using Satellite Data and GIS Technique. *Journal of the Indian Society of Remote Sensing, Vol. 32, No.2, pp.145- 157.*
- Davidson, D. (1980). The Evaluation of Land Resources, Second edition, Longman Series, United Kingdom.
- Davidson, D. (1992). The Evaluation of Land Resources. *Stirling University Press: Stirling, Scotland, UK.*
- Dingman, S. (2002). Physical hydrology, Second edition prentice, Hall New Jersey.
- Eastman, J. (2001). Guide to GIS and Image Processing Volume. *Clark University: Worcester, NE, USA.*
- ESRI (Environmental Systems Research Institute). (1996). Building applications with map objects. Redlands, Calif. Environmental Systems Research Institute Press.
- FAO. (1991). Land use planning applications. Proceedings of the FAO Expert Consultation, 1990.
- FAO. (2001). Irrigation Water Management: Irrigation Methods, Rome, Italy.

- FAO. (, 1976.). A framework for land evaluation. FAO Soils Bulletin No. 32. FAO, Rome.
- FAO. (, 1979.). Land evaluation criteria for irrigation. Report of an Expert Consultation, 27 February-2 March 1979. *World Soil Resources Report No. 50. FAO Rome. 219 p.*
- FAO. (1983). Guidelines for the preparation of irrigation and drainage projects. Revised version.
- FAO. (1985). Guidelines Land Evaluation for Irrigated Agriculture. FAO Soils Bull 55, Rome, 290 pp.
- FAO. (1986). Crop water requirements, Irrigation and Drainage paper No. 24, Rome, Italy.
- FAO. (1992). Crop water requirements. FAO Irrigation and Drainage paper 24. Italy, Rome.
- FAO. (1996). An interactive multi-criteria analysis for land resource appraisal. Rome, Italy.
- FAO. (1997). Irrigation potential in Africa: A basin approach FAO Land and Water Bulletin 4.
- FAO. (1998). Guidelines for computing Crop Water Requirements, Irrigation and Drainage Paper, No. 56. Rome, Italy.
- FAO. (1999). The future of our land facing the challenge. Guidelines for integrated planning for sustainable management of land resources far, Rome. Land and Water Digital Media Series 8.
- FAO. (2003). Unlocking the water potential of Agriculture. *Rome, Italy.*
- FAO. (2007). Land evaluation towards a revised framework. Land and Water Discussion Paper 6 FAO, Rome.
- Fasil, K. (2002). Analysis of Yield Gap for Wheat Cultivation in the Highlands of North Ethiopia. *Ph.D. Thesis, Gent University, Gent, Belgium.*
- Girma, N. (2015). GIS-Based Physical Land Evaluation for Surface Irrigation System; Case Study of Walga Sub Basin, Oromia, Ethiopia.

- Gupta, H.V., Sorooshian, S. and Yapo, P.O.. (1999.). Status of automatic calibration for hydrologic models: Comparison with multilevel expert calibration. *Journal of Hydrologic Engineering*, 4(2), pp.135-143.
- Hagos F, Makombe G, Namara RE, Awulachew SB. (2009). Importance of irrigated agriculture to the Ethiopian economy: Capturing the direct net benefits of irrigation.
- Hailegebriel Shiferaw. (2007). Irrigation Potential Evaluation and Crop Suitability analysis using GIS and Remote Sensing Technique in Belles Subbasin. *Beneshangul Gumez Region MSc thesis, Addis Ababa University*.
- IFAD. (1987). Staff Appraisal Report. Ethiopia, Special Country Program. Report No. 6393-ET.
- Janssen. R, and Rietveld, P. (1990). Multi-criteria Analysis and GIS: An Application to Agriculture Land use in the Netherlands.
- Jaruntorn, B., W. Det, and S. Katsutoshi. (2004). 2004. GIS_based land suitability assessment for Musa. *Graduate School of Agricultural Science, Ethime University, Japan*.
- Jarvis A, Rubiano J, Nelson A, Farrow A, Mulligan M. (2004). Practical use of SRTM data in the Tropics: Comparisons with Digital Elevation Models generated from Cartographic data. working document 198. *International Center for Tropical Agriculture: Cali, Colombia*.
- Jensen J. R. ((2003).). Introductory Digital Image Processing, a Remote Sensing Perspective. *3 rd edition, pp 505-508*.
- Kaczmarek, Z. (1993). Water balance model for climate impact analysis. . *ACTA Geophysica Polonica, 41/4, 1-16*.
- Kebede G. (2010). GIS-based surface irrigation potential assessment of river catchments for irrigation development in dale woreda, Sidama zone, SNNP. *MSc. Thesis Haromaya*.
- Kousari, M.R.; Malekinezhad, H.; Ahani, H.; Zarch, M.A.A, . (2010). Sensitivity analysis and impact quantification of the main factors affecting peak discharge in the SCS curve number method. *An analysis of Iranian watersheds. Quat. Int. 226, , 66–74*.

- Krause, P., Boyle, D., & Bäse, F. (2005). Comparison of different efficiency criteria for hydrological model assessment. *Adv. Geosci.*, 5, 89–97.
- Magoma, D. (2009). Hydrological Modeling Using SWAT in Wetland Catchments: The Case Study of Rugezi Watershed in Rwanda, First annual Nile Basin research conference, Dar s Salaam, Tanzania. Mann, H.B., 1945. Non-parametric test against the trend. . *Econometrica*, 13: 245– 259.
- Makombe, G.; Namara, R.; Hagos, F.; Awulachew, S. B.; Ayana, M.; Bossio, D.,,. (2011). , A comparative analysis of the technical efficiency of rain-fed and smallholder irrigation in Ethiopia. *Colombo, Sri Lanka: International Water Management Institute. 37p. (IWMI Working Paper 143).*
- Meron, T. (2007). Surface irrigation suitability analysis of Southern Abbay Basin by implementing GIS techniques. *MSc thesis Addis Ababa University, Addis Ababa.*
- Michael .A. M. (2008). Irrigation Theory and Practice, Second edition VIKAS Publishing house Pvt Ltd. India.
- MoA. ((2011a).). Natural Resources Management Directorates; Small-Scale Irrigation Situation Analysis and Capacity Need Assessment, Addis Ababa, Ethiopia.
- Moriasi, D.N.; Arnold, J.G.; Van Liew, M.W.; Bingner, R.L.; Harmel, R.D.; Veith, T.L. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Trans. ASABE*, 50, 885–900.
- MoWIE. (2010). Environmental and social impact assessment of Seraba irrigation and drainage project.
- MoWR. (2002). Water sector development program 2002-2016, Volume II: Main Report. Ministry of Water Resources, Federal Democratic Republic of Ethiopia, Addis Ababa.
- Munyaneza, O., Mukubwa, A., Maskey, S., Wenninger, J. and Uhlenbrook, S., . (2013). Assessment of surface water resources availability using catchment modeling and the

- results of tracer studies in the mesoscale Migina Catchment, Rwanda. . *Hydrol. Earth Syst. Sci. Discuss.*, 10: , 15375-15408.
- Nash, J., & Sutcli. (1970). River flow forecasting through conceptual models part I—A discussion of principles. *J. Hydrol.* , 10, 282–290.
- Nations, U. (2017). Department of Economics and Social Affairs, Population Division. *Revision key findings and Advance Tables. ESA/P/WP/248.*
- NEDECO. (1998). Tekeze River Basin Integrated Development Master Plan Project, Vol 5 & 6. *Ministry of water resources, Addis Ababa.*
- NEDECO. (1998). Tekeze River Basin Integrated Developmental Master plan Project, Volume 5 and 6. *Ministry of water resources, Addis Ababa.*
- Neitsch et al. (n.d.). soil and water assessment tool model: current developments and applications.
- Nemec. (1973.). Engineering hydrology. . *Mc Graw-Hill publishing company limited. New Delhi.*
- O’Loughlin, G., Huber, W. and Chocat, B. (1999). Rainfall-runoff processes and modeling. *Journal of Hydraulic Research*, 34(6), pp 733-751.
- Oyebande, L. (2001). Water problems in Africa-how can sciences help? Hydrological Sciences. *Journal*, 46(6), pp 947-961.
- Playan, E. &. (2006). Modernization and optimization of irrigation systems to increase water productivity. *Agricultural Water Management*, 80 (2006), pp. 100-116.
- Rahman, A. (2007). Application of remote sensing and GIS technique for urban environmental management and sustainable development of Delhi, India. In M. Netzband, W. L. Stefnow, & C. L. Redman (Eds.), *Applied remote sensing for urban planning, governance, and sustainability. Berlin: Springer-Verlag.*, pp. 165–197.
- Refsgaard, J.C.. (1997). Parameterisation, calibration, and validation of distributed hydrological models. *Journal of hydrology*, 198(1), pp.69 -97.

- S.M., S. (1999.). Procedures for systematic Processing of rainfall data. India's water. *Current science*102, pp 964-967.
- Saaty, T. (1977,). A scaling method for priorities in hierarchical structures. *J. Math. Psychol.* 15, 234–281.
- Sang, J. (2005). Modeling the impact of changes in land use, climate, and reservoir storage on flooding in the Nyando basin. M.Sc. *Thesis, Jomo Kenyatta University of Agriculture and Technology, Kenya.*
- Santhi, C., Arnold, J.G., Williams, J.R., Dugas, W.A., Srinivasan, R. and Hauck, L.M.. (2001). Validation of the swat model on a large river basin with point and nonpoint sources. *JAWRA Journal of the American Water Resources Association*, 37(5), pp.1169-1188.
- SCS (Soil Conservation Service). (1985). National Engineering Handbook, Section 4. Hydrology, Soil Conservation Service, USDA, Washington, D.C.
- Service, N. R. (2004). Estimation of Direct Runoff from Storm Rainfall. *National Engineering Handbook Part 630 Hydrology, chapter 10, Washington, D.C.*
- Sieber, J., Yates, D., Huber Lee, A., & Purkey, D. (2005.). WEAP a demand, priority, and preference driven water planning model. *Part 1, model characteristics, Water International*, 30(4), 487–500.
- Soulis KX, Valiantzas JD, Dercas N, Londra PA. (2009). Investigation of the direct runoff generation mechanism for the analysis of the SCS-CN method applicability to a partial rea experimental watershed. . *Hydrol. Earth Syst. Sci.* 13, 605-615.
- Suat Irmak and Dorak.Haman. (2003). Evaporation:- Potential or References? *Florida Cooperative Extension Service, Institute of flood and agricultural sciences university of Florida.*, P 120-146.
- Supiah S, Normala H. (2002). Rainfall-Runoff simulation using Mike11 name. *Journal of civil engineering* 15, 26-38.
- UN. (2006). Coping with Water Scarcity-A Strategic Issue and Priority for System_Wide Action. *UN Thematic Initiatives, New York.*

- Winchell, M. R., Srinivasan, R., Di Luzio, M., and Arnold, J. (2008). ArcSWAT2. Interface for SWAT 2005, User manual.
- Wind, Y., & Saaty, T. (1980). Marketing applications of the analytic hierarchy process. *Manag. Sci.*, 26, 641–658.
- WMO (World Meteorological Organization). (2008). Guide to meteorological instruments and method of observation: Part I. Measurement of meteorological variables, 7. Geneva, Switzerland.
- World, B. (1973). Ethiopia: Agriculture sector review. *Volume II, Annex 11. Report No. PA-143a. Washington.*
- Yang Yi, D. H. G. (2003). Application of GIS and Remote Sensing for Assessing Watershed Ponds for Aquaculture development in Thai Nguyen, Vietnam. *School of Environment, Resources and Development Asian Institute of Technology.*
- Yates D, Sieber J, Purkey D, Huber-Lee A, Galbraith H. (2005a). WEAP21: a demand, priority, and preference-driven water planning model: part 2, aiding freshwater ecosystem service evaluation. *Water Int 30 (4)*, 487–500.
- Yates D, Sieber J, Purkey D, Huber-Lee A., (2005b). WEAP21. a demand-, priority, and preference is driven water planning model part 1, model characteristics. . *Water Int 30(4):*, 487–500.

APPENDICES

Appendix 7. 1: Annual rainfall stations used in developing double mass curve

year	Dinsho	Agarfa	Sinana	Robe
1987	1756	715.5	779.4	779.4
1988	1599	942	1036.8	1036.8
1989	1458.9	1280.8	999.9	999.9
1990	1243.9	1311.9	907.2	907.2
1991	1142.1	988.8	875.9	875.9
1992	1488.7	1439.1	1226.4	1226.4
1993	1248.4	1269.7	1053	1053
1994	1085.3	1242.3	1114	1114
1995	1058.4	1038.7	984.3	984.3
1996	1274.1	991.4	1013.7	1013.7
1997	1397.9	1185.6	1000.4	1000.4
1998	1444.8	1009.3	1208.3	1208.3
1999	1230.9	1199.6	1089.5	1089.5
2000	1428.2	963.5	981.4	981.4
2001	1485.6	1027.9	906.7	906.7
2002	1233	920.7	806.9	806.9
2003	1175.5	906.3	687.4	687.4
2004	1297	904.5	685.7	685.7
2005	1042	1044	931.8	931.8
2006	1524.7	1018.5	1016.7	1016.7
2007	1356.9	1019.3	855.8	855.8
2008	1264.7	981.9	777.9	777.9
2009	903.1	773.6	744	744
2010	1379.8	1134.5	940.8	940.8
2011	1015.9	673.7	691.8	691.8
2012	905.8	1046.9	722.1	722.1
2013	1492.6	964.8	859.1	859.1
2014	953.6	974.5	667.7	667.7
2015	778.9	694.9	667	667
2016	1050.7	930.4	795.6	795.6
2017	964.6	893.6	909.9	909.9

Appendix 7. 2: Mean monthly rainfall(mm) stations in the study area

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dinsho	16.3	31.3	104.1	171.4	113	82	152.3	204.3	167.6	117.2	54.6	33.7
Agarfa	22.3	37.6	81.7	140	102	71.3	114.5	131.7	124.6	112.1	44.5	33.4
Sinana	23.7	25.6	78.6	127.5	115.6	49.4	67.1	104.5	133.4	106.6	46.6	22.5
Robe	19.1	23.4	65.4	113.8	79.1	59.5	101.6	131.2	116.1	78.5	37.6	17.3

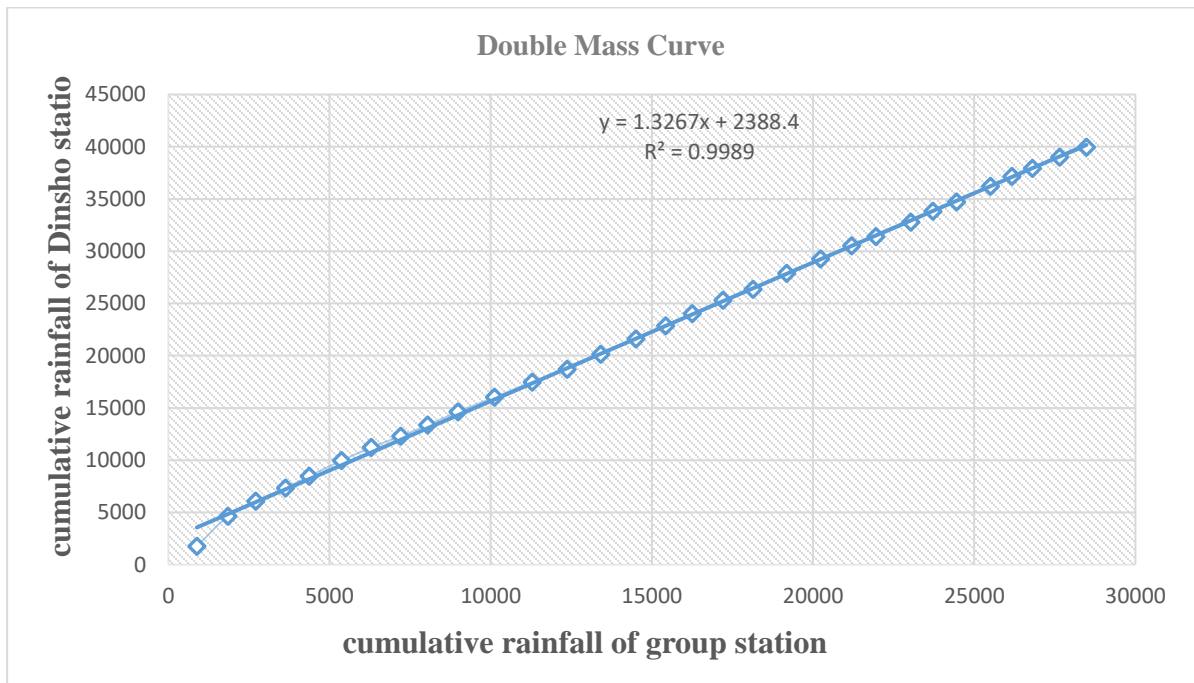
Appendix 7. 3: Mean monthly Maximum and minimum temperatures of the study area

No	Stations	parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1	Robe	Tmax(°C)	22.7	23.6	23.4	22.1	22.3	22.9	22.1	21.4	21	19.9	20.6	21.6
		Tmin(°C)	6.1	7.1	8.4	9.7	9.6	9.3	9.3	9.2	9.1	8.7	7	6
2	Sinana	Tmax(°C)	22.6	23.9	23.2	21.7	21.7	21.5	21.2	21.4	21.3	20.5	21	22.1
		Tmin(°C)	5	5.9	7.8	8.8	8.9	8.9	8.3	8.7	9.1	8	5.6	4.5
3	Dinsho	Tmax(°C)	17.7	18.4	19.4	18.5	18	18.7	17.6	17.3	17.1	16.4	16.9	17.3
		Tmin(°C)	2.7	2.8	4.2	5.8	5.4	5.1	5.3	5.1	4.7	4.7	3	2.6
4	Agarfa	Tmax(°C)	23.7	24.5	24.5	23.9	24.1	24.4	24.1	24	23.9	23.4	23.5	23.6
		Tmin(°C)	6.7	7.5	8.9	9.8	9.6	8.9	8.8	8.9	8.6	8	6.7	6.2
	Av.min TMP	AV Tmin(°C)	5.1	5.8	7.3	8.5	8.4	8.1	7.9	8.0	7.9	7.4	5.6	4.8
	Av.max TMP	AV Tmax(°C)	21.7	22.6	22.6	21.6	21.5	21.9	21.3	21.0	20.8	20.1	20.5	21.2

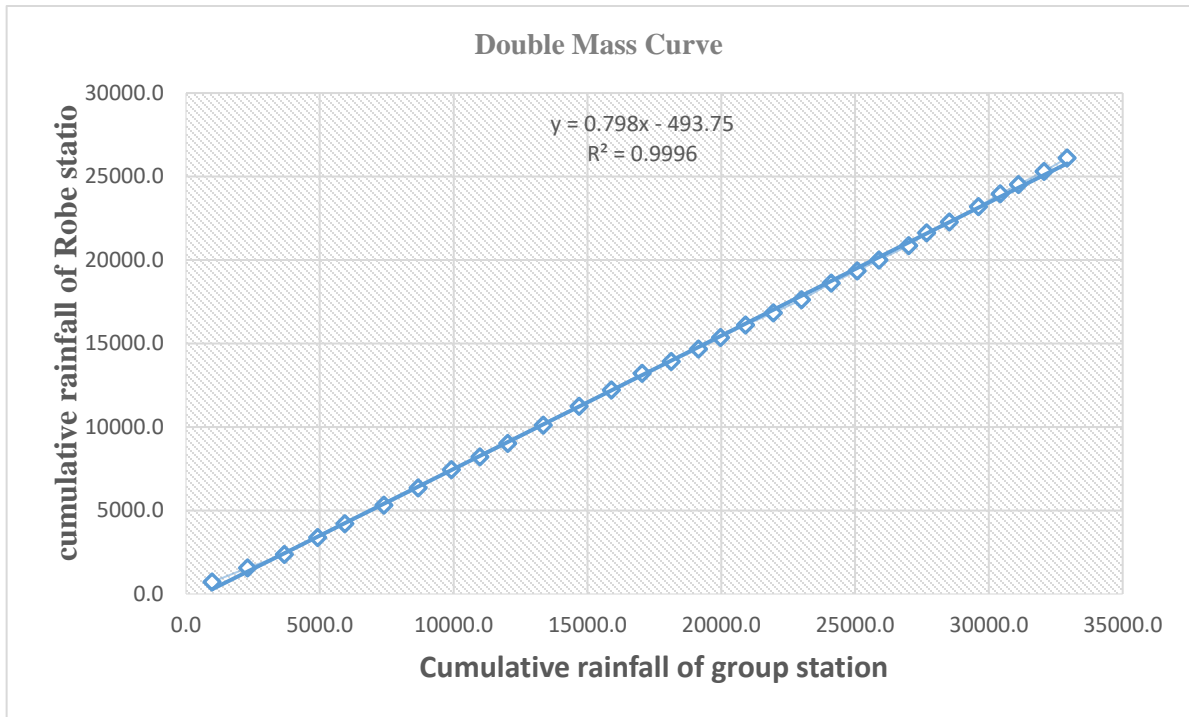
Appendix 7. 4: Minimum monthly simulated flow (m3/s) at sub-watershed obtained from SWAT outputs.

Month	subwat1	Subwat2	Subwat3	Subwat4	Subwat5	Subwat6
Jan	0.70	2.90	1.00	2.63	5.61	2.70
Feb	0.57	2.36	0.81	2.14	4.56	2.14
March	0.57	2.34	0.81	2.12	4.52	1.95
April	1.30	5.36	1.85	4.86	10.38	4.50
May	1.22	5.00	1.73	4.54	9.69	4.02
June	1.07	4.42	1.53	4.01	8.56	3.66
July	1.40	5.76	1.99	5.22	11.16	5.00
Aug	1.80	7.42	2.56	6.73	14.37	5.99
Sept	1.81	7.45	2.57	6.75	14.42	6.03
Octo	1.89	7.77	2.69	7.04	15.04	6.33
Nov	1.38	5.67	1.96	5.14	10.98	4.75
Dec	1.06	4.34	1.50	3.93	8.40	3.79

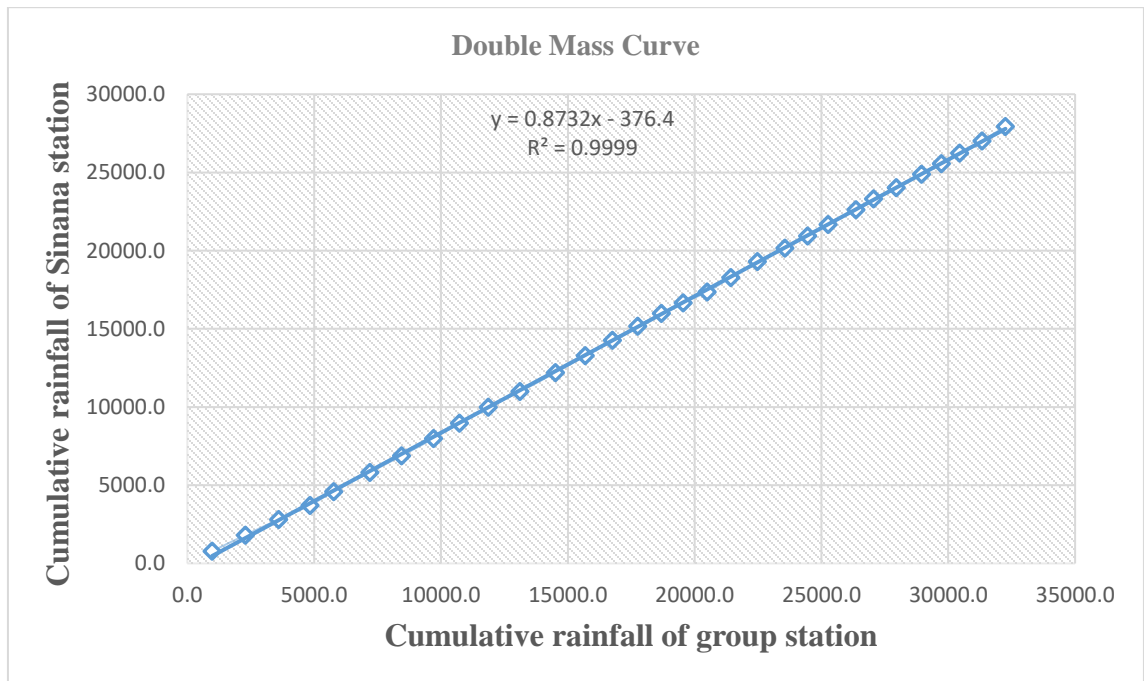
Appendix 7. 5: Double mass curve for Dinsho rain gage station



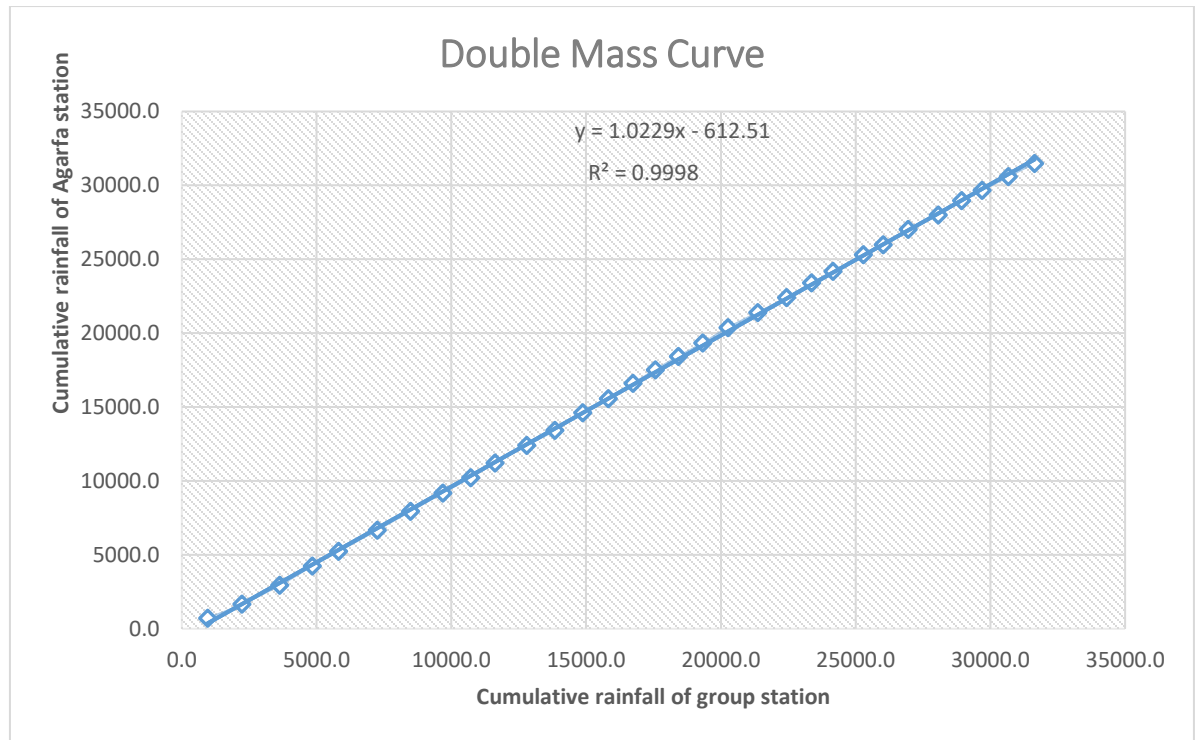
Appendix 7. 6: Double mass curve for robe rain gage station



Appendix 7. 7: Double mass curve for Sinana rain gage station



Appendix 7. 8: Double mass curve for Agarfa rain gage station



Appendix 7. 9: ETo and climatic data Meteorological Station (1987-2017)

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m ² /day	mm/day
January	5.1	21.7	55	138	8.8	20.9	3.84
February	5.8	22.6	53	156	9	22.4	4.3
March	7.3	22.6	60	156	7.8	21.4	4.2
April	8.5	21.5	71	138	7	20.2	3.77
May	8.4	21.6	69	147	7.1	19.8	3.75
June	8	21.9	67	156	8	20.6	3.9
July	8	21.1	73	147	6.8	19	3.53
August	8	21	76	156	6.6	19.3	3.53
September	7.9	20.8	76	130	6.1	18.7	3.42
October	7.4	20	75	112	5.7	17.5	3.16
November	5.6	20.5	68	104	7.3	18.9	3.3
December	4.8	21.1	60	121	8.4	19.9	3.52
Average	7.1	21.4	67	138	7.4	19.9	3.68

Appendix 7. 10: CWR and IWR estimation for pepper

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	1	Init	0.6	1.94	19.4	18.1	1.3
Nov	2	Init	0.6	1.97	19.7	11.7	8
Nov	3	Init	0.6	2.03	20.3	10.4	9.9
Dec	1	Deve	0.67	2.35	23.5	9.1	14.4
Dec	2	Deve	0.81	2.9	29	6.9	22.1
Dec	3	Deve	0.95	3.52	38.8	7.2	31.6
Jan	1	Mid	1.06	4.07	40.7	7.7	33
Jan	2	Mid	1.07	4.23	42.3	7.7	34.6
Jan	3	Mid	1.07	4.39	48.3	7.8	40.4
Feb	1	Mid	1.07	4.55	45.5	6.7	38.9
Feb	2	Late	1.05	4.62	46.2	6.1	40.1
Feb	3	Late	0.98	4.3	34.4	11.5	22.9
Mar	1	Late	0.93	4.05	20.2	8.7	11.5
					428.2	119.7	308.5

Appendix 7. 11: CWR and IWR for potato

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	1	Init	0.5	1.62	16.2	18.1	0
Nov	2	Init	0.5	1.64	16.4	11.7	4.7
Nov	3	Deve	0.53	1.8	18	10.4	7.7
Dec	1	Deve	0.73	2.55	25.5	9.1	16.5
Dec	2	Deve	0.95	3.43	34.3	6.9	27.3
Dec	3	Mid	1.14	4.25	46.7	7.2	39.5
Jan	1	Mid	1.16	4.46	44.6	7.7	36.9
Jan	2	Mid	1.16	4.6	46	7.7	38.3
Jan	3	Mid	1.16	4.78	52.6	7.8	44.7
Feb	1	Late	1.16	4.94	49.4	6.7	42.7
Feb	2	Late	1.07	4.7	47	6.1	40.8
Feb	3	Late	0.95	4.13	33.1	11.5	21.6
Mar	1	Late	0.83	3.58	35.8	17.4	18.5
					465.7	128.4	339.3

Appendix 7. 12: CWR and IWR estimation for Barley

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. req
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Dec	1	Init	0.3	1.03	10.3	9.1	1.3
Dec	2	Deve	0.35	1.24	12.4	6.9	5.4
Dec	3	Deve	0.68	2.48	27.3	7.2	20.1
Jan	1	Mid	1.05	3.91	39.1	7.7	31.4
Jan	2	Mid	1.17	4.51	45.1	7.7	37.4
Jan	3	Mid	1.17	4.69	51.6	7.8	43.7
Feb	1	Mid	1.17	4.87	48.7	6.7	42
Feb	2	Mid	1.17	5.04	50.4	6.1	44.3
Feb	3	Mid	1.17	5.01	40	11.5	28.5
Mar	1	Late	1	4.25	42.5	17.4	25.1
Mar	2	Late	0.7	2.92	29.2	22	7.2
Mar	3	Late	0.39	1.58	15.8	25	0
					412.5	135.2	286.5

Appendix 7. 13: CWR and IWR estimation for Wheat

Month	Decade	Stage	Kc	ETc	ETc	Eff	Irr.
			coeff	mm/day	mm/dec	rain	Req.
Dec	1	Init	0.3	1.05	10.5	9.1	1.4
Dec	2	Init	0.3	1.08	10.8	6.9	3.8
Dec	3	Deve	0.3	1.12	12.4	7.2	5.2
Jan	1	Deve	0.49	1.87	18.7	7.7	11
Jan	2	Deve	0.78	3.08	30.8	7.7	23.1
Jan	3	Mid	1.08	4.42	48.6	7.8	40.8
Feb	1	Mid	1.17	4.99	49.9	6.7	43.2
Feb	2	Mid	1.17	5.17	51.7	6.1	45.5
Feb	3	Mid	1.17	5.12	40.9	11.5	29.4
Mar	1	Mid	1.17	5.07	50.7	17.4	33.4
Mar	2	Late	1.01	4.34	43.4	22	21.4
Mar	3	Late	0.71	2.92	32.2	27.5	4.6
Apr	1	Late	0.42	1.66	14.9	31.9	0
					415.5	169.6	262.8