

**GIS BASED ASSESSMENT OF POTENTIAL AREA OF RAIN
WATER HARVESTING FOR CROP PRODUCTION AT DARO-LABU
DISTRICT, WEST HARARGHE, OROMIA, ETHIOPIA**

M.Sc. THESIS

BAYISA MULETA HUNDE

December, 2020

HARAMAYA UNIVERSITY, HARAMAYA

**GIS Based Assessment of Potential Area of Rainwater Harvesting for
Crop Production at Daro-Labu District, West Hararge,
Oromia, Ethiopia**

**A Thesis Submitted to the School of Water Resource and Environmental
Engineering,
Directorate for Post Graduate Program
HARAMAYA UNIVERSITY**

**In Partial Fulfillment of the Requirement for the Degree of MASTER
OF SCIENCE IN WATER RESOURCE AND ENVIRONMENTAL
ENGINEERING (IRRIGATION ENGINEERING)**

Bayisa Muleta Hunde

**December 23, 2020
Haramaya University, Haramaya**

APPROVAL SHEET
HARAMAYA UNIVERSITY
DIRECTORATE FOR POSTGRADUATE PROGRAM

I hereby certify that I have read and evaluated the Thesis entitled “**GIS Based Assessment of Potential Area of Rainwater Harvesting for Crop Production at Daro-Labu District, West Hararge, and Oromia Regional State, Ethiopia**” prepared under our guidance by Bayisa Muleta. I recommend that it be submitted as fulfilling the thesis requirement.

Teshome Seyoum (Dr. -Ing)	_____	_____
Major Advisor	Signature	Date
Shimelis Assefa (PhD)	_____	_____
Co-Advisor	Signature	Date

As members of the Examining Board of the Final MSc. Thesis open defense, I certify that we have read and evaluated the Thesis prepared by **Bayisa Muleta** and examined the candidate. I recommended that the thesis be accepted as fulfilling the thesis requirement for the degree of Master of Science in Water Resource and Environmental Engineering

(Irrigation Engineering)

Tena Alamirew (PhD)	_____	08/12/2020
Chairperson	Signature	Date
Shimelis Birhanu (PhD)	_____	08/12/2020
Internal Examiner	Signature	Date
Moltot Zewde (PhD)	_____	08/12/2020
External Examiner	Signature	Date

Final approval and acceptance of the Thesis is contingent upon the submission of its final copy to the council of Graduate Study (CGS) through the candidate department or school graduate committee (DGC or SGC).

DEDICATION

I dedicate this thesis manuscript to my mother Nedhi Jirachis who passed away without seeing my efforts.

STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this thesis is my own research work and that all sources of materials used for this thesis have been duly acknowledged. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis, and compilation of this thesis. Any scholarly matter that is included in the thesis has been given recognition through citation. This thesis has been submitted in partial fulfillment of the requirements for MSc. degree at Haramaya University and is deposited at the University Library to be made available to borrowers under the rules of the Library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of an academic degree, diploma or certificate.

Brief quotations from this thesis are allowable without special permission, if accurate acknowledgment of the source has made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the School Head of Water Resource and Environmental Engineering or the Dean of the School of Graduate Studies when in his or her judgment the proposed use of the material is in the interest of scholarship. In all other instances, however, permission can be obtained from the author.

Name: Bayisa Muleta Hunde

Signature _____

Date: 23/12/2020

Place: Haramaya University (Institute of Technology)

School of Water Resource and Environmental Engineering

BIOGRAPHICAL SKETCH

The author was born in June 1990 in Ilu District (Kule gefersa kebele), South West Shoa Zone of Oromia, Ethiopia, from his father Muleta Hunde and his mother Nadhi Jirachis. As a young child, the author was sent to school and started his primary education in Kule Primary School, (Grade 1- 6) from 1998–2003 G.C and (Grade7-8) at Asgori Primary School from 2004-2005 G.C, he took Regional primary School Examination (Grade 8th) in 2005 G.C. He complete his high school education at Teji Secondary School, from 2006-2007 G.C at Teji town.

He attended preparatory school at Yehibret Firie Secondary and Preparatory School (YFSPP) since 2008-2009 and took ESLCE examination. Since 2010, he joined Wollega University to attain his education and graduated with Bachelor of Science in Water Resource and Irrigation Management (WRIM) in June 30, 2012. After graduation, Oromia Agricultural Research Institute (OARI) employed him, he served as Junior Irrigation, and Water Harvesting Researcher at Mechara Agricultural Research Center found in West Hararghe Zone. After he served for more than three years, he joined Haramaya University, Post-graduate Program in October 2017/18 to pursue his MSc degree study under the program of Water Resource and Environmental Engineering of Irrigation Engineering Department.

ACKNOWLEDGEMENT

This study would not have been realized without the genuine and valuable support, guidance, and encouragement of my advisors, friends, families, multiple organization and institutes. I want to extend my thanks to Oromia Agricultural Research Institute (OARI) and Mechara Agricultural Research Center for helping me by finance and facilitating other material used for thesis accomplishment.

I am also grateful thanks to my major advisor Dr.-Ing Teshome Seyoum and co-advisor Dr. Shimelis Assefa for their guidance and encouragement. I have also like to thanks Dr. Solomon Abera for coordination, facilitating and finalizing my works, I would like to extend my special thanks to all finance personnel at Mechara Agricultural Research Center (McARC). I have also grateful thanks to my all brothers (Mosissa Muleta, Abebe Muleta, Kelbecha Muleta and Ayeta Muleta) and sister Dawit Muleta, for helping and inspiration me from the beginning of academic education to now.

Finally, my thanks go to my colleagues and friends Ayana Bulti, Wozir Mohammed, and Mosisa Mazgebu on behalf of supporting me during my thesis work. Alemu Negera for their appreciation and encouragement for waiting me in his home during data collection and analysis. Anybody else who contributed to the completion of this study in anyway but may have been omitted is also acknowledged.

ACRONYM AND ABBREVIATIONS

AHP	Analytical Hierarchy Process
CA	Catchment Area
CBO	Community Based Organization
CGIAR	Consultant Group for International Research
CWR	Crop Water Requirement
CN	Curve Number
DEM	Digital Elevation Model
DSMW	Digital Soil Management of the World
FAO	Food and Agricultural Organization
GIS	Geographical Information System
GPS	Geographical Positioning System
GWMPM	Geographical Water Management Potential Model
HSG	Hydrological Soil Group
IMSD	Integrated Mission for Sustainable Development
McARC	Mechara Agricultural Research Center
Masl	meter above sea level
MoA	Ministry of Agricultural
MCDM	Multi Criteria Decision Making Method
MCE	Multi Criteria Elevation
OARI	Oromia Agricultural Research Institute
OWWDE	Oromia Water Work Design and Enterprise
RWH	Rain Water Harvesting
RWSM	Rain Water Simulation Model
RS	Remote Sensing
SRTM	Shuttle Radar Topography Mission
SCS	Soil Conservation Services
USDA	United State Development of Agriculture
WHZ	West Hararghe Zone

TABLES CONTENTS

CONTENTS	page
APPROVAL SHEET	ii
DEDICATION	iii
STATEMENT OF THE AUTHOR	iv
BIOGRAPHICAL SKETCH	v
ACKNOWLEDGEMENT	vi
ACRONYM AND ABBREVIATIONS	vii
LIST OF TABLES	x
LIST OF FIGURES	xi
LIST OF TABLES IN APPENDIX	xiii
LIST OF FIGURES IN APPENDIX	xiv
ABSTRACT	xv
1. INTRODUCTION	1
2. LITERATURE REVIEW	5
2.1. Rainwater Harvesting Definition and Classification	5
2.1.1. Types of rainwater harvesting technologies	6
2.1.2. Rooftop water harvesting	7
2.1.3. Surface runoff harvesting	8
2.2. Rainwater Harvesting Practice in Ethiopia and its Benefit	9
2.2.1. Rainwater harvesting practice and benefit in Ethiopia	9
2.2.3. Assessment of wainwater harvesting in the study area	10
2.3. Major Components of Rainwater Harvesting Systems	11
2.3.1. Rainwater harvesting methods and components	11
2.3.2. Catchment area	11
2.3.3. Runoff delivery systems	12
2.3.4. Drainage patterns	12
2.3.4. Hydrological soil group of West Hararghe Zone	13
2.3.5. Silt trap or sediment pond	13
2.3.6. Storage facility of water harvesting	14
2.4. Suitability of Sites for Rainwater Harvesting	14

2.4.1. Factors affecting suitability of site for rainwater harvesting	14
2.4.2. Suitable area for rainwater harvesting systems	16
2.4.3.1. Using GIS and RS for selecting RWH sites	18
2.4.3.2. Modeling of rainwater harvesting	19
2.5. Crop Production Under Irrigation	20
2.5.1. Determination of crop water requirement	20
2.5.2. Review of CROPWAT Model	20
2.5.3. Overview of CROPWAT Model	21
3. MATERIALS AND METHODS	23
3.1. Description of the Study Area	23
3.1.1. Location of the study area	23
3.1.2. Climate	23
3.1.3. Topography and soil type	24
3.2. Methods of Data collection and Analysis	24
3.3. Assessment of Topography and Land feature	25
3.3.1. General approach of rainwater harvest (RWH) mapping	25
3.3.2. Using Digital Elevation Model (DEM)	25
3.3.2.1. Contour data	26
3.3.2.2. Slope of the study area	26
3.3.3. Soil texture and soil depth	26
3.3.4. Rainfall data validation	26
3.3.4.1. Estimation of missing data	27
3.3.4.2. Consistency of rainfall data	27
3.3.5. Runoff depth estimation	30
3.3.6. Land use and land cover	32
3.3.6.1. Image pre-processing	33
3.3.6.2. Image classification	33
3.3.6.3. Accuracy assessment	34
3.4. Mapping Potential Area of Rain Water Harvesting	34
3.4.1. Criteria of selection and assessment of suitability level	34
3.4.2. GIS based mapping potential areas of RWH of the study site	34
3.4.3. A GIS model for generating RWH suitability map	35
3.5. CROPWAT 8.0 Model Input data	35

3.5.1. Dependable rainfall	36
3.6. Data Analysis	37
4. RESULTS AND DISCUSSION	39
4.1. Slope and Soil Physical Properties for Water Harvesting	39
4.1.1. Slope suitability class	39
4.1.2. Soil physical properties	41
4.1.2.1. Soil texture class of the study area	41
4.1.2.2. Soil depth classification and suitability of the study area	42
4.2. Land Use and Land Cover Classification	44
4.2.1. LU/LC suitability class	44
4.2.2. LULC accuracy assessment	47
4.2.3. Suitability of hydrological soil group	47
4.2.4. Suitability of rainfall of the study area	48
4.3.5. Curve Number (CN) classification of the study area	50
4.3. Mapping Potential Area Using Weight Overlay method	52
4.3.1. Identification of Rainwater Harvesting Potential site of Daro Lebu District	54
4.4. Selected Crop Water Requirement of Daru Labu District	55
4.4.1. Gross irrigation requirement of the study area	55
4.4.2. Net irrigation requirement (NIR) of the study area	57
4.4.3. Actual crop water requirement	58
5. SUMMARY, CONCLUSION AND RECOMMENDATION	59
5.1. Summary and Conclusion	59
5.2. Recommendation	60
6. REFERENCE	61
7. APPENDICES	72
7.1. Rainfall data	73
7.2. Mean Climatic Data and ETo of Five Meteorological Station	78

LIST OF TABLES

Tables'	page
1. Area, Annual Rainfall and Altitude of the five-meteorology station	29

2. Classification of Antecedent Moisture Condition (AMC)	31
3. Spatial Database and Sources.	37
4. Software Packages and material used to manage and analysis	37
5. Slope classification and area coverage of Daro-labu District	40
6. Spatial distribution of soil texture in the study area	42
7. Soil suitability Classification results for water harvesting	43
8. LULC classification area covered of Daru Labu District	45
9. Hydrological soil group by area coverage	46
10. Area influenced under different SCS-CN method	48
11. SCS-CN and runoff potential area coverage of the study area	50
12. The Estimation Runoff depth and Volume of water Harvest of Daro Labu District	51
13. Factors of influence of RWH potential site map of Daro Labu district	52
14. Weightage values and rank for water harvesting potential site	53
15. Growth and Net irrigation Requirement of maize, tomato, , and onion at Daro Labu District	55

LIST OF FIGURES

Figures	page
----------------	-------------

1. Classification of RWH systems flow chart	6
2. Components of a rainwater harvesting system	11
3. Location map of the study area.	24
4. Digital Elevation Map of Daro labu District	26
5. Double mass curve of Average Annual Rainfall of Five Meteorological Station	29
6. Area considered under Thiessen polygon map of the study area	31
7. Growing and dry seasons for Daro Labu District area.	32
8. Flow chart of methodology of assessment of potential areas of RWH site	40
9. Slope classification and slope suitability map of Daro labu District	42
10. Soil texture map of Daru labu District	43
11. Major Soil Type Water Harvesting Suitability Map of Daro labu District	46
12. LULC map of Daro labu District	47
13. Percentage Area coverage of LULC type of Daro Labu District	49
14. Hydrological Soil Group Map of Daru labu District	50
15. Annual rainfall distribution map of Daro Labu District	50
16. Soil Conservation Service Curve Number map of the study area	53
17. Graph of mean annual rainfall runoff relationship of Daro labu District	53
18. Weighted overlay result of RWH potential site map of Daro Labu district	54
19. Water harvesting suitability site map of Daro labu District	56
20. Growth, Net and Actual irrigation water requirement of Tomato, onion and maize at the study area	60

LIST OF TABLES IN APPENDIX

Appendix Tables	page
1. Corrected Rainfall of Mechara Meteorology Station (mm)	71
2. Corrected Monthly Rain fall data of Micheta meteorology station (mm)	72
3. Corrected Monthly Rainfall data of Dumuga meteorology station	73
4. Corrected Monthly Rainfall Data of Chancho Meteorology Station	74
5. Corrected Monthly Rainfall Data of Gelemso Meteorology Station	75
6. Mean Monthly Climate Data of Mechara Meteorological Station	76
7. Mean Monthly Climate data of Micheta Meteorological Station	76
8. Mean Monthly Climate Data of Dumuga Meteorological Station	77
9. Mean Monthly Climate data of Chancho Meteorological Station	77
10. Mean Monthly Climate Data of Galemso Meteorological Station	78
11. Seasonal wet and dry rainfall using excel sheet for the computation of expected runoff depth	79
12. CWR of Tomato, onion and maize at Mechara Meteorological Station	80
13. CWR of Tomato, onion and maize at Michata Meteorological Station	81
14. CWR of Tomato, onion and maize at Dumuga Meteorological Station	82
15. CWR of Tomato, onion and maize at Chancho Meteorological Station	84
16. CWR of Tomato, onion and maize at Gelemso Meteorological Station	85
17. Soil Texture classification and its normal range of infiltration rate	87
18. SCS-Curve Number for HSG under AMC II Conditions	87

LIST OF FIGURES IN APPENDIX

Appendix Tables	page
1. Band of Aerial Spot image map of Daro Labu District	87
2. Accuracy assessment of supervised land classification of the study area	88

GIS Based Assessment of Potential Areas of Rainwater Harvesting for Crop Production at Daro Labu District, West Hararge Oromia, Ethiopia

ABSTRACT

Rainwater harvesting is the process of intercepting, conveying, and storing rainfall for future use as an alternative source of water in the drought prone areas of Ethiopia especially eastern Oromia. The aim of the research was to assess and mapping potential area of water harvesting site in Daro Labu District. There are various methodologies and criteria to identify suitable sites and techniques for rainwater harvesting (RWH). Determining the best method or guidelines for site selection, however, is difficult. GIS is the recent technology of spatiotemporal data used to assess the factor of influences for rainfall and runoff depth estimation for identification of potential area of RWH for crop production and mapping of the potential site. The influence factors for consideration of the assessment was climate data, soil texture and depth, land use and land cover (LULC) type, slope difference was used. The SCS–CN for rainfall runoff depth estimation was used to compute runoff and volume from the land surface depend on the level of antecedent moisture condition (AMC) and length of wet and dry season of the study area. The total area of the catchment was about 156064.72 ha with antecedent moisture condition (AMC) of II, I III by having the values of 82, 67, and 91 respectively. The annual average rainfall of 20 years was 925.2 mm with maximum and minimum of 1134 mm and 737.3 mm, with average annual runoff depth estimate of 185.3 mm. From the estimated annual runoff the volume of water harvested was about $289.14 \times 10^6 \text{ m}^3$. The suitability map of the study area shows that, extremely potential, highly potential, moderately potential, marginal and not potential accounts by coverage areas about (12,828.52 ha) 8.22%, (25,220.05 ha) 16.6%, (99,038.67 ha) 63.5%, (11,777.28 ha) 7.54%, and (7120.20) 4.62% respectively. The runoff in the study area was affected by geomorphological factors, particularly, land use change, topography, soil texture and depth, slope, and affects the runoff rate and volume significantly. In order to change the water harvested for crop production and meet the irrigation requirements of selected crop (tomato, onion, and maize) was 528 mm, 354.3 mm and 558.5 mm respectively was taken. The total cultivated area was about 58.6% and the area can be irrigated using the volume of water harvested was about 63% of the total cultivated area for single crop season of the study area. Thus, Rainwater harvesting can be considered as livelihood income generation and increases with production and productivity of the communities as well.

Key words: ArcGIS, Rainwater Harvesting, SCS-Curve Number, CWR, Daro Labu

1. INTRODUCTION

The ever-increasing world population has threatened by the ever-continuing water shortage problem. Climate change and a growing demand for water for agricultural and urban development are increasing the pressure on water resources. Between 75 and 250 million people in Africa are projected to be exposed to increased water stress by 2020, yields from rain fed agriculture could be reduced by up to 50% in some regions, and agricultural production, including access to food, may be severely compromised (Field *et al.*, 2014). The United Nations Environment Program estimates that more than two billion people will live under conditions of high water stress by 2050, which would be a limiting factor for development in many countries around the world (Sekar and Randhir, 2007).

According to World Water Council (WWC, 2010), the consumption of renewable water resources has grown six-fold in the 20 century responding to three times increase of the world population. They emphasized that the demand for water within the next fifty years will increase due to prediction of 40 to 50% population growth coupled with industrialization and urbanization, resulting in serious consequences on the environment. Fresh water resources are depleting due to over-exploitation, water quality degradation, and climate change (Sen *et al.*, 2011). According to FAOWATER (2012), the situation will become worse due to the heavy pressure on neighboring water resources placed by the rapid growth of urban areas. These areas become the end for the urban water cycle because of the high consumption rate of blue water, being the water source a river or ground water aquifer.

In recent decades, because of new technological possibilities, many countries are supporting updated implementation of such practice to address the increase in water demand pressures associated with climatic, environmental, and societal changes (Amos *et al.*, 2016). In urban areas, RWH consists of the concentration, collection, storage, and treatment of rainwater from rooftops, terraces, enclosures, and other impervious building surfaces for on-site use. Ghaffarian Hoseini *et al.* (2016) suggest these uses can globally account for 80-90 percent of overall household water consumption, and highlight the significant of water conservation benefits associated with RWH implementation. Consequently, installation of RWH systems increases water self-sufficiency of communities and can help delay the need to construct new centralized water infrastructures

(Steffen *et al.*, 2012). Water scarcity and need for water supply augmentation are not the only reasons that have motivated communities to increase RWH system installation. Water is a very crucial element but finite and considered a limited natural resource.

Ethiopia has suffered from the lack of clean and drinking water supply due to climate variability has a big effect on crop production (Alemayehu and Bewket, 2016). However, Ethiopia's geographic location has provided it with relatively high rainfall rates, which make rainwater as an additional water resources supply in Ethiopia (Feki *et al.*, 2014). Due to the high pollution rates in most surface water in Ethiopia, it does not considered a safe or an economic water supply resource. Therefore, water supply systems depend on ground water recharge (Ali, 2012).

The high rainfall amounts makes rainwater as a potential resource in Ethiopia, which increases the need for private and onsite water supply management initiatives. Ethiopia also facing a high adoption rate of water harvesting technologies around 42% (Wakeyo & Gardebroek, 2015). Moreover, there has limited number of study that evaluates the relation between rainwater harvesting and crops yield (Bouna, Hegde, and Lasage, 2016). Hence, good rainwater harvesting and management technologies had needed to improve rainwater use efficiency and sustain rain feed agriculture in Sub-Saharan Africa (Biazin *et al.*, 2012). In fact, consolidated scientific and dark literature of the last twenty years shows that RWH belongs to the large family of detention-based Low Impact Development (LID) or Sustainable Drainage System (SDS) approaches and can be adopted as a complementary measure to reduce frequency, peaks, and volumes of urban runoff if systems are appropriately designed.

The incorporating demands that align with local rainfall patterns can substantially increase the efficiency of the system. In terms of both water conservation and storm water mitigation (Zhang *et al.*, 2009). When used in conjunction with infiltration based solutions, excess overflow water from RWH systems (that would otherwise generate street runoff or enter the storm sewer network) can be infiltrated (often after preliminary treatment, as determined by national regulations) for groundwater recharge (Dillon, 2005).

Recent studies have shown that infiltration techniques coupled with RWH can also help in modifying the urban micro-climate by increasing moisture content and evapotranspiration

(Hamel *et al.*, 2012) so mitigating the heat island phenomenon (Furumai, 2008; and Coutts *et al.*, 2012).

Environmental benefits concerning the reduction of emissions and the decreasing of consumed resources with RWH system implementation have been explored in recent years (Angrill *et al.*, 2012). In this regard, the scientific literature shows that the selected use of rainwater in the building and the type of implementation project (renovation or new construction) significantly affect the economic feasibility of the system and implications of RWH for energy consumption have currently contested (Pinzon *et al.*, 2015).

According to Parkes *et al.* (2010) suggests that the water supplied by RWH systems typically requires greater operational energy to deliver than the mains water it displaces. However, Ward *et al.* (2011) indicate that this is very much context dependent and in fact technological innovation in pump design and in low or no energy RWH systems makes this less of an issue going forward. Jiang *et al.*, (2013) found that RWH systems might lead to a decrease of energy usage. There are several benefits of rainwater harvesting, such as to control excessive runoff, flood in the downstream catchment, and to improve soil moisture and for soil conservation (Madan *et al.* 2014; Ammar *et al.* 2016; Li *et al.* 2018). Other projects are using harvested rainwater within houses for thermal energy recovery and building cooling (An *et al.*, 2015; and Kollo and Laanearu, 2016).

The application of GIS can be helpful for a first screening and identification of areas potentially suitable for RWH (Prinz *et al.*, 1998). However, RWH potential areas in Ethiopia do almost not exist and there is not so much documented work in this regard. On the other hand, Ethiopia was known as the water rich country in eastern Africa, having twelve big rivers and basins. The country is currently economically sustainable to potentially utilize and its large rivers for different well-being of the community integrates with national, regional and local interests at required level. Ethiopia constitutes diversified agro-ecological zones which enable the country to produce many types of agricultural products of both crops and livestock's.

The annual average rainfall of Ethiopia ranges between 400 to 1300 mm, and rain fed agriculture is predominantly practiced agricultural system in the country. Even though, 3.5 million hectare of land is suitable for potential irrigated agriculture practice, in terms of the water resources for water supply and agricultural purposes, only 0.2 million hectare of land is currently under irrigation. In this case, only about 25 percent of the people have access

to clean water of some kind. The present water requirement of the land to produce a one-season crop will require around 3% of the total runoff (Getachew, 2009; and Fitsum *et al.*, 2014). The most source of water resource available is rainfall as a local source, and that is why rainwater harvesting is extremely necessary.

Different studies used different parameters for estimation and allocation. For instance, FAO, (2003) as cited by Kahinda *et al.*, (2008) lists six key factors when identifying by consideration of RWH sites. Climate, topography, agronomy practice soils moreover, socioeconomic criteria had influences the importance of water harvesting. In addition, used physical (land use, rainfall, and soil texture and soil depth), ecological and socio-economic factors might be a problem and should be identified through research work. Rao *et al.* (2003) identified land use, soil, slope, runoff potential, proximity, geology, and drainage as criteria to identify suitable sites for RWH.

The eastern Ethiopia especially west, Hararge Zone (WHZ), there is insufficient of scientific information and practices to properly allocate and plan RWH interventions. The selection of potential areas of RWH is influenced by different factors including biophysical and socio-economic conditions. The problem of water and sensitive land is certainly acute and harsh, which demands special methods of control and management. Owing to increasing population and development of agriculture, water from various sources consumed at such a fast rate that it is going to pose a grave water crises in near future. Besides, in the areas where irrigation water made available unforeseen problems like water logging, alkalinity and salinity of the soil and various water borne diseases and social problem have appeared in the absence of any scientific management of watershed. Hence, the present research has been planned to give thought to these problems of water allocation and to suggest ways and means through rain water harvesting and proper watershed and catchment area management.

Objective

The general objective is to assess the GIS based potential areas of rainwater harvesting for crop production

Specific Objectives

- ✓ To assess GIS based potential areas of Rainwater harvesting at Daro-Labu District,
- ✓ To determine, mapping the rainwater harvesting potential area and estimation runoff depth using SCS-CN of the study area for crop production at Daro-labu District,

2. LITERATURE REVIEW

2.1. Rainwater Harvesting Definition and Classification

The term rainwater harvesting (RWH) is used in different ways and thus no universal definition has been adopted (Ngigi, 2003). According to Mzirai and Tumbo, (2010) RWH is the process of intercepting and concentrating rainwater in order to increase water infiltration into the soil for direct use by plants or in reservoirs for later application when needed to mitigate dry spells. Sekar and Randhir, (2007) defined RWH as a technique which can be used to minimize water loss and to supplement water supplies in watershed systems. The process of concentrating precipitation through runoff and storing it for beneficial use were implemented (Oweis *et al.*, 2012). The collection and concentration of rainwater and runoff and its productive use for irrigation of annual crops, pastures and trees, for domestic and livestock consumption and for ground water recharge (Prinz, 2011).

Ethiopian agriculture characterized by extreme dependence on rainfall, low use of modern agricultural inputs and low output levels. Over 80% of the population's livelihood in Ethiopia is contingent upon this sector, which contributes 45% to the national GDP, on average (Bewket, 2009). Subsistence rain-fed agriculture has been widely practiced for many centuries.

Based on grid-based average annual rainfall and the land area, the study estimates that Ethiopia receives about 980 billion (1 trillion) meter cube of rainfall a year (Awulachew, 2010). While Ethiopia has abundant annual rainfall; the rainfall varies spatially, temporarily and inter-annually (yearly cycles). About 80 percent of rainfall occurs between June and September, while yearly variability can also be significant (e.g., about 30% average variation year over year). Consequently, increasing rainwater storage capacity and improving water control and rainwater management techniques, especially rainwater harvesting, are critical to ensure that Ethiopia gets maximum use of its rainfall (Awulachew, 2010).

Runoff may be harvested from roofs and ground surfaces as well as from intermittent or ephemeral watercourses and thus water harvesting falls into two broad categories: Water harvesting techniques, which harvest runoff from roofs or ground surfaces named RWH and all systems, which collect discharges from watercourses named floodwater harvesting

(Critchley *et al.* 1991). RWH technologies and systems can be classified in several ways, mostly based on the runoff generation process, size of the catchment and type of storage.

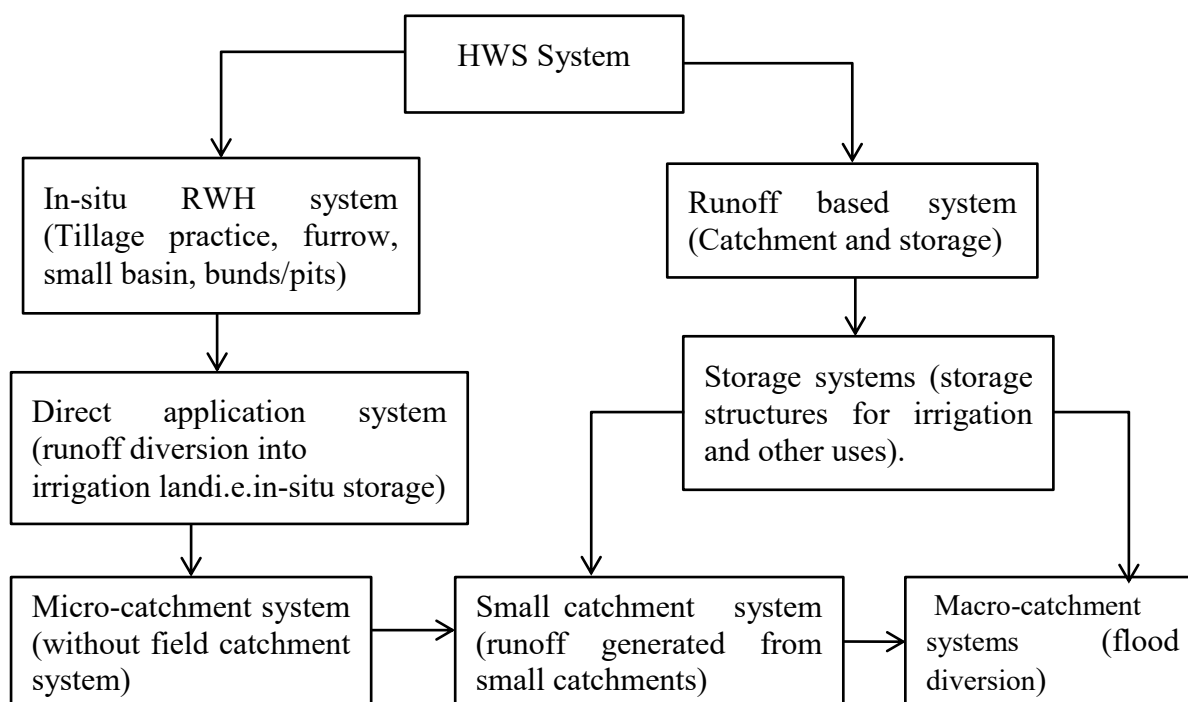


Figure 1: Classification of RWH systems flow chart

Runoff generation criteria yields two types of systems i.e. runoff based systems (runoff concentrated from a catchment) and in-situ water conservation (rainfall conserved where it falls). The runoff storage criteria yield two categories, i.e., storage within the soil profile and storage structures. The size of catchment yields two categories, i.e., macro catchments and micro catchments (within field).

In general, RWH systems for all consumption and crop production are divided into three different categories basically determined by the distance between catchment area (CA) and cropped basin (CB) (utilization area): *In-situ* RWH, internal (Micro) catchment RWH and External (Macro) catchment RWH (Hatibu and Mahoo 1999).

2.1.1. Types of rainwater harvesting technologies

A. **In-situ RWH:** The first step in any RWH system involves methods to increase the amount of water stored in the soil profile by trapping or holding the rain where it falls. This may involve small movements of rainwater as surface runoff in order to concentrate the water where it needed most. *In-situ* RWH do sometimes called water conservation and is the prevention of net runoff from a given cropped area by holding rainwater and

prolonging the time for infiltration. This system works better, where the soil water holding capacity is large enough and the rainfall is equal or more than the crop water requirement. Essentially, it includes all conventional approaches to soil and water conservation designed to enhance rainwater infiltration. Examples of *in-situ* RWH techniques include deep tillage, dry seeding, mixed cropping, ridges and borders, terraces (“*fanya juu*” and “*fanya chini*”) and trash lines (Mbilinyi *et al.* 2005), vegetative/stone contour barriers, contour trenching, contour farming and tie ridging methods (Sivan, 2006).

B. Internal (Micro) catchment RWH: This is a system where there is a distinct division of CA and CB but the areas are adjacent to each other. It mainly used for growing medium water demanding crops such as maize, sorghum, groundnuts and millet. The major characteristics of the system include small semi-circular pits, strip catchment tillage, contour bunds, semi-circular bunds, at-type system and land conservation aspects.

C. External (Macro) catchment RWH: This is a system that involves the collection of runoff from large areas, which are at an appreciable distance from where it is being used. This method is sometimes applied with intermediate storage of water outside the CB for later use as supplementary irrigation. This system involves harvesting of water from catchments ranging from 0.1 hectare to thousands of hectares located either near the cropped basin or far away. The catchment areas usually have slope ranging from 5-50%, while the harvested water is used either on cropped areas, which are terraced, or on flat lands. When the catchment is large and located at a significant distance from the cropped area the runoff water is conveyed through structures of diversion and distribution networks.

2.1.2. Rooftop water harvesting

Roof water harvesting is a system of collecting rainfall water from the roof of a building and storing it in some storage facilities for future use when there is shortage of water (Haile and Merga, 2002). Large scale and modern water supply schemes in rural Ethiopia remains a challenge owing to the unique and rugged terrain and the scattered settlement pattern of the rural people. One technique that appeals today that can be of significant importance in the development of the subsector is roof water harvesting at household level. The roof water harvesting in Ethiopia has the advantage of being low cost, relatively simple in design (household technology), less laborious and time saving (Alem,

1999). It provides adequate water during the rainy season, a period when the rural people are busy with the farm activities and when there is shortage of labor.

2.1.3. Surface runoff harvesting

Runoff refers to rainwater that flows off a surface other than roof (Awulachew *et al.*, 2009). The surface may be a rock, pavements, fields, or roads. Some surfaces are permeable while others are impermeable. Rain that falls on the surface can be collected and used for either irrigation or domestic purposes. In some cases, depending on the quality, it has been used for flushing toilets and cleaning activities in households. It could even be used to recharge aquifers. This method is also very common in urban areas in many parts of the world, where the surfaces are less permeable and therefore the seepage is minimal (Nthuni *et al.*, 2014). The amount of water collected by this method depends on the amount of the rainfall, the permeability of the surface, the area of the surface and the slope of the surface among other factors.

Rainwater harvesting technologies could significantly enhance the productivity of rain-fed agriculture in semi-arid areas, where the rainfall is usually unsatisfactory to meet crop water requirements throughout the crop-growing season. Rain-fed agricultural production contributes 60% of the world's food supply (Bot *et al.*, 2000). Farmers typically practice these mechanical operations with the point of increasing the soil water holding capacity through increased porosity, which boosts infiltration rates, and therefore decreases surface runoff, allowing the crop to have improved soil water availability. However, crop production yields using conventional tillage are usually very little, especially in semi-arid areas. One of the major causes for this is the fact that huge amounts of water are lost through runoff, which triggers increase of water scarcity for crop production, as well as soil nutrient deficiency. Therefore, an optimization of potential rainfall utilization through the practice of rainwater harvesting techniques in dry areas would reduce the risk of crop failure due to enhanced water availability to plants.

Collecting and using rainwater would help to save municipal and groundwater sources. This may decrease rainwater runoff and the necessity for downstream rainwater management and treatment. Rainwater is much clean as it rains, but the surface may contains pollutants, Therefore adjustment and necessary treatment and filtration are needed

before harvesting and storing rainwater. Harvested rainwater used mainly for irrigation and domestic usage (Ling and Benham, 2014).

2.2. Rainwater Harvesting Practice in Ethiopia and its Benefit

2.2.1. Rainwater harvesting practice and benefit in Ethiopia

Ethiopia has the history of water harvesting even before 560 BC, when rainwater harvested and stored in ponds for agriculture and other water supply services. According to Hailemichael (2011), the Konso people (lived southern part of Ethiopia) had a long and well established tradition of building rainwater harvesting structure in level terrace practiced with each farmer to produce good yield of sorghum under extreme unsuitable climatic conditions. Much works has done during the last two decade to promote water harvesting to produce good results especially in micro watershed management of sustainable land management and drought mitigation (Yohannes and Haile, 2010). According to Awulachew and Merrey (2007), Ethiopian agriculture is mainly practiced rain fed agricultural system with approximately 3.5 million hectare of land is suitable for irrigated agriculture. Over 90% of the food supply comes from rain-fed smallholder agriculture (Rahmato, D., 1999).

The primary goal of the Ethiopian government water policy is developing water resources for economic and social benefits of the people on a sustainable basis. Rainwater harvesting has been one of the prominent water security strategies from other optional strategies. Even if RWH strategy is not new in Ethiopia, it has widely preferred among development agencies, research institutes, policy makers, and agents. Using multiple water harvesting technologies such as ponds, dug-wells, sand-dams, sub-surface dams, in-situ and roof catchment among others, rainwater can be harvested and stored in flash floods, surface runoff and the ephemeral rivers (Rahmato D., 1999).

Among many parameters and factors, the geographical analysis is important, as these are some of the driest regions in Ethiopia, with frequent and prolonged droughts. The primary strategy of the country on RWH is to explore, enhance, and optimize local rainwater harvesting technologies and to strengthen local capacities to sustainably manage the productive assets (Biazin, B. *et al*, 2012).

2.2.2. Rain water harvesting (RWH) and irrigation potential

Currently, rainwater use in Ethiopian agriculture involves both un managed and managed rainwater use in rain fed agriculture. In terms of increasing irrigation potential incrementally to the formal irrigation component, through RWH and better water management, it can provide an additional 0.5 Mha in irrigation. 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 in supporting with integrated water resource production like water harvesting potential areas (Kebede, 2010).

2.2.3. Assessment of rainwater harvesting in the study area

Most people working in the field of RWH argue that the constructed RWH structures do not perform as planned. A number of studies have been conducted to evaluate the performance of the ambitious plan of the government to develop RWH. All the water users indicated that the catchment for collecting runoff was sufficient but not the size of the RWH structure, because of insufficient water collection or leakage problems due to poor construction (Segers *et al.* 2007). Similar conclusions were drawn by (Alamerew 2006) who summarized the various constraints in implementing the RWH projects including inadequate public awareness and ownership of local communities, lack of adequate knowledge and skills in management of RWH schemes, insufficient involvement of communities in planning and implementation processes and lack of facilitation for establishment of community-based organizations.

Rainwater harvesting impact assessment at Alaba Woreda showed a positive effect on agricultural productivity (Amha 2006). Despite its potential, adoption of RWH technology is slow. Some reasons for the low adoption were poor quality of the construction resulting in cracks in the cemented floor and loss of water, improper site selection (insufficient runoff) and fear of malaria spread.

The RWH structures in Ethiopia face many problems, many of which originate from the speed and scale of implementation (Rami 2003). Among the identified problems were poor site selection and leakage were the most known problem of water harvesting structures. This was attributed to the lack of skilled labor during construction, the poor quality of work as result of the allocation system imposed by the regional Government that put junior

experts and development agents under pressure to construct tanks quickly. (3) Siltation and (4) wastage and uneconomical use of water.

Promotion of RWH in Ethiopia has given more emphasis on structural storage (*ex-situ* deep ponding) than *in-situ* RWH. However, *in-situ* RWH is preferred as it does not require water lifting from the pond and water application, is more closely linked to traditions, and the costs are lower (Desta 2004). As conclusion given by (Mesfin 2004) that the most efficient and cheapest way of conserving water is *in-situ* RWH. Evaporation losses can be reduced greatly if rainfall is stored in the soil rather than in an open structure. (Beyu and Alemu 2008) further concluded that *in-situ* RWH practices are also more economically feasible to resource poor farmers than *ex-situ* RWH methods.

2.3. Major Components of Rainwater Harvesting Systems

2.3.1. Rainwater harvesting methods and components

Rainwater harvesting includes all methods of concentrating, diverting, collecting, storing, and utilizing/managing runoff for productive purposes. Rainwater harvesting is relevant to areas where the rainfall is inadequate to balance evapotranspiration (ET) of crops. The principle of collecting and using rainwater from a small catchment area often referred to as 'Rainwater Harvesting'. The water harvesting as the collection, storage and utilization of any farm water for irrigation. Irrespective of the technique used to collect and store water or the ultimate use of the water, all water-harvesting systems have the following components shown in figure 2.

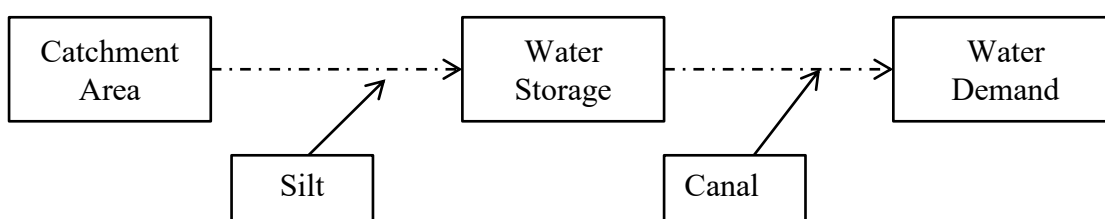


Figure 2: Components of a rainwater harvesting system

2.3.2. Catchment area

Catchment is an area where rainwater is concentrated and contributes some or all its share of rainwater to a target area. It can be agricultural, rocky or marginal land, or even a rooftop or a paved road. The rainwater harvested from catchment area should be

proportional to command land. The only requirement for a catchment surface is that it has to be impermeable and does not seriously contaminate the water. Ground catchment systems are cheaper than roof catchments and water could collect from larger area. The main disadvantage in using the ground as a collecting surface is that the water supply can easily become contaminated, and since it can only be stored below the surface, it is generally less convenient to withdraw it for use. According to Nordin and Hamid (2011), there are six components of any RWH system; catchment area gutters, downspouts filtration system storage system delivery system, and treatment system to increase the volume of runoff there are three catchment treatment methods; coverings ground catchments using plastic sheet cement, tiles and other impervious materials (Gould and Petersen, 1999). Moreover, the catchment area should be sufficiently away from pollution sources (toilets, animal sheds, etc.), and must be protected from contamination (Aroka, N., 2010). The size of the catchment area can be determined by using the following equation (Gould and Peterson, 1999 and MOA, 2002)

2.3.3. Runoff delivery systems

In order to convey runoff from the catchment to the storage, some sort of delivery system is normally required. The diversion channel leading runoff from the ground catchment area to the silt trap and into the tank should be made of compacted earth, or lined with cement or other materials. Depressions or primary sediment pits were used for ground catchment delivery systems to settle sediment as much as possible before entering silt trap. If the catchment area is a roof top, fix a gutter and flush guard to carry water from the roof into the tank (Aroka, N., 2010)

2.3.4. Drainage patterns

The suitability for cropping area of a water harvesting system depends on the drainage density. The drainage density is a good indicator of the suitability of the area for water harvesting, areas with high drainage density will rank higher in suitability for cropping area of a water harvesting system than area with low drainage density (Prinz *et al.*, 1998). Water harvesting structures located at a great distance from the river(s) has a much greater potential for water loss due to evaporation and seepage (Risinger and Turner, 2004). It is, therefore, suggested that distances closer to the river are more desirable for locating water harvesting structures. Bothale *at el.*, (2002) described that water harvesting structures are preferred along streams at distances of about 500 m distance on either side of the river (a

buffer of 1 km) is sufficient. It is important to note that none of the above parameters can be used independently to identify potential sites for RWH technologies. Usually a combination of all possible parameters is used to support the decision making process.

2.3.4. Hydrological soil group of West Hararghe Zone

Soil properties influence the relationship between runoff and rainfall since soils have differing rates of infiltration. Permeability and infiltration rate are the principal data required to classify soils into Hydrologic Soils Groups (HSG). Based on infiltration rates, the Soil Conservation Service (SCS) has divided soils into four hydrologic soil groups as follows:

Group A: Sand, loamy sand or sandy loam is the soils having a low runoff potential due to high infiltration rates. These soils primarily consist of deep, well-drained sands and gravels.

Group B: Silt loam, or loam. Soils having a moderately low runoff potential due to moderate infiltration rates. These soils primarily consist of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

Group C: Sandy clay loam soils known with having a moderately high runoff potential due to slow infiltration rates. These soils primarily consist of soils in which a layer exists near the surface that impedes the downward movement of water or soils with moderately fine to fine texture.

Group D: Clay loam, loam, sandy clay, silt-clay, or clay is that soils with high runoff potential due to very slow infiltration rates. These soils primarily consist of clays with high swelling potential, soils with permanently high water tables, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious parent material.

2.3.5. Silt trap or sediment pond

It is used to allow the sediment which is being carried in the runoff from the catchment area to settle. Its size is determined according to sediment characteristics and flow discharge. If a lot of sediment is expected, a two-chamber silt trap is recommended one chamber to catch sand, and the second one to trap finer material. A filter mesh is used to trap leaves, twigs and other debris before the water drains into the tank. It is dug at least 3m away from the storage tank to prevent water from over topping during heavy rains and damaging the tank (MoA, 2002).

2.3.6. Storage facility of water harvesting

It is the place where runoff water is stored from the time it is collected until it is used. Different size and shape of surface and sub-surface storage structures are available. Storage tanks and ponds are the common ones. Storage tanks can be above ground, which are common in the case of roof catchment systems or underground tanks, which are normally associated with ground catchment systems (Gould and Peterson, 2003).

The choice of suitable and cost effective rainwater harvesting tank having appropriate volume needs careful consideration of the existing catchment area, rainfall conditions and the amount of water required. Field experience has shown that universally ideal rainwater harvesting tank design does not exist. Local materials, skill and costs, personal preference and other external factors may favor one design over another (Gould and Peterson, 2003).

In many rainwater-harvesting systems the water storage facility is the most expensive single item and may represent in excess of 50% of the total cost of the entire system (Kihara, 2002). Unlined earthen tanks or ponds are usually not a satisfactory structure for water storage unless seepage losses can be controlled. In some installations, lining with plastic sheets or soil sealed with concrete or any other suitable materials can control seepage. Controlling water lost by evaporation is one of the most effective methods of maintaining adequate water storage and should be an integral part of any open water storage facility (Arega, 2003).

In tropical and hot arid climates, water tanks should be white-washed or lined with white color material to make it more reflective and reduce the effect of solar heating (Gould and Peterson, 2003). Although relatively expensive, a roof over the rainwater storage facility is an effective means of controlling evaporation (Hune and Kimeu, 2002) and reduces the risk of contamination by preventing insects and small animals entering the storage (Gould and Peterson, 2003).

2.4. Suitability of Sites for Rainwater Harvesting

2.4.1. Factors affecting suitability of site for rainwater harvesting

Extensive literature exists on the social and economic significance of RWH sites and how they benefit the communities that use them (Amha, 2006; Kessler, 2006; Ketsela, 2009). (Bulcock and Jewitt, 2013) indicated that research has also been done to assess the suitability of selected research catchments for the setting of RWH technologies. Amha,

(2006) in his study in Ethiopia reported that there are two major steps that need to be followed when selecting RWH technologies and sites where they can be implemented. These are; setting priorities the people's choice land technical knowhow and criteria.

The selection of a specific technique must consider the social and cultural aspects prevailing in the area of interest as they are vital and will determine the success or failure of the technique implemented. This is mostly essential in the arid and semi-arid regions and may help to explain and understand the failure of many projects that did not consider the people's priorities. In arid and semi-arid areas, the majority of the population experienced fundamental regimes over the centuries, which set priorities for their survival.

FAO (2003) reported that the suitability of the area for RWH depends on a number of factors such as, rainfall, soil, land use, topography and socioeconomic factors. Thus, other researchers have used these parameters in identifying RWH suitable sites. Prinz *et al.*, (2008) For instance, in their study considered rainfall and topography to identify potential RWH sites. Kahinda *et al.*, (2008) in South Africa identified six key factors when identifying RWH sites: This are; hydrology (rainfall–runoff relationship and intermittent watercourses), topography, crop characteristics, soils types and socioeconomic like work force, people's priority, population density, experience with RWH, land tenure, accessibility and water laws. Therefore it was recommended to integrate socioeconomic factors when deciding the suitability of an area to RWH (Crotchet, 1991). Similarly Amha, (2006) reported that consideration of social and cultural aspects is particularly important in the arid and semi-arid regions of Africa and may help to explain the failure of the technology.

The fundamental selection criteria for the different RWH technologies are based on soil moisture regimes and slope of the area. For this reason, an area is considered suitable for RWH if it has soils with high water holding capacity such as clay loam while RWH is not suitable for areas that have shallow sandy soils because due to low water holding capacity. This agrees with the study by (Kahinda *et al.*, 2008; and Mbilinyi *et al.*, 2014) that recommended RWH technologies to be implemented on soils with high water holding capacity. On the other hand, areas with slope of less than 5 % are considered suitable for RWH which also agree.

2.4.2. Suitable area for rainwater harvesting systems

Rainwater harvesting systems can be applicable in all agro- climatic zones and can be more appropriate in arid, semi-arid and sub humid areas; where water demand of crops is higher than the supply because of low and uneven seasonal distribution of rainfall, and high evapotranspiration; in areas where other permanent water sources such as rivers, shallow wells and springs are not available or uneconomical to develop (Gary, 2011). The main reasons for the importance of rainwater harvesting compared to other options are rainwater can easily be available in moisture stress areas compared to others sources of water; rainwater harvesting requires low level of external energy for its extraction or transportation; can easily be implemented using family labor and locally available materials and it is simple to manage and operate.

The factors that should be taken into consideration in identifying areas/sites for implementation of rainwater harvesting systems were: availability of irrigable land, land use and land cover of the catchment, topography and terrain profile, soil type and soil depth, meteorology and hydrology data, socio-economic and infrastructure conditions, and environmental and ecological impacts. A preliminary study before designing and constructing the tank is required and if possible, compare two or more locations before selecting any one site (Marco and Hune, 2000).

2.4.3. Techniques of site selection for rainwater harvesting

Integrated Mission for Sustainable Development (IMSD) was devised to identify the physical suitable sites for RWH technologies in Africa (Jasrotia *et al.*, 2009). The guidelines set by (Oweis *et al.*, 1998) are the most comprehensive since they consider land of complex terrain for RWH technology. They determine criteria for different types of RWH technologies and set ideal and suitable limits for factors such as rainfall, soil texture, soil depth, slope, land use (cover), socio-economic (population density) and ecological conditions. According to FAO (2003) promotion of RWH technologies in areas receiving less than 100mm/year or more than 1000 mm/year of rains is not recommended (Mati *et al.*, 2006). There is no incentive to implement RWH technologies in areas with annual rains in excess of 1000mm/year whilst there is hardly any productive water-based activity in areas with annual rainfall less than 100 mm/ year. Mwenge Kahinda *et al.*, (2008) used

annual rainfall as one of the criteria for selecting potential areas for in-field RWH technologies.

The suitability of an area as a catchment area in RWH depends mostly on its soils characteristics. Soils with high infiltration rates, such as sandy soils, are not favorable for RWH technologies because large size of the soil particles determines how much rainwater can be stored in the soil profile. Tumbo *et al.*, (2014) explained that soil texture determines the total water storage of the soil, which determines moisture availability in *in-situ* RWH for crops during dry spells. Similarly White, (1987) recommended that fine and medium textured soils are generally the more desirable for RWH because of their better retention of nutrients and water. However soils with high percentage of silt and clay particles have higher water holding capacity (Ball, 2001).

Therefore, the main challenge in implementation of RWH technologies such as contour tied ridges and soil mulching is how to minimize water losses mainly due to evaporation and seepage respectively (Ngigia *et al*, 2005). The soil depth must be deep enough to allow for excavation of RWH technologies as well as ensuring adequate rooting development and storage of the harvested water. Moges (2004) noted that the deeper the soil the higher is the water storage capacity and vice versa. As Ketsela, (2009) said that, sites with deep soils are relatively suitable for location of RWH technologies than shallow ones as deep soils have higher capacity of storing the harvested runoff as well as providing a greater amount of total nutrients for plant growth.

Thus the deeper the soil, the more suitable it is for in field RWH (FAO, 2003b). (Ketsela 2009) and (Mwenge Kahinda *et al.*, 2009) also used soil depth as the factor for selecting in-field RWH suitable sites. Alazba and Shereif (2014) indicated that slope of the catchment affects how quickly water will runoff during a rain event.

A steep area will shed runoff quickly while a less-steep, flatter area will cause the water to move more slowly, raising the potential for water to remain on the soil surface. Mati and Bock, (2006) recommended the use of slope of the land in site selection and implementation of all ground based RWH technologies. Critchley *et al.* (1991) recommended the use of In-situ RWH in areas where slopes are less than 5 % because of large quantities of earthwork required which is often costly and uneven distribution of runoff. Mwenge-Kahinda *et al.* (2009) noted that there is a correlation between the runoff generated in a catchment and land use of the area for a particular rainfall event.

The increase in the vegetation density in the area results in a consequent increase in interception, and infiltration rates hence runoff is reduced (Thompson, 1999). Therefore, design of RWH must take into account the runoff factor. In other studies Ketsela, (2009; Mwenge-Kahinda *et al.* (2009); Ziadat *et al.*, (2012) have recommended the use of socioeconomic and ecological data in order to improve on the RWH suitability model.

2.4.3.1. Using GIS and RS for selecting RWH sites

Computer technology has advanced greatly in recent decades, including Geographic Information Systems (GIS) packages supported by Remote Sensing (RS). These offer cost effective and timesaving methods for identifying suitable sites for RWH (Ammar *et al.*, 2016). RS can be used to obtain accurate information with high spatial and temporal resolution image of the concerning area. GIS are very essential tools, particularly in areas where very little information is available, which is often the case in developing countries (Mahmoud and Alazba, 2014). GIS is a useful instrument for collecting, storing, analyzing and retrieving spatial and non-spatial land data (Mati and Bock, 2006).

Several thematic layers can be generated by applying spatial analysis with GIS software. These layers can then be overlaid for identifying suitable sites for RWH. The use of RS and GIS in decision making and planning about the type of RWH technology to be implemented in a particular spatial watershed is extremely important to avoid investing on unproductive technologies. Mahmoud and Alazba (2014) also used a GIS-based decision support system (DSS) that used remote sensing (RS) data, field survey, and GIS to delineate potential RWH areas in the interested study area. (Ketsela 2009) in his study applied a GIS approach by integrating different factors such as, soil depth, soil texture, climate, land cover, slope and groundwater but did not include socioeconomic factors. Hence, socioeconomic factors (e.g. market access, infrastructure, population density) were recommended to be important for a complete assessment of the RWH land suitability.

Napoli *et al.* (2013) indicated the importance of carrying out the field surveys when identifying suitable sites that may have been missed by the GIS data. The final suitability maps are very important as they give the farmers' opportunity to state their needs (Ammar *et al.*, 2016). Thus, GIS and RS have been proven to be time saving, flexible and cost-effective tool for suitability of RWH technologies especially for large areas. The

suitability maps are easy to understand and provide information to quickly identify areas that are more suitable than the other for implementation of RWH technologies.

The weighted overlay also known as Multi Criteria Evaluation (MCE) is the most commonly used GIS method of analysis that integrates data for several criteria. Malczewski (2004) in his study indicated that the use of Multi- Criteria decision-making methods (MCDM) with GIS have considerably advanced the conventional map overly approaches to the land-use suitability analysis. Analytic hierarchy process (AHP) is one of the GIS- based MCDM that combines and processes spatial data (Input) into a resultant decision (Output). Key steps in AHP as indicated by Malczewski (2004) include; (i) the GIS capabilities of data acquisition, storage, retrieval, manipulation and analysis, and (ii) the MCDM capabilities for merging geographical data and decision maker's preferences into same dimensional values of alternative decisions. Thus, AHP is a very important decision making tool that can be used to assist in obtaining an appropriate decision over suitability assessment of RWH.

The process illustrated by Saaty, (2008) involves the identification of factors that are selected in a hierarchy manner starting from the overall goal to criteria, sub- criteria and alternatives. Saaty, (2008) outlined four major steps in undertaking AHP organized in order to make a decision over alternatives. These are; (i) Definition of the problem to be considered, identify the goal which is the criteria that other elements usually the alternatives will depend on which should be at the top of the decision making tree, (ii) develop a pair wise comparison matrix, (iii) Applying criteria to alternatives and rank alternatives, and (iv) Conduct sensitivity analysis by weighting. The weighing assigned to the thematic layer vary from one site to the other hence may not be replicated (Munyao, 2010).

2.4.3.2 Modeling of rainwater harvesting

Rainwater harvesting can be visualized through hydrological models that are able to show directions of flow, runoff and run on area and identify locations for harvesting advance. Quantification of harvested rainwater has been done using a rainfall runoff modeling (RRM) in order to determine the effects of different RWH technologies on soil moisture (Makurira *et al.*, 2009). Researchers have used various models in modeling RWH

with some focusing on specifically RWH while others used general hydrological models and others have even used a combination of RWH and hydrological models.

All runoff models are simplifications of the mathematical description of the actual process of runoff in nature (Jones, 2013). Some models are simplified than others but all have one thing in common thus the mathematical description that enables various factors that are being considered to make quantitative predictions (McCartney *et al*, 2004). Factors involved in runoff such as soil characteristics, differ extensively over small distances. It is difficult to account for each variation in space in a mathematical model (Jones *et al.*, 2013). The main challenge is taking into account changes in land use/ cover to make the predictions of the model to be very useful (Ncube, 2006)..

2.5. Crop Production Under Irrigation

2.5.1. Determination of crop water requirement

As Smajstrla (2002) defined crop water requirement as the total water allocated to fulfill crop's evapotranspiration demand from irrigation or precipitation hence, it does not decrease the production. Crop evapotranspiration relates to the quantity of water that is lost by evapotranspiration. It is important to verify crop water requirement in order to understanding irrigation demand in better way. Irrigation water requirement is basically understood the variation in the crop water requirements and the effective amount of available precipitation. With Irrigation water requirement we have to consider including the amount of water for leaching of soil and its adjustment for non-uniformity of water application (FAO, 1998). The equations given below are used to estimate the "crop water requirement" (CWR) which is basically equal to the crop evapotranspiration in normal considerations. In order to practically compute the actual crop evapotranspiration (ET_c), requires estimating potential or reference Evapotranspiration after that, imposing the proper crop coefficients (K_c).

2.5.2. Review of CROPWAT Model

This study find out the possible solutions for various problems in conditions of improving irrigation water allocation and use in shortage supply context, to be more specific at Daro Labu District area . Hereby, to come up with an appropriate and standard calculation for estimation of irrigation practices through understanding of crop water requirement,

planning of cropping options under various irrigation management system, and other assigned relevant objectives and scopes, CROPWAT model, which is a practical tool for helping researcher to analysis results with draw conclusion, is appropriate to apply in context of this study. Further, use of this model is helping to achieve meaningful comparisons results. And another important property of the CROPWAT model is that, it let to have extension of the decisions and conclusions from studies to conditions not tested in the field. Therefore, it can offer practical recommendations to farmers and extension staff on deficit irrigation scheduling under various conditions of water supply, soil, and crop management conditions.

CROPWAT is a decision support system, originated by land and Water development division “of FAO by Smith (1992). In order to estimate, reference evapotranspiration, water requirement and to support Irrigation water requirement (IWR). The algorithm for the estimation CWR and IWR in the model is based on the calculation of the reference evapotranspiration (ET_o) which is counting as per Penman-Monteith and other crops parameters. To develop irrigation scheduling under different management system and scheme supply, to evaluate irrigation application efficiency, rain fed production and effect of drought,

CROPWAT would be the appropriate tool for developing these all climatic and crop data are essential as inputs for CROPWAT model for determination of crop water requirements. The development of irrigation scheduling, rain fed agriculture evaluation and over all irrigation practices are grounded on a daily soil water balance approach using various alternatives in terms of supply and irrigation management system (Amir, 2001).

2.5.3. Overview of CROPWAT Model

CROPWAT is a computer program to calculate crop water requirements, reference evapotranspiration and irrigation requirements from climatic and crop data. Furthermore, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying cropping patterns. CROPWAT is one of the models that are being extensively used in the field of water management throughout the world which is designed by Smith (1991) of the Food and Agricultural Organization (FAO). CROPWAT facilitates the estimation of the crop evapotranspiration, crop water requirements and irrigation schedule with different

cropping patterns for irrigation planning (Kuo *et al.*, 2006; Gowda *et al.*, 2013; Martyniak *et al.*, 2006; Dechmi *et al.*, 2003; Zhiming *et al.*, 2007).

CROPWAT is a decision support system developed by the Land and Water Development Division of FAO for planning and management of irrigation. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rain fed conditions or deficit irrigation (FAO 1992).

Water use requirement for same crop varies under different weather conditions. To achieve effective planning on water resources, accurate information is needed for crop water requirements, irrigation withdrawal as a function of crop, soil type and weather conditions (George *et al.*, 2000; Gouranga and Verma, 2005).

CROPWAT is a FAO model for irrigation management designed by (Smith,1991) which integrates data on climate, crop and soil to assess reference evapotranspiration (ET_o), crop evapotranspiration (ET_c) and irrigation water requirements. The climatic input data required are reference evapotranspiration (monthly/decade) and rainfall (monthly/decade-/daily). Reference evapotranspiration can be calculated from actual temperature, humidity, and sunshine/radiation and wind-speed data, according to the FAO Penman Monteith method (FAO, 1998).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location of the study area

The assessment was accompanied in Western Hararghe zone of Oromia Region, at Daro Labu district. It is located 435 km to the east of Addis Ababa and 115 km from Chiro (Zonal Capital) to the south on a gravel road, that connects to Arsi and Bale Zones. Geographically location was found between latitudinal and longitudinal positions are lies between $40^{\circ}20'00''$ - $40^{\circ}70'00''$ E and $08^{\circ}15'00''$ - $08^{\circ}40'00''$ N respectively and found within Wabe Shebelle river basin catchment areas (figure 3).

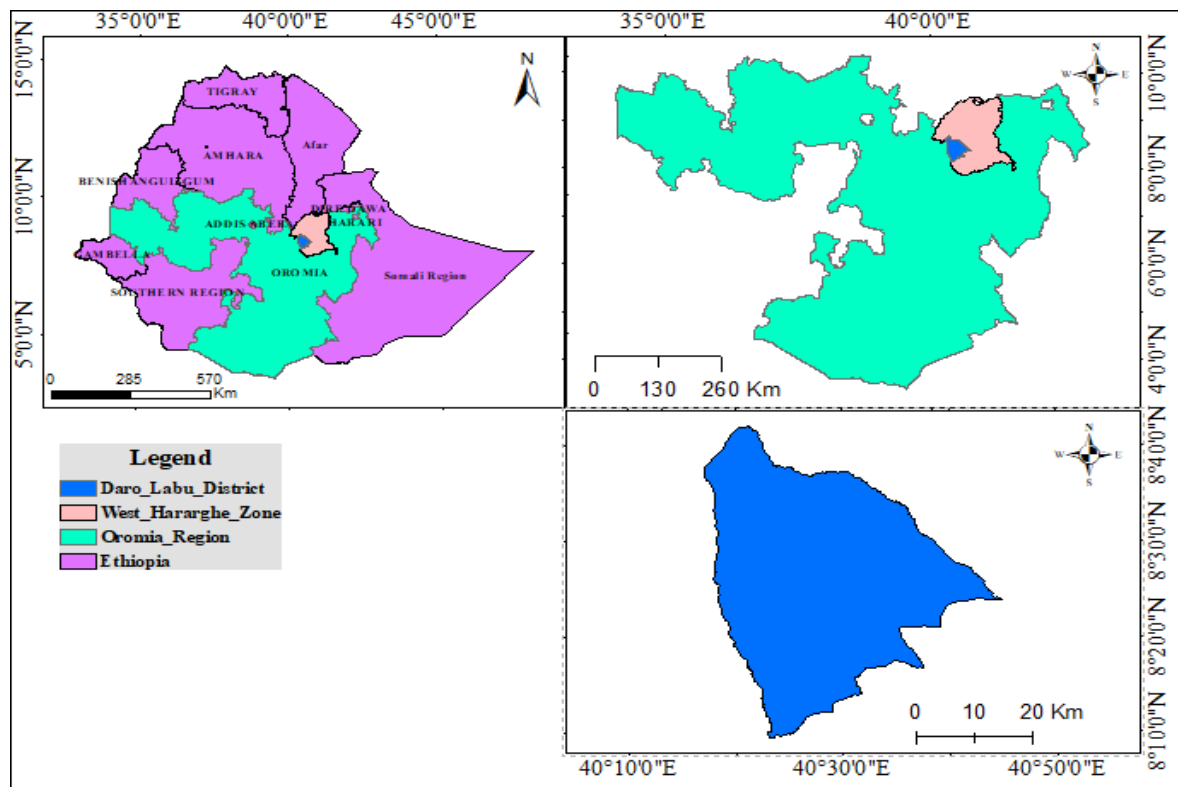


Figure 3: Location map of the study area.

3.1.2. Climate

The area has bimodal type of rainfall distribution with annual rainfall ranging from 750-1200 mm with average annual rainfall of 1090 mm and ambient temperature of the district varies from 14 to 26°C with an average of 20°C summarized from Mechara Meteorology Station. The nature of rainfall is very erratic and causing marvelous erosion.

The predominant production system in the district has mixed crop-livestock production with unusual sub-systems. The crops grown in the area includes cereal (maize, sorghum, and finger millet), fruit crops like banana and mango and pulse crop (soya bean, groundnut) were produced for consumption. The other production especially cash crop Hararghe specialty coffee and Chat has been produced.

3.1.3. Topography and soil type

The land feature of the district is known by undulated type and an even mountainous with altitude range from 1041-2774 m a.s.l. (Ethio-DEM, 2017). The area coverage is about 156064.72 ha with major soil type of the area is covered by Chromic Cambisols (43.28%), Chromic Vertisols (21.3%), Rendzinas (20.6%) and Vertic Cambisols (9.89%) and its texture is sandy clay loam which is reddish in color (FAO Soil Classification 2015).

3.2. Methods of Data collection and Analysis

The collected data of soil was analyzed and organized by excel then interpretation such as homogeneity test consistency of the continuous data (rainfall data) was done depend on the result. The spatial data analyzed by ArcGIS software. Those parameters were (i.e. slope and contour interval analysis), DEM was used to identify the slope factor from the respective topo-map of the area was analyzed.

Data on land use and land cover, size, physical performance and present capacity of each components of the system was collected from different respective office for estimation of Rainwater Harvesting of the study area. Different shape file of soil suitability map were taken from Oromia water work design and enterprise (OWWDE).

Meteorological data of the district was taken from Ethiopian national meteorological agency (NMA) The secondary data include cloud free Landsat 8 image (spatial resolution of 30 m distance) and Advanced Space borne thermal emission and reflection radiometer (ASTER) data (30 m x 30 m) DEM, was downloaded from United States Geological Survey (USGS) of Global Visualization Viewer

Website :(<https://earthexplorer.usgs.gov>).

3.3. Assessment of Topography and Land feature

3.3.1. General approach of rainwater harvest (RWH) mapping

The identification of suitable areas of RWH was used to a multi-objective and multi-criteria problem. The multi-objective and multi-criteria methodology were used to involved the following major steps: Selection of criteria; Assessment of suitability level criteria for potential area of water harvesting assignments of weights overlay to these criteria; Collection of spatial data for the criteria including GPS/ GCPs to supplement and generating maps for each using GIS tools; Developing a GIS-based suitability model using GIS Model builder which combines maps through MCE process; and Generate suitability maps was done.

3.3.2. Using Digital Elevation Model (DEM)

The DEM was employed to offer varieties of data that assist in produced landforms map, soil types, and hydrologic information drainage networks and sub-catchment boundary of the study area was done by extracting from DEM in order to investigate the spatial relationship of agricultural fields and the catchment-drainage networks. Digital Elevation Model data was developed using the method described in the procedure of extraction through ASTER data (figure 4).

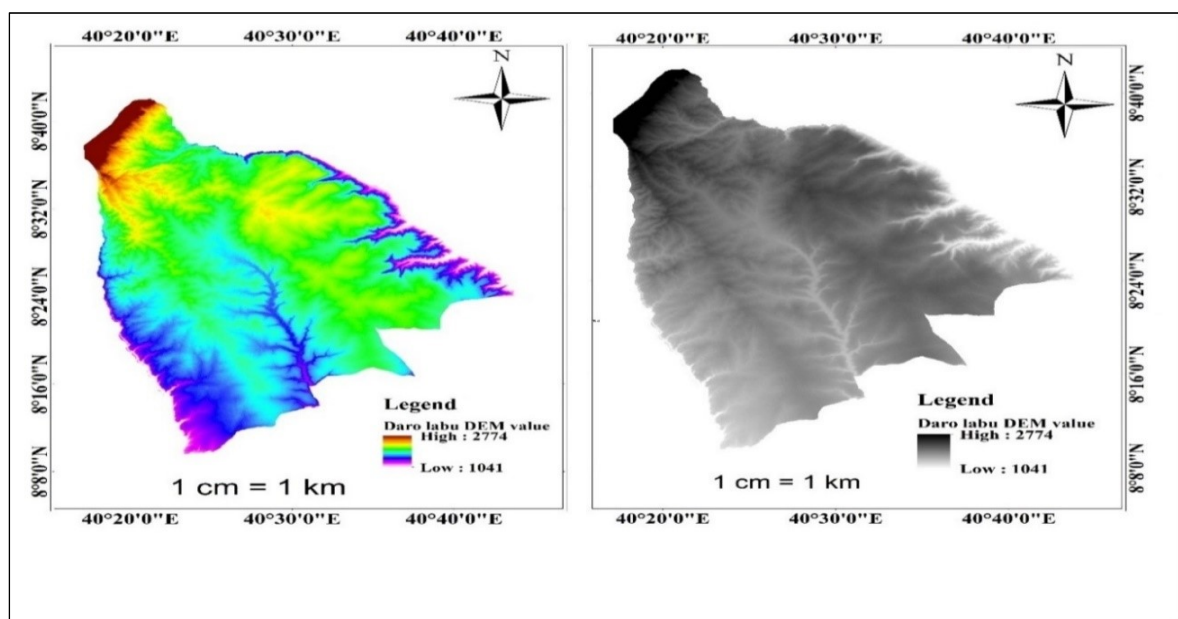


Figure 4: Digital Elevation Map of Daro labu District

3.3.2.1. Contour data

To identify the contour of the study area, digital elevation model (DEM) raster surface was used to create contour lines by 25 m intervals in raster (grid) format. The employed GIS algorithm considers the line segments that fall within a cell or its eight neighboring cells, in calculating the contour density. The grid density was reclassified into sub classes and used as one input parameter in the GWAMP model. Digital elevation models (DEMs) was computerized representations of land surface arrangement.

3.3.2.2. Slope of the study area

Slope data were generated from the DEM grid corresponding to the boundary of the catchment. The slope assignment corresponds to the maximum change in elevation between a cell and its eight neighbors, i.e. the steepest downhill gradient for a grid cell on a raster surface. The slope was expressed in percent ranging from zero (0) to 100. If any neighborhood cell was assigned to the value of the center cell and slope is computed. At the end the slope (percentage) data was classified into seven categories according to FAO guidelines was used for the values (>3%, 3-5%, 5-8%, 8-16%, 16-30%, and greater than 30%) was Down loaded from (<http://www.iiasa.ac.at/Research/LUC/GAEZ/index.htm>)

3.3.3. Soil texture and soil depth

To derive the soil texture, depth, drainage and infiltration attributes based on the dominant soil type map was extracted from the Harmonized World Soil Database (DSMW, 2009) with a spatial resolution of 25 x 25 arc minutes. The soil class attributes was taken from the International Soil Information Research Center (ISRIC). The soil depth map was a simplified version of the soil depth data from the FAO spatial data repository (FAO, 2007).

3.3.4. Rainfall data validation

The district of twenty years (1999-2018) climate data of five meteorological station (*Mechara, Micheta, Gelemso, Dumuga and Chancho*) daily rainfall, maximum and minimum temperature, Relative humidity, sunshine hours and wind speed was taken from national meteorological agency (NMA).The data were used to estimate the annual precipitation amount of the study area. Annual average rainfall of five meteorology station

was taken and runoff estimation was computed from annual rainfall amount also calculated as well yearly water has been harvested was estimated. The weather data also used to for crop water requirement using dependable method of effective rainfall from mean monthly rainfall.

3.3.4.1. Estimation of missing data

Missing records of the rainfall stations were estimated by using normal ratio method which is recommended to estimate missing data in regions where annual rainfall among stations differ by more than 10% (Dingman, 2002). This approach enables an estimation of missing rainfall data by weighting the observation at N gauges by their respective annual average rainfall values as expressed by equation 1 (Yemane, 2004).

$$P_x = \frac{1}{N} \left[\sum \frac{P_x}{P_i} * P_g \right] \quad (1)$$

Where:

P_x = missing data,

P_x = the annual average precipitation at the gauge with the missing data,

P_i = annual average values of neighboring stations

P_g = monthly rain fall data in station for the same month of missing station

N = the total number of gages under consideration

The monthly maximum and minimum temperature values at *Mechara*, *Micheta*, *Dumuga*, *Chanco* and *Gelemso* stations have been averaged into annual maximum and minimum long term monthly values. These values were used as input data for evapotranspiration computations. Other climatic data such as sunshine duration, relative humidity and wind speed data of the stations were averaged into long term mean monthly values and used for evapotranspiration calculation.

3.3.4.2. Consistency of rainfall data

Double-mass curve analysis revealed that there is good direct correlation between the cumulative rainfall of the five meteorological station (*Mechara*, *Micheta*, *Dumuga*, *Chanco* and *Gelemso*) with the cumulative average rainfall of the five stations ($r=0.999$). This indicates that the rainfall of the all station is consistent. Figure (5) the correlation coefficients of the five stations indicated that there is good direct correlation

between the stations' records and their corresponding base stations. Therefore, that the rainfall data from all stations were used for further application. Sometimes the rainfall amount at certain rain gauge station for a certain days or months may be missing due to the absence of instrumental failure or some observer. In such like cases, the nearby station technique was used to estimate the missing data.

To prepare the rainfall data for further application, their consistency checked using double mass curve analysis was used. A plot of accumulated rainfall data at site of interest against the accumulated average at the surrounding stations had been generally used to check consistency of rainfall data. To check the degree of consistency, Nemec (1973) provided the value of 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

$r = -1$: reciprocal linear correlation

The stream flow and rainfall data are relatively consistent if the periodic data are proportional to an appropriate simultaneous period, and of these data, which are inconsistent, can be adjusted by proportioning, using correlation coefficient, between the stations (selesh, 2000, Moutaz, 2001 and Yarahmad, 2003).

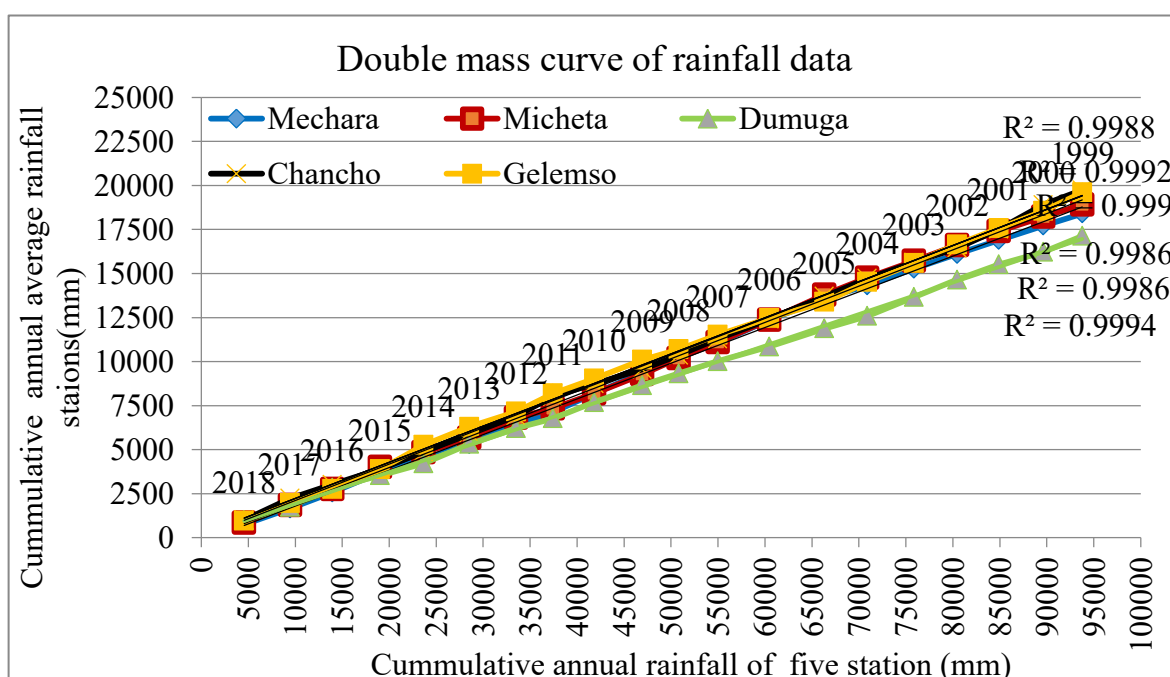


Figure 5: Double mass curve of Average Annual Rainfall of Five Meteorological Station

3.2.4. Thiessen polygon method

Rainfall distribution by The Thiessen polygon method accepts that the estimated values taken on the observed values of the nearby station (Nalder *et al.* 1998). Nearest neighbor, methods were intensively examined by pattern recognition procedures. Despite their inherent simplicity, nearest neighbor algorithms are considered versatile and robust. Although more sophisticated alternative techniques have been developed since their inception, nearest neighbour methods remain very popular (Ly *et al.* 2013).

The application of rain gauge as precipitation input carries many uncertainties. The spatial and temporal distribution of rainfall at sub-basin scale, using GIS approaches are found to be very effective in the study area.

Table 1: Area, Annual Rainfall and Altitude of the five-meteorology station

S/No	Meteorology station	Area (ha)	Area (%)	Annual RF(mm)	Mean Altitude
1	Micheta	63068.5	40.41	1005.33	1805
2	Mechara	28268.6	18.11	1014.83	1791
3	Dumuga	53762	34.45	1052.79	1572
4	Chancho	5828	3.73	980.26	1400
5	Gelemso	5143	3.30	1006.68	1786

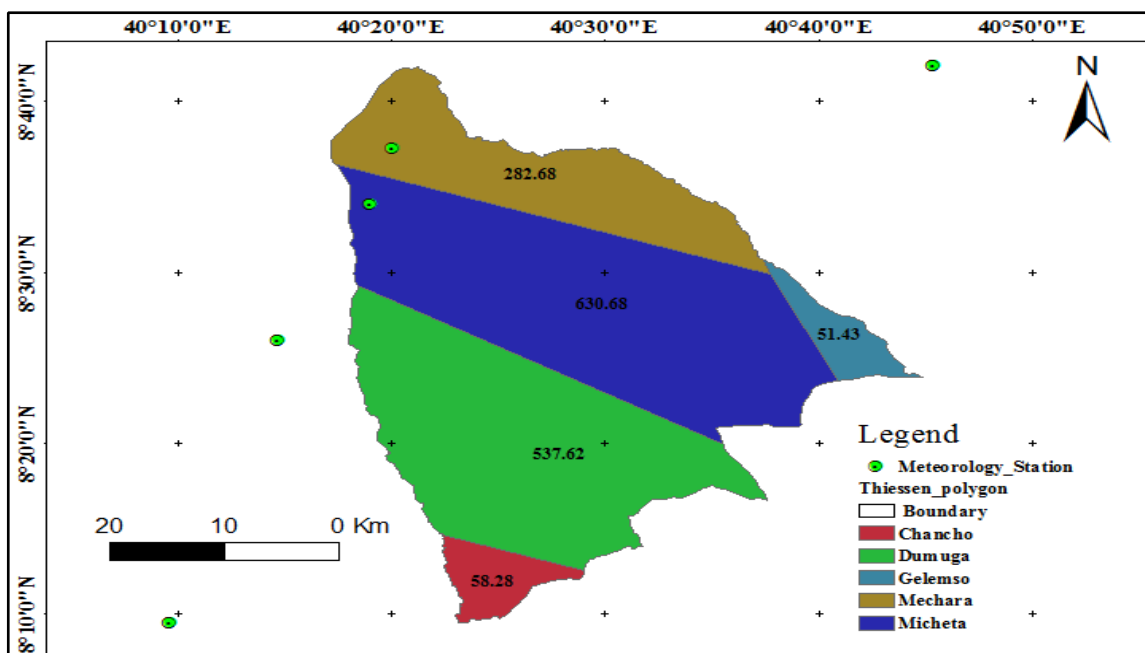


Figure 6: Area considered under thiessen polygon map of the study area

3.3.5. Runoff depth estimation

The run off depth estimation was done by calculate the runoff for each grid cell using monthly precipitation, land use land cover and soil type. Soil Conservation Service and Curve Number (SCS-CN) method were used to calculate the potential runoff in the study area. This method requires the determination of the maximum retention (S), which depend on the curve number (CN). Curve number value was computed which dependent on land-use classification and the hydrological soil group (HSG) of the land type. Land use/land-cover corresponds to the water retention capacity of the soil, were also a determinant factor for the rainfall-runoff relationship. Based on world land-use/land-cover classes, it was done from spot image using satellite extraction land sat of 2016.

Rainfall Runoff depth estimation was depends on the AMC of the five day rainfall depth amount which is listed as (Table 2). This was done using the runoff curve number method and computing the expected runoff using the local climate time series data from Daro-labu district weather station. The data was opened up in an Excel file and the corresponding runoff curve numbers for each individual 5 day rainfall accumulation classified and assigned.

The corresponding runoff was then determined and analysis carried out to find the expected runoff. The steps followed to estimate runoff potential was,

- i. Local planting season dates were obtained from New LocClim and a cumulative 5 day rainfall total column was created in the excel sheet. Single point mode search was used in New LocClim and an actual location for Daro Labu District with coordinates 40.77E, 8.57N was picked. The data obtained for the vegetative/cropping season was as shown in figure 5 below. From the data, there are two seasons a year in Daro Labu District area. One beginning on 8th March and ending on 3rd May, lasting 67 days and another one beginning on 29th March and ending on 26th October lasting 299 days. These are close estimates of the climate in this area, even when the actual dates of rain onset are determined meteorologically and sometimes delay or arrive earlier depending on the monsoon wind currents and heating in the Indian Ocean.

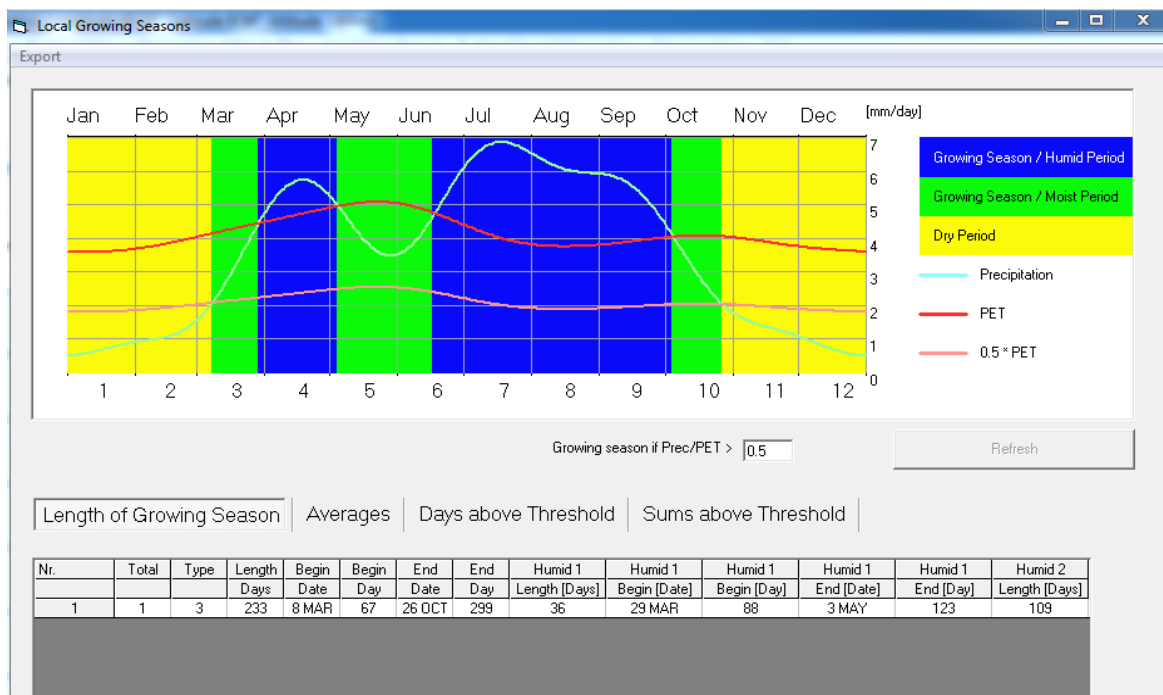


Figure 7: Growing and dry seasons for Daro Labu District area.

These dates for the growing period are important because most of the rainwater harvesting is expected to be done in the growing periods when there is plenty of rainfall. The rainfall-runoff relationship using the Curve number analysis method developed by the USDA was calibrated based on a consecutive five day total rainfall summation. This is because when it rains in the dry season or at the start of the growing season, the soil is dry and soil moisture depletion is high.

- ii. A column for rain in 5 days was created in the Excel data file for Daro-labu district climate (for all five-meteorology station).
- iii. The growing season and dry season were defined basing on results From New Loclim in another column.
- iv. Every 5 day rainfall total was classified depending on its intensity using guidelines in step I, step II and step III all created as conditions in the excel datasheet columns based on the Antecedent Moisture condition of the soil as shown in Table1 below.
- v. Determination of actual curve number: For each 5 day total rain depending on whether it lies in the dry or wet season, there are three possible runoff curve numbers. For each 5-day rain, the respective curve number in column excel sheet for data were obtained. Prior to this step, its good analysis to classify the data separately into class I curve number value, class II or class III respectively.

Table 2: Classification of Antecedent Moisture Condition (AMC)

AMC	Total 5 day Antecedent Rainfall (mm)	
	Dormant season	Growing season
I	< 13	<36
II	13- 28	36 – 54
III	> 28	>54

Source: Silveira *et al* (2000)

$$S = \frac{25400}{CN} - 254 \quad (\text{S in millimeter}) \quad (2)$$

$$Q = \frac{(P-Ia)^2}{(P-Ia+S)} \quad \text{For } Ia < 0.2 \quad (3)$$

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)} \quad \text{For } P > 0.2S \quad \text{and } Q = 0 \quad \text{for } P < 0.2S \quad (4)$$

Where:

Q = runoff depth, (mm)

P = rain fall, (mm)

S = maximum recharge capacity of the considered after 5 days rainfall antecedent

Ia = 0.3S (initial abstraction of rainfall by soil and vegetation, mm)

CN = Curve Number, was found out from the table (Mockus,1964 and (USDA, 2004)).

$$\text{weighted } CN = \sum \left(\frac{C_x * A_x}{A_{tot}} \right) \quad (5)$$

Where CN = the respective land type curve number

Cx = Values of weight land type

Ax = the area of the respective land class

3.3.6. Land use and land cover

Land use land cover of the study area was done from spot image land from (Spot Satellite Pour l' Observation de la Terre) using remote sensing taken from Ethiopian Mapping Agency Now called Ethiopian Geospatial Information of data spot image 2016. In order to do the image classified into land use and land cover of the study area using ArcGIS Map ver. 10.4. Land-use and land-cover was extracted from Landsat 8 OLI Satellite Imagery, using ERDAS Imagine version 15 image classifications. A different LU/LC classes were applied through supervised classification, and maps such as reference and topographic maps, from Google earth explorer and world land-cover images was used.

The Vector data of remote sensing spot image was change into raster form using image classification from ArcGIS map toolbar and the Spot image area has already been classified into different LULC using ERDAS IMAGE classification. Land cover/use of the study area has also the factor, which used to evaluate the land suitability for water harvesting. In this research, lands cover classification done using SPOT 8 (Système Pour l'Observation de la Terre) satellite images for identifying land cover types to estimate potential water harvesting land. The classification was carried out using ERDAS IMAGE 15 software in the following steps.

3.3.6.1. Image pre-processing

Successful identification of land cover usually requires multi-temporal images. The SPOT image for the study area was assessed. The format of this image was Image, which could be imported into ERDAS Image directly. The SPOT image was geo-referenced by supplementary data such as topographic maps and geographic coordinates of the study area. Then true color composite images were created by combining spectral bands that most closely resemble the range of vision of the human eye which in the SPOT images were used for land cover analysis.

3.3.6.2. Image classification

There are two approaches to extract spectral information: the supervised and unsupervised classification (Long, 2004). Unsupervised classification is the method in which image pixels assigned to spectral classes without the user having previous knowledge about the study area whereas, supervised classification is a method that involves selection of areas in the image, which statistically characterize the categories of interest. Prior to the fieldwork, unsupervised classification from the SPOT image was conducted to understand the general land cover classes of the study area. Based on results from unsupervised classification and information from topographic map of the study area, sample-training sites were selected to collect geographic coordinates and field photographs during the fieldwork. The geographic coordinate values of field photographs were added to the SPOT image by Ground Control Points Selection dialog box in ERDAS Image classification. This information were then used in the selection region of interest for the supervised classification.

3.3.6.3. Accuracy assessment

To validate and crosscheck the result of the SPOT classification with known ground truth data, accuracy assessment was checked for the signature values of the classified images by calculating the confusion matrix in ERDAS software. The confusion matrix is a table with the columns representing the reference (observed) classes and the row the classified (mapped) classes (Rossiter, 2001). The ground truth data was used in the maximum likelihood report as the independent dataset from which the classification accuracy were compared. The accuracy is essentially a measure of how many pixels in the ground truth region of interests (ROIs) were classified correctly (Appendix Figure 2). Items calculated include; overall accuracy, kappa coefficient and confusion matrix. The overall accuracy was calculated by summing the number of pixels classified correctly and dividing by the total number of pixels.

3.4. Mapping Potential Area of Rain Water Harvesting

3.4.1. Criteria of selection and assessment of suitability level

Depend on information obtained from field survey supported by expert judgment; six criteria was selected for the identification of potential areas of rainwater harvesting i.e. (soil texture, soil depth, rainfall (precipitation and evapotranspiration), topography, population density and land use land cover was used.

The different scale on which the criteria were measured, MCE requires that the values contained in the criterion map were converted into comparable units. The criteria maps were re-classed into five comparable units i.e. classes namely; 5 (very high suitability), 4 (high suitability), 3 (medium suitability), 2 (low suitability), and 1 (very low suitability). The suitability classes was used as base as to generate the criteria maps (one for each criterion).

3.4.2. GIS based mapping potential areas of RWH of the study site

The GIS database of RWH potential in Daro-Labu District was developed using Arc GIS and Arc view (version 10.4) software, using both vector and raster (gridded) available databases. The major variables identified for prioritizing RWH in the GIS were rainfall,

topography (slope and contour interval), soils, land suitability and drainage or hydrological soil group of the study area was identified.

3.4.3. A GIS model for generating RWH suitability map

Generating suitability map was done in a suitability model builder of ArcGIS 10.4. The model produces RWH suitability maps by incorporating various factor maps layers using a Multi-Criteria Evaluation (MCE). Several tools of ArcGIS environment were built-in the model to solve various spatial challenges that included reclassifying values, projecting, and overlaying. All vector type format maps were converted into raster datasets to enable the ArcGIS weighted overlay. A weighted linear combination (WLC) of MCE is standardized to a common numeric range, and then summed by means of a weighted average. All factors were combined by using a weight to each factors followed by a summation of the results to generate a suitability map calculated using equation 6 by Malczewski (2004).

$$S = \sum W_i X_i \quad (6)$$

Where

S = suitability output level per pixel i

W_i = weight of factor i

X_i = criterion score of factor i

Therefore the higher the suitability value, S of a given site (pixel) i, the more suitable the pixel is for RWH technologies. S is based on the established suitability ranking of 1-5 where 1 denotes the sites (pixels) that are not suitable and 5 indicates areas (pixels) that are very highly suitable for Rainwater harvesting (RWH) adopted from (De Winnaar *et al.*, 2007).

3.5. CROPWAT 8.0 Model Input data

After all assessment of water harvesting done, and amount of annual Runoff depth was estimated, crop water requirement of the study area was done for validating the runoff production of the study area. Therefore, that for CWR there is different input parameter used. The software requires the following input data: Climate data: Temperature,

Humidity, Wind and Sunshine hours. The process of rainfall data, crop and cropping information. Crop name, planting date, crop Coefficient (Kc), Stages length(days), critical depletion fraction(p), yield response factor (Ky), crop height in m(if available), rooting depth (m) Soil data: Total available soil moisture,(FC-WP), maximum rain infiltration rate, maximum rooting depth, Initial soil moisture depletion(% TAM) and Initial available soil moisture were used as an input data.

$$CWR_i = \sum_{t=t}^T i (Kc_i \cdot ET_o - P_{eff}) \quad (7)$$

Where

CWR_i = crop water requirement of a in mm per day

Kc_i = crop coefficient of given crop I during the growth stage in which

t = initial growth stage T is the final growth stage respectively.

P_{eff} = effective rainfall

$$NIR = ET_c - E_{ffrain} \quad (8)$$

Where: NIR is net irrigation requirement, ET_c is crop evapotranspiration and Effective rainfall.

3.5.1. Dependable rainfall

After rainfall consistency and homogeneity was done the dependable rain fall for minimize the risk of long and short term climate change also determined using the 80% probability or frequency method for computing crop water requirements partially or fully covered by rainfall. However, while the rainfall contribution may be substantial in some years, in other years it may be limited. Therefore, in planning and designing irrigation projects, the use of mean values of rainfall should be avoided if more than 10 years of annual rainfall data are available, as is the case for five meteorological Station . In such cases, by using these data a probability analysis were carried out so that a dependable level of rainfall selected was used.

The dependable rainfall is the rain that accounted for with a certain statistical probability, determined from a range of historical rainfall records (FAO 1992). The portion of rainfall that finds its way into a river known as the effective rainfall, because the rest is lost in evaporation, detention on the vegetation and ground surface or retention in the soil. As the storm proceeds, the portion of effective rainfall increases and that of lost rainfall decreases.

Effective rainfall is determined using USDA method and that was deducted from gross irrigation to supply the remaining irrigation requirement (equation 8 & 9).

The irrigation water applied to bring the soil moisture content at the root zone to field capacity taking into account the effective root zone depth. The depth of water was determined using the following equation (eqn...9):

$$d = \sum_i^n \frac{M_{fci} - M_{bi}}{100} B_i x D_i \quad (9)$$

Where; d = net amount of water to be applied during an irrigation, mm

M_{fci} = field capacity moisture content in the ith layer of the soil, percent

M_{bi} = moisture content before irrigation in the ith layer of the soil, percent

B_i = bulk density of the soil in the ith layer

D_i = depth of the ith soil layer, mm, within the root zone, and

n = number of soil layers in the root zone D.

3.6. Data Analysis

Table 3: Spatial Database and Sources.

S/N	Data type	Sources of data
1	Digital Elevation Model (DEM)	ASTER from(www.earthexplorer.usgs.gov)
2	Meteorological data	Ethiopia National Metrological Agency (NMA)
3	Soil Data	HWSDs Ver. 1.2, OWWDE and MoW
4	Landsat8 (OLI) data	Ethiopia Mapping Agency (EMA)
5	Ground Control Points (GCP's)	GCPs were collected from each LULC

Table 4: Software Packages and material used to manage and analysis

S/N	Software/ Application Used	The Software / Application Purpose
1	ArcGIS 10.4	Data Visualization and map layout working
2	ERDAS IMAGE 15	Image preprocessing and Classification
3	New LocClim	Seasonal wet and dry period extraction
4	CROPWAT 8.0	Determine CWR
5	GPS (Android TS)	Collect Ground Control Point (GCP)
6	Microsoft Office 10	For manage and compile document

SOFTWARE USED: - The software used to prepare and analyze data were ArcGIS ver.10.4, ERDAS IMAGE Version 15, CROPWAT 8, New LocClim version 1.10 and MS Excel were used.

ArcGIS Map:- is computer-based system that stores geographically referenced data, links it with non-graphic attributes (data in tables) allowing for a wide range of information

processing including manipulation, analysis and modeling. A GIS also provides for map display and production.

ERDAS IMAGE: is an image processing software package that allows users to process geospatial and other imagery as well as vector data. Erdas can also handle hyper spectral imagery and LiDAR from various sensors.

CROPWAT 8.0 Model: - is a decision-support computer program based on a number of equations, developed by the FAO to calculate reference evapotranspiration (ET₀), crop water requirement (CWR), irrigation scheduling, and irrigation water requirement (IR), using rainfall, soil, crop, and climate data computation and for windows that a computer program for the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data. In addition, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns. CROPWAT 8.0 can also be used to evaluate farmer's irrigation practices and to estimate crop performance under both rain fed and irrigated conditions.

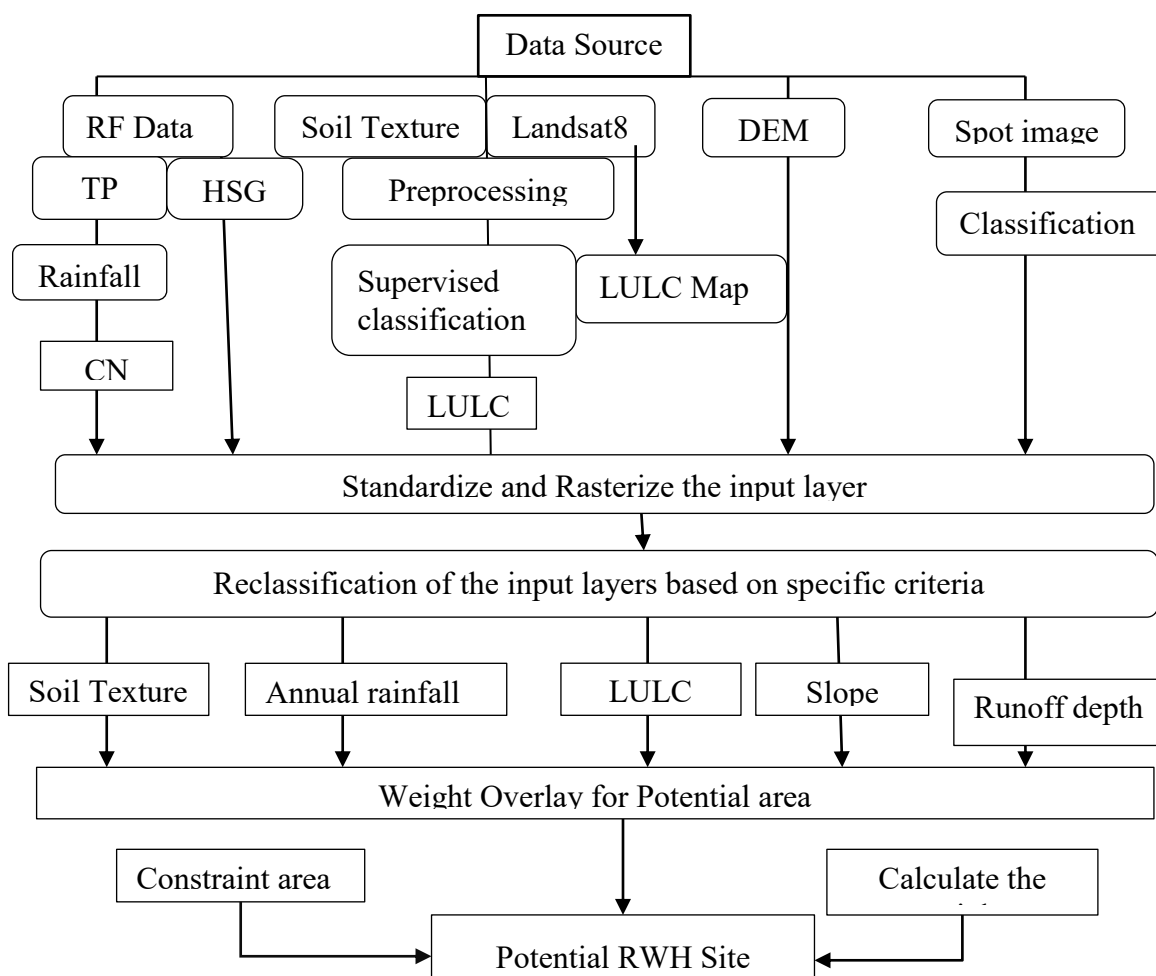


Figure 8: Flow chart of methodology of assessment of potential areas of RWH site

4. RESULTS AND DISCUSSION

4.1. Slope and Soil Physical Properties for Water Harvesting

4.1.1. Slope suitability class

More than 46 percent of the area of district slope was found at less than 3 percent as well as, 37 percent of the study area also found under slope 3-5 percent. According to FAO(1990) slope suitability classification for water Harvesting 0-3 percent slope was highly suitable, 3-5 percent slope was moderate suitable. In general, the steeper and longer a slope is, the faster water runoff generate, and the greater potential there is for erosion. But many other factors come into play in determining what becomes of a slope over time when exposed to storm water runoff (Table 5). Rainwater drains into a body of water by first passing over, under, or through several landmarks (Figure 8). According to previous research and the result obtained the slope value greater than.

S/No	Value (%)	Area(ha)	Area (%)	Slope Type	Suitability level
1	<3	73161.34	46.88	Gentle	Very highly

2	3-8	59032.28	37.83	Moderate	Highly
3	8-16	15776.86	10.11	Mode Steep	Moderate
4	16-30	6479.38	4.15	Steep	Low
5	>30	1611.72	1.03	Highly Steep	Very low
Total		156064.27	100.00		

Table 5: Slope classification and area coverage of Daro-labu District

As it shown (Table 5) the slope of the study was done and resulted with, the highest area coverage. In relation to water harvesting the highest potential found with the slope less than 3% and the lowest values were found at the slope greater than 30%, which was steep, and the water runoff rather than accumulated to harvest and infiltrated into underground resource water at steep slope area (Figure 9). The slope suitability for RWH is influenced by steepness, so that as the slope increase from steep to gentle and rather flat the water harvesting has been increases for suitability this also suggestion by (Ketsela 2009 and Tumbo *et al.*, 2014).According to FAO 1990 the slope which classes zero to 5 percent were highly suitable and 5 to 8 percent were moderately suitable for water harvesting which is also agree with the work of (Kahinda *et al.*, 2009 and Mbilinyi *et al.*, 2014).

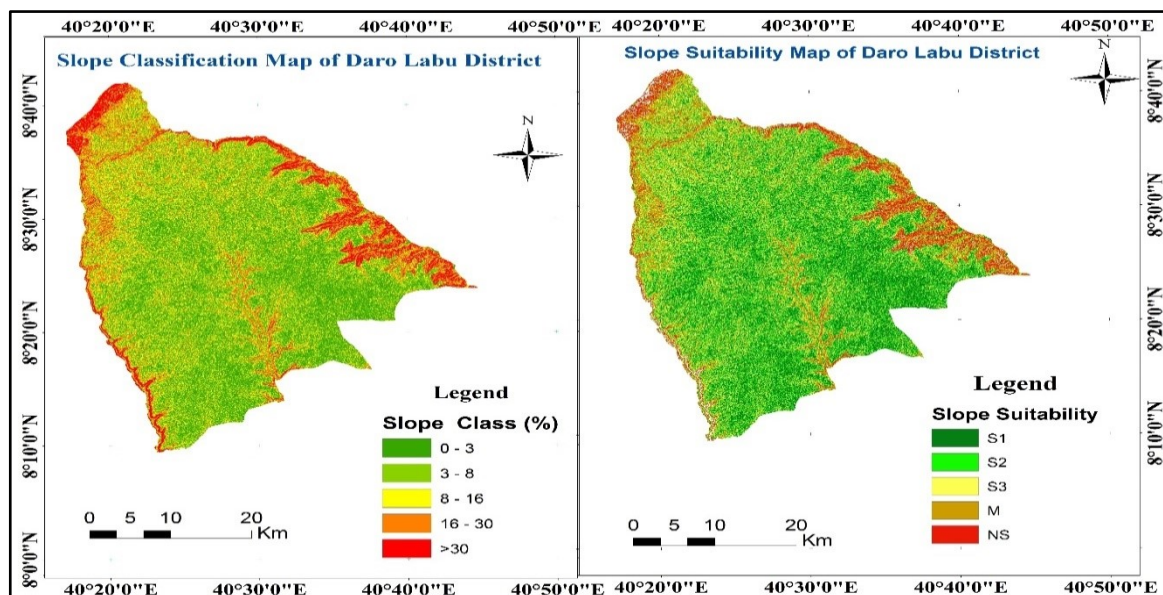


Figure 9: Slope classification and slope suitability map of Daro labu District

4.1.2. Soil physical properties

4.1.2.1. Soil texture class of the study area

The study area has been characterized by diversified geomorphology and soil patterns. However, the identification of representative soil textures and their physical as well as chemical properties were based on the FAO/ UNDP's (1999) classification. The area of soil texture was classes as shown in figure7. Spatially, the area coverage of soil texture of the district was, sandy clay loam (53.8%) was the highest coverage followed by clay soil (21.78%), loam soil (14.28%), clay loam (7.3%), sandy soil (1.9%), sandy loam, (0.9%) respectively. These textural soil classes indicates that the more in clay content there is the higher the soil moisture and at the area of high sandy content there is high run off (Figure7). The laboratory result from sample taken were also described in (Table 6). In order to identify suitability area of water harvesting with respect to soil texture suitability class has affected by clay content. The higher the clay contents there is higher soil moisture and water accumulation for harvesting which suggestion by FAO soil classification (1999 and 2003) this remedial also agree with (Tumbo *et al.*, 2014).

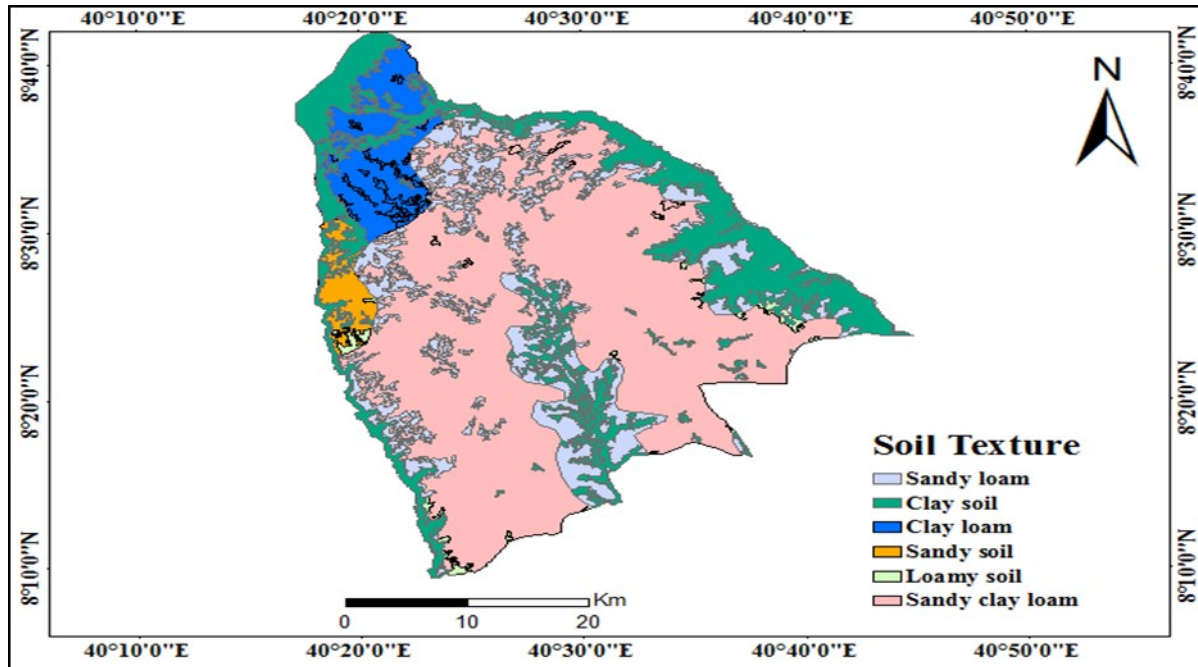


Figure 10: Soil texture map of Daru labu District

Table 6: Spatial distribution of soil texture in the study area

Soil Texture	Area (ha)	Area (%)	Drainage	Infiltration (mm h ⁻¹)
--------------	-----------	----------	----------	------------------------------------

Clay	33,996	21.78	Poor	2
Clay Loam	11,354	7.28	Imperfect	10
Sandy loam	1,421	0.91	Moderate	30
Sandy Clay Loam	83,947	53.79	Well to Moderate	25
Loam	22,280	14.28	Well	15
Sand	3,063	1.96	Very well	50
Sum	156,064.72	100.00		

Source: FAO soil classification (1992)

4.1.2.2. Soil depth classification and suitability of the study area

The soil depth of Daro Labu District area was characterized by shallow soil which 10cm to deep soil up to 150cm depth were found (OWWDI and HWSDB). Depend on the soil depth there is an effect on surface runoff potential area. The overall soil suitability of Daro Labu District in relation to water harvesting suitability was described in (Table 6) and figure 10.

Table 7: Major soil type suitability classification results for water harvesting

Soil Type	SMU	Depth (cm)	Texture	Drainage	Flooding	Erosion	WH Suitability	Area (ha)	% of Coverage
Luvisols haplic	IV LVha	140	SCL	Well	none	sheet	S1	1024.78	0.66
Luvisols chromic	IV LVcr	140	SCL	Well	none	sheet	S2	83534.8	53.53
Luvisols vertic	III LVvr	150	CL	Well	none	sheet	S3	10126.5	6.49
Leptosols lithic	V LPli	15	C	E/well	none	sheet/splash	S3	5252.08	2.10
Leptosols lithic rendzic	V LPli	10	L	E/well	none	sheet/splash	S1	10253.1	6.57
Leptosols lithic	IV LPli	10	L	Well	none	sheet	S2	12026.7	7.71
Vertisols haplic	IV VRha	180	C	Mode well	none	none	S3	2024.78	1.30
Vertisols calcic	V VRcc	165	C	Poor	For 1 month	none	NOT	3394.75	0.89
Vertisols eutric	III VReu	145	CL	Imperfect	15 days	rill/gulley	S3	1228.4	0.79
Vertisols chromic	IV VRcr	140	C	poor	none	none	NOT	4580.8	0.31
Cambisols dustic	III CMdu	140	SL	Well	none	sheet/splash	S2	3088.8	1.98
Cambisols chromic	IV CMcr	60	SL	Well	none	sheet/splash	S2	965.080	0.62
Nitisols eutric	III NTeu	180	S	Well	for one month	none	S2	27630.2	17.06

Source: Ethio Soil map (2014)

SMU= soil map unit, WH= water harvest, C= clay, L=loam, CL=clay loam, S= sand, SCL sandy clay loam, E=excessively, Mod=Moderate

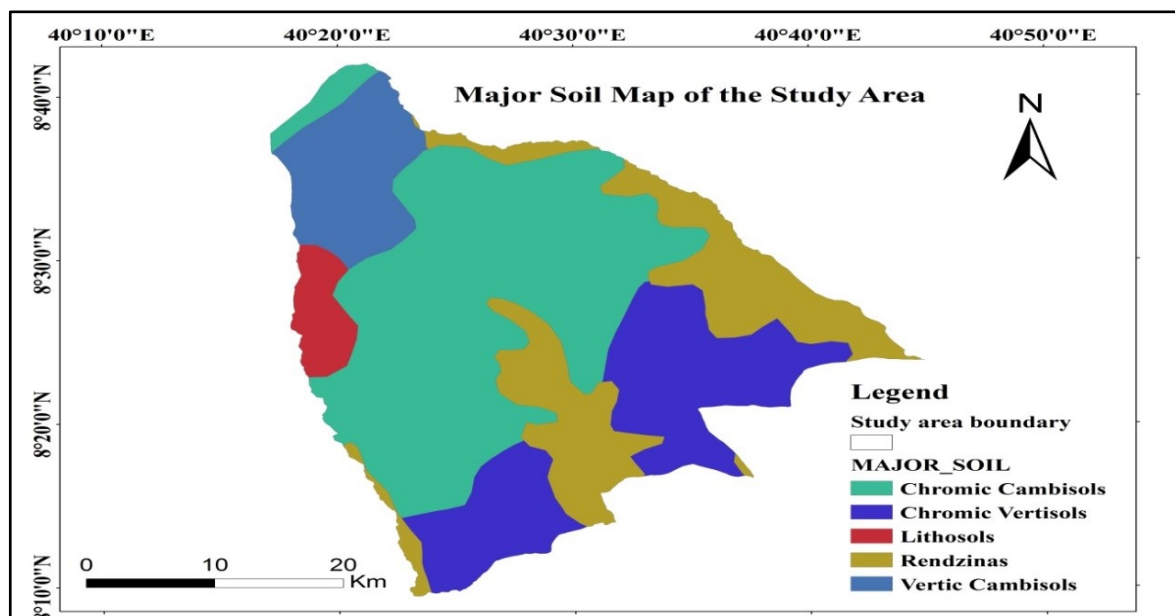


Figure 11: Major Soil Type Water Harvesting Suitability Map of Daro labu District

4.2. Land Use and Land Cover Classification

4.2.1. LU/LC suitability class

The comparison of requirements of land-use types with properties of land units is brought together in a land suitability classification. Suitability is indicated separately for each land/use type, showing whether the land is suitable or not suitable, including where appropriate degrees of suitability (Table 8). The major reasons for lowering the classifications, i.e. the land limitations, should be indicated (because of erosion hazard in one area or a high water-table in another, for instance). In large or complex surveys involving many mapping units land evaluation can be assisted by the use of geographic information systems (Figure 12). A major facility is that, if the land suitability data are entered into such system, when a change is made to one or more limiting values, new maps of land suitability can be rapidly produced. According to this, results of land use and land cover (LULC) shows that forest land, vegetation coverage land, cultivated land, Settlement land, and small coverage. Land-use land-cover layer map analyzed and reclassified based on the effects of land-cover classes on both the surface runoff depth and RWH structural technologies. Built up and cultivated lands was rated in high suitability class, for their suitability for most types of RWH technologies whereas settlements and forest was rated low, for their unsuitable and not economically feasible (Table 8). The results obtained were; built up, vegetation, forestry, Tree and shrubs, and agricultural areas by the Land

Resources Conservation Department of Daro Labu District Agricultural Office. Remote sense satellite images were interpretation results of spot image satellite of vector formats of 2016. The result revealed that the study area was dominantly covered with cultivated land of 58% followed by tree and shrubs which account 25.97%, vegetation cover about 8.77% the rest was forest land and built up with area coverage of 5.66% and 1.02% respectively (Table 8) and (Figure 11).

Table 8: LULC classification area covered of Daro Labu District

S/N	LULC	Area (ha)	Area (%)	Suitability Class
1	Vegetation	13,693.07	8.77	Less suitable
2	Tree & Shrubs	40,533.55	25.97	Suitable
3	Forest	8,829.24	5.66	Not suitable
4	Cultivated land	91,423.08	58.58	Very suitable
5	Build up area	1,585.61	1.02	Extremely suitable

NB*:- S/N= sequence number, LULC= Land use land cover

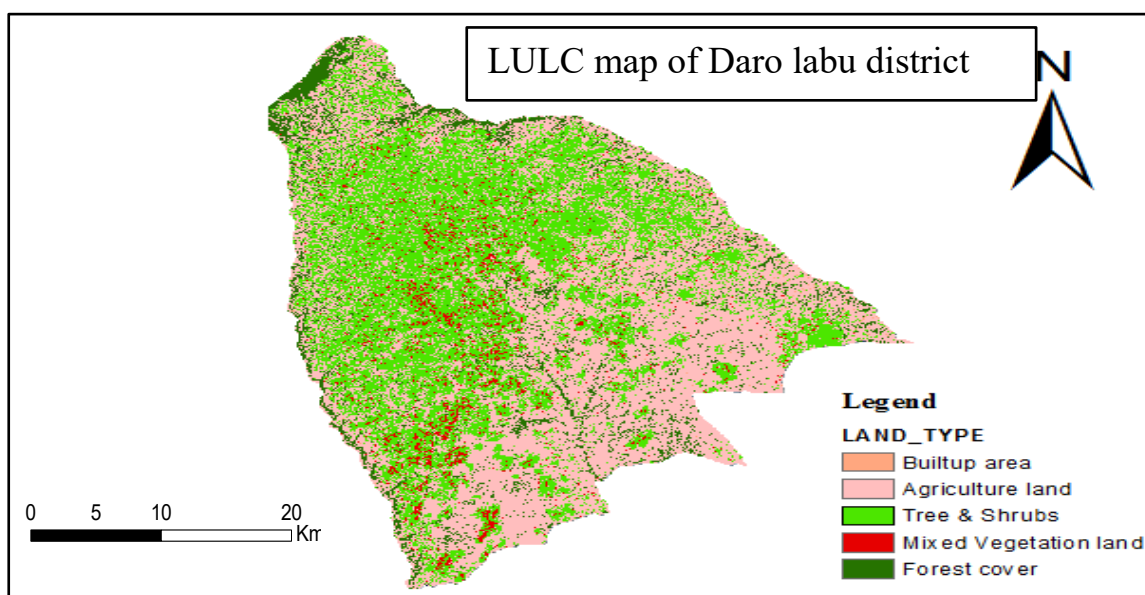


Figure 12: LULC map of Daro Labu District

Vegetation: Vegetation is an assemblage of plant species and the ground cover they provide. It is a general term, without specific reference to particular taxa, life forms, structure, spatial extent, or any other specific botanical or geographic characteristics. It is broader than the term flora which refers to species composition. Perhaps the closest

synonym is plant community, but vegetation can, and often does, refer to a wider range of spatial scales than that term does, including scales as large as the global. Primeval redwood forests, coastal mangrove stands, sphagnum bogs, desert soil crusts, roadside weed patches, wheat fields, cultivated gardens and lawns; all are encompassed by the term vegetation.

Shrub Land: A shrub is a woody plant that is typically less than 8 meters tall. Unlike a tree, shrubs have several stems and vary widely in size; some shrubs are less than 2 meters high (e.g., rose bushes), while others are around 6 to 8 meters tall (e.g., evergreen hedges such as *Leylandii*).

Tree: The difference between Forest and Other land with tree cover is the land use criteria. 2. Includes groups of trees and scattered trees (e.g. trees outside forest) in agricultural landscapes, parks, gardens and around buildings, provided that area, height, and canopy cover criteria are met. 3. Includes tree stands in agricultural production systems, for example in fruit tree.

Forest: A forest is an area of land dominated by trees. Hundreds of definitions of forest are used throughout the world, incorporating factors such as tree density, tree height, land use, legal standing, and ecological function. The Food and Agriculture Organization defines a forest as land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use. Using this definition FRA 2020 found that forests covered 4.06 billion hectares or approximately 31 percent of the global land area in 2020 but are not equally distributed around the globe.

Agricultural Land: Agricultural land is defined as the land area that is either arable, under permanent crops, or under permanent pastures. Arable land includes land under temporary crops such as cereals, temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow.

Agricultural land is typically land devoted to agriculture, the systematic and controlled use of other forms of life particularly the rearing of livestock and production of crops to produce food for humans. It is thus generally synonymous with farmland or cropland, as well as pasture or rangeland.

Built-up area: Built-up and related land, in land use and agriculture statistics, comprises residential land, industrial land, quarries, pits and mines, commercial land, land used by public services, land of mixed use, land used for transport and communications, for technical infrastructure, recreational and other open land

4.2.2. LULC accuracy assessment

One of the most important final steps at classification process is accuracy assessment. The aim of accuracy assessment to quantitative assesses how effectively the pixels were sampled into the correct land cover classes. Moreover, the key emphasis for accuracy assessment pixel selection was on areas that clearly identified on Landsat high-resolution image, Google earth, and Google Map. A total of 120 points (locations) created were in the classified image of the study area. The Accuracy Assessment Cell Array Reference column filled was according to the best guess of each reference point (Appendix Figure 2).

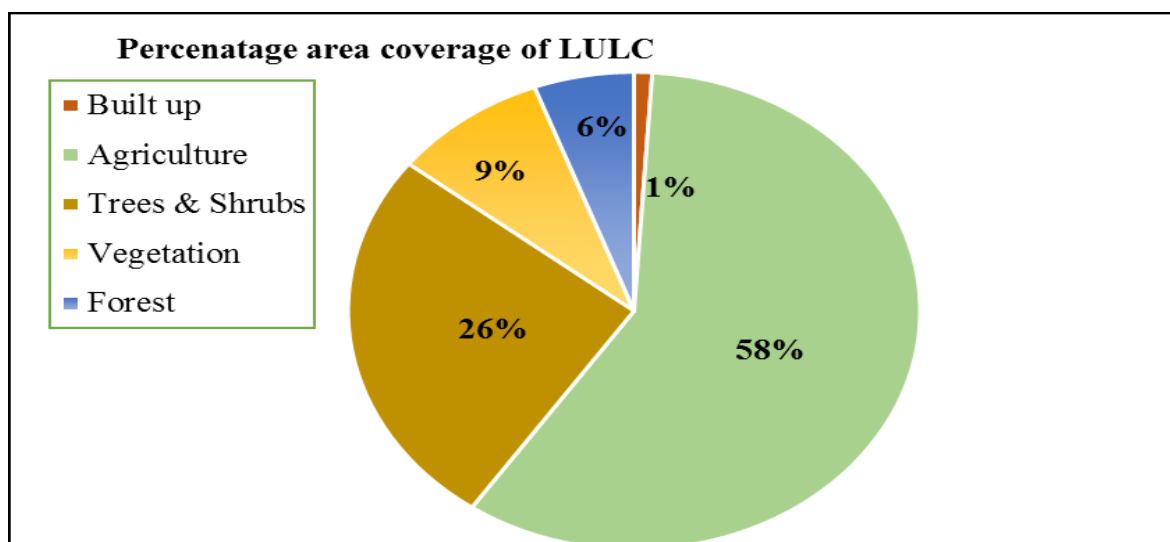


Figure 13: Percentage Area coverage of LULC type of Daro Labu District

4.2.3. Suitability of hydrological soil group

Table 9: Hydrological soil group by area coverage

S. No	HSG	Area (ha)	Percent	Drainage	Texture	Infiltration
1	A	83947	2.87	Well	S	High
2	B	22280	14.28	Mod well	SCL	Moderate
3	C	4484	53.79	Moderate	C	Slow
4	D	45350	29.06	Poor	CL	Poor
Sum		156064.72	100			

Source: Ethio Soil map (MOWEP, 2016)

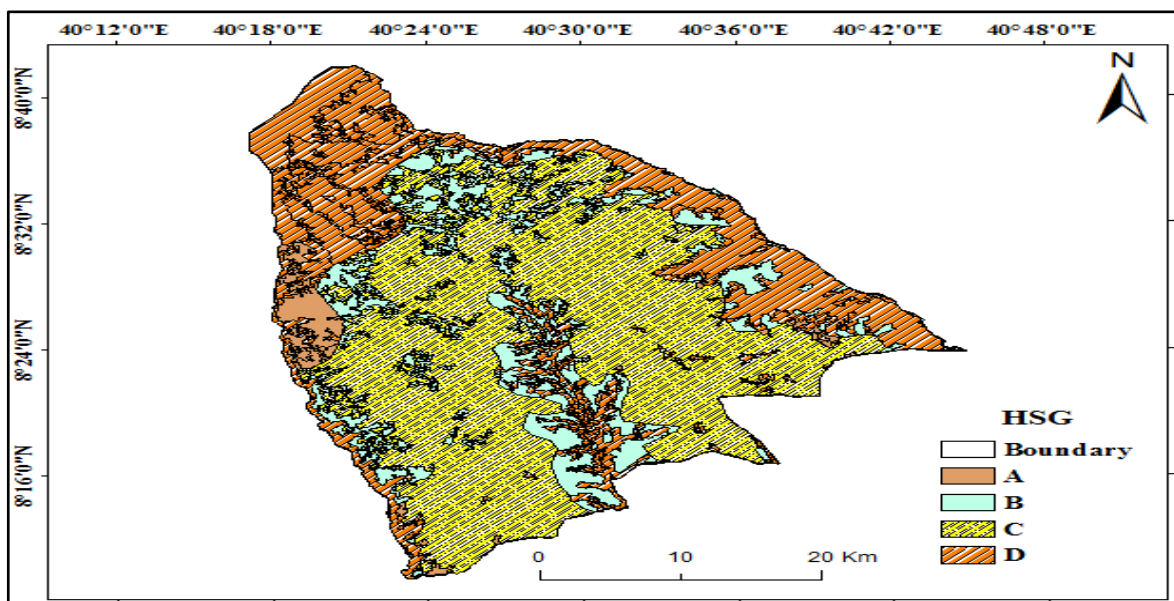


Figure 14: Hydrological Soil Group Map of Daru Labu District

Hydrological soil groups were based on estimates of runoff potential that affected with soil type. Soils have assigned to one of four hydrological soil groups according to the rate of water infiltration, when the soils do not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms. As it can be seen in the table, the hydrological soil group with class (HSG-C) has the higher area coverage with 53.79% followed by HSG-D (29.06%), HSG-B (14.38%) and HSG-A with area coverage of 2.87%, respectively. As described in USDA-NRCS (2009), soils with hydrological group of A and B, have moderately low runoff potential; when they are saturated, whereas the soil in HSG-D and HSG-C have high runoff potential. Therefore, the runoff potential with respect to HSG shows high runoff with D, moderately potential with C, lower potential with B, and poorly runoff potential with A respectively (Table 8) and (Figure 14).

4.2.4. Suitability of rainfall of the study area

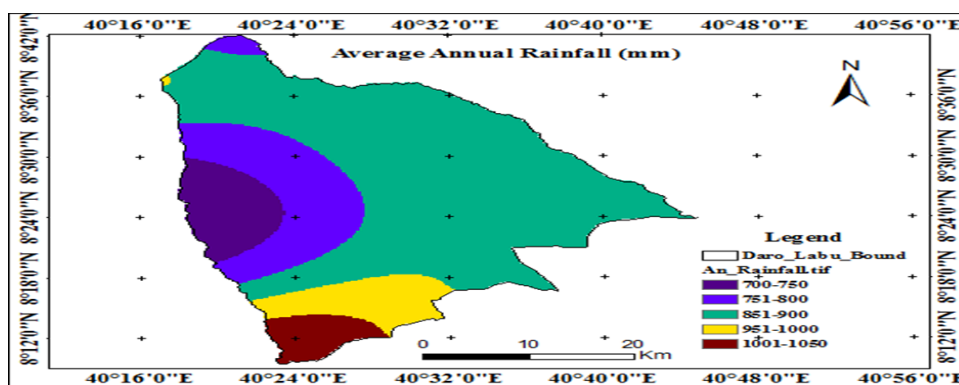


Figure 15: Annual rainfall distribution map of Daru Labu District

The suitability of annual rainfall amount was highly suitable with greater than 1000 mm suitable 900 mm to 1000 mm, medium suitable from annual amount of 800 mm – 900 mm and less than 700 mm was poorly suitable area (Figure 15). There was been of the highest area coverage with medium potential mean annual rainfall twenty year of Southeast to Northeast parts of the study area.

Table 10: Area influenced under different SCS-CN method

Land type	HSG	CN value	Area(ha)	Area cover (%)	Weighted CN= CN*%A
Agricultural land	A	76	2487.01	1.59	1.21
	B	86	12500.33	8.01	6.89
	C	90	48451.85	31.05	27.95
	D	93	27983.89	17.93	16.68
Vegetation cover	A	49	282.10	0.18	0.09
	B	69	2202.56	1.41	0.97
	C	79	9492.56	6.08	4.80
	D	84	1715.87	1.10	0.92
Tree and Shrubs	A	35	637.51	0.41	0.14
	B	56	5646.68	3.62	2.03
	C	70	26307.50	16.86	11.80
	D	77	7941.86	5.09	3.92
Forest	A	30	314.10	0.21	0.06
	B	50	729.16	0.79	0.39
	C	59	1445.86	3.67	2.17
	D	67	6180.54	1.11	0.74
Built up area	A	49	95.14	0.06	0.03
	B	69	276.86	0.18	0.12
	C	79	605.27	0.39	0.31
	D	84	608.34	0.39	0.33
G. Total			156064.75	100	82.00

NB*:- HSG= Hydrological Soil Group, CN= Curve number

Despite considering the relative proportion of the hydrologic soil group, it can be concluded that most of the soils in the study area had been contributing a significant amount of runoff, and only a low to medium proportion of the precipitation is infiltrated to the soil. So that the soil texture and hydrological soil group of the area were mostly covered with moderate to poor drainage types of soil. The value of curve number as it shows in the (Table 10) below were under hydrological soil group HSG_C of 26.41% and HSG_D of 15.25% were the highest coverage area under agricultural land and under

HSG_C covered about 11.40% and 10.44% under vegetation cover and wood land type respectively. Hence the HSG of C and D were known by high runoff potential soil type the area would have generate high amount of runoff per hectare of land per year.

The rainfall runoff model of the area was estimated after considering different factors of the influential such as climate (rainfall, temperature, relative humidity, sun shine hour and, Wind speed) soil type (texture structure depth) topography (slop and contour), seasonal variation which can be affect the amount of rainfall runoff of the study area as a whole. Depend on the factors the amount of runoff estimated was shows in (Table 10).

The result of SCS-CN method of rainfall runoff estimation of twenty years data of (1999-2018) shows with minimum records of 122.7 mm in 2011 and maximum records of 288.77 mm in 2005 with annual average of 185.25 mm (Table 10) and (Figure 12). Accordingly, the volume of estimated water harvested has been accounted to $2.89 \times 10^8 \text{ m}^3$. This estimation obtained was in line with the work of (Gatechew Haile 2018).

4.3.5. Curve Number (CN) classification of the study area

The SCS-CN of Daro Labu area was done from LULC type and derived from FAO CN classification. Depend on the value of CN obtained the area covered and CN suitability class also determined. The CN values for the study area was range from 40 - 100 with different suitability levels described (Table 10).

Table 11: SCS-CN and runoff potential area coverage of the study area

CN range	Runoff Potential	Area (ha)	%	Suitability
30-40	None	23556	15.09	Not Suitable
41-50	Marginal	125.61	8.05	Marginal
51-60	Less Potential	154.05	9.87	Less Suitable
61-70	Medium	105.70	6.77	Suitable
71-80	High	485.90	31.14	High suitable
81-90	Highly Potential	151.8	16.13	Very high suitable
91-100	Extremely Potential	202	12.94	Extremely suitable

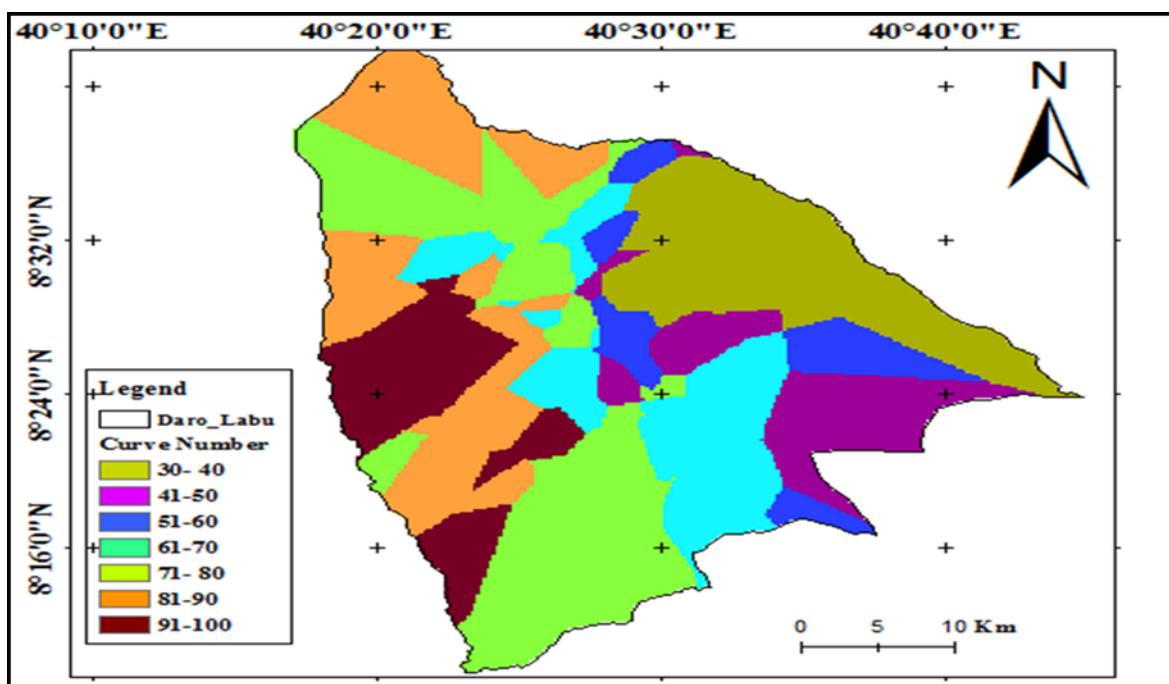


Figure 16: Soil Conservation Service Curve Number map of the study area

As it shows from (figure 16) the curve number of the study area has been affected by soil type and texture class of the soil of the study area. So that, the GIS based analysis of curve number CN value indicates that the North West of the District is high to extremely high potential water harvesting site of the area. However, the North and South east of the District of the area was low to medium water harvesting potential area (Table 11).

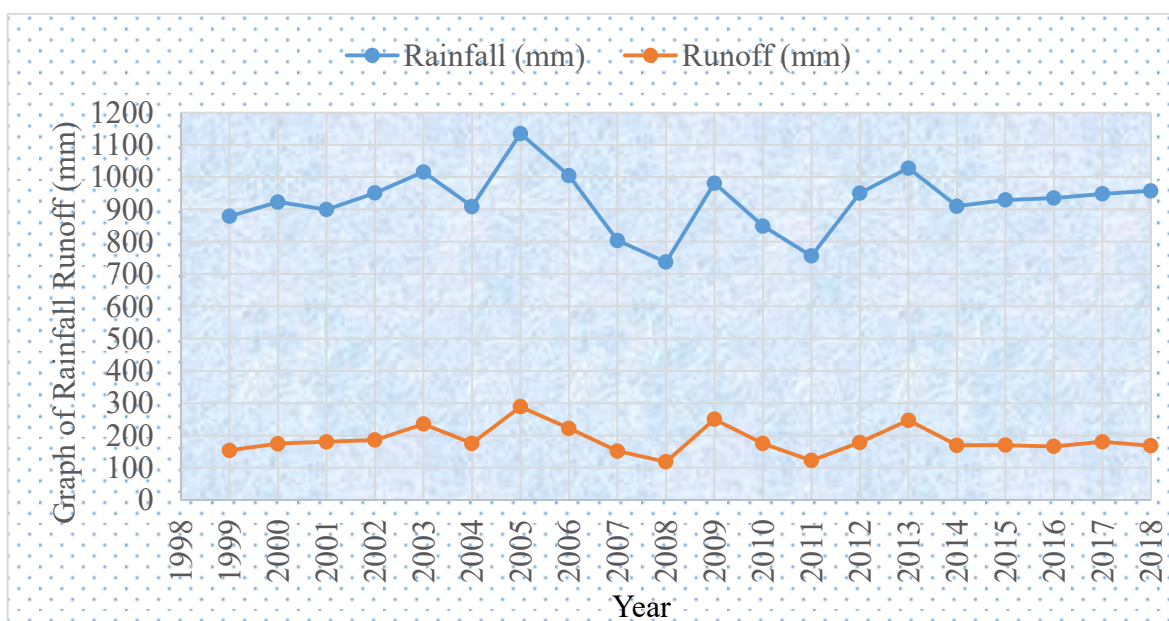


Figure 17: Graph of mean annual rainfall runoff relationship of Daro labu District

Table 12: The Estimation runoff depth and volume of water harvesting of Daro Labu District

Year	Rainfall (mm)	Runoff (mm)	Runoff(%)	Volume of WH (Mm ³)
1999	878.72	153.84	17.51	240.10
2000	923.09	174.66	18.92	272.59
2001	899.63	180.45	20.06	281.63
2002	950.93	185.89	23.75	352.55
2003	1016.11	235.44	18.25	289.41
2004	909.22	175.34	18.56	263.39
2005	1134.78	288.77	21.90	387.80
2006	1004.71	221.95	20.10	315.18
2007	803.91	151.49	18.84	236.43
2008	737.28	118.40	21.23	244.26
2009	981.31	250.20	15.95	390.49
2010	848.78	175.13	29.48	273.33
2011	755.82	122.70	23.17	191.50
2012	950.48	178.67	12.91	278.86
2013	1028.21	247.08	17.38	276.36
2014	910.14	169.59	19.46	264.68
2015	929.10	170.00	18.25	421.39
2016	935.21	165.95	28.87	258.99
2017	948.12	180.41	17.50	281.57
2018	957.81	167.99	18.84	262.18
An. Average	925.17	185.26	20.02	289.14

4.3. Mapping Potential Area Using Weight Overlay method

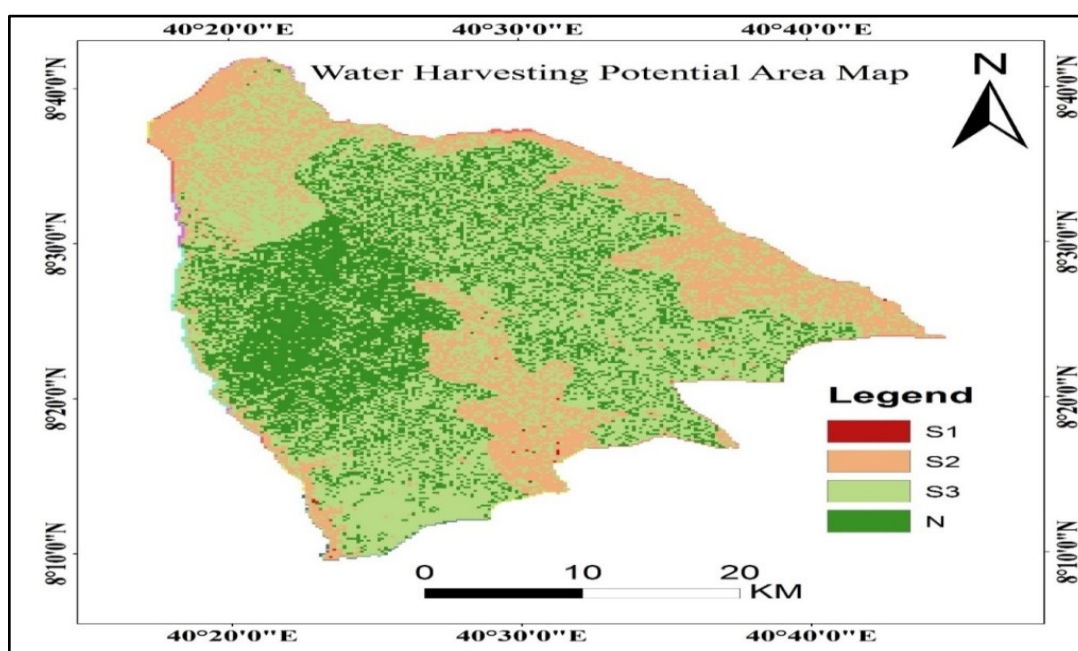


Figure 18: Weighted overlay result of RWH potential site map of Daro Labu district

Table 13: Factors of influence of RWH potential site map of Daro Labu district

S/N	Parameter	Description	Area (Km ²)	Area (%)	Suitability Rank
1	Texture	C, CL	989.00	63.37	S1
		SL, SCL	291.35	18.67	S2
		S, SC	280.25	17.96	S3
2	Soil depth (cm)	>100	1115.8	71.5	S1
		50-100	9.7	0.6	S2
		25-500	159.9	10.2	S3
		0-25	275.3	17.6	N
3	Annual RF(mm)	>1000	64.99	4.16	S1
		950-1000	117.74	7.54	S2
		900-950	990.31	63.46	S3
		850-900	259.30	16.61	Marginal
		<800	128.30	8.22	N. Suit
4	Slope (%)	<3	731.62	46.88	S1
		3-8	590.32	37.83	S2
		8-16	157.77	10.11	S3
		16-30	64.79	4.15	Marginal
		>30	16.12	1.03	N. Suit
5	LULC	Built up	15.86	1.02	S1
		Tree & Shrubs	405.34	25.97	S4
		Cultivated	914.23	58.58	S3
		Open grass	136.93	8.77	N
		Forest	88.29	5.66	S2

Table 14: Weightage values and rank for water harvesting potential site

S/N	Area(ha)	Area (%)	Rank	Suitability
1	12828.52	8.22	1	Extremely
2	25220.05	16.61	2	Very high
3	99038.67	63.46	3	Moderate
4	11777.28	7.54	4	Marginal
5	7,210.2	4.62	5	NS
Sub Total	156064.72	100.0		

The overall results of weights overlay of potential area of Daro Labu District shows that, only 8.2% of the total area was extremely potential water harvesting, due to clay and clay loam soil texture, soil depth (>100 cm), annual rainfall(>1000 mm), slope (<3%) and consolidated or built up and land use/cover was considered (Table 14). The next suitability resulted with 16.6% of all was highly potential due to the factors suitability with soil texture of sandy loam and sandy clay loam, soil depth (50-100 cm), annual rainfall of (950-

1000 mm). The weighted criterion (Table 14) was aggregated to produce a final suitability map according to defined regulation in ArcGIS (Figure 18). To this effect, out of the total area of the study area which is 156064.72 ha, a small portion of about 12,828.5 ha (8.22%) of the district was assessed highly suitable for water harvesting due to factors such as gentle slope (0–3%), absence of impermeable layer within 150 cm soil depth, impermeable soil depth with built-up area of land cover type and annual rainfall greater than 1000 mm (Figure 18). The second portion of 25,922.4 ha (16.61%),) of the total area of the study area was calculated as moderately suitable site for water harvesting due to moderate slope (3–8%), annual rainfall amount with 950-1000 mm. The largest part of the study which account about 99,038.7ha (63.46%) of the total area was evaluated as moderately suitable because of factors such as slope (8-16%) annual rainfall amount was between 850-900 mm with semipermeable soil depth of less than 50 cm and cultivated land cover type was verified. The fourth suitability classification of the potential was evaluated as marginal low suitability area due to annual rainfall amount less than 700 mm (figure 18 and Table 14). The largest part of unsuitable land is in the west and south west central part of the study area. The rest which account about 7210.20 ha (4.62%) of the catchment district of land was not suitable for water harvesting because of steep slope greater than 30%, shallow soil depth of 10 cm and may be rockiness land was considered as unsuitable site.

4.3.1. Identification of Rainwater Harvesting Potential site of Daro Lebu District

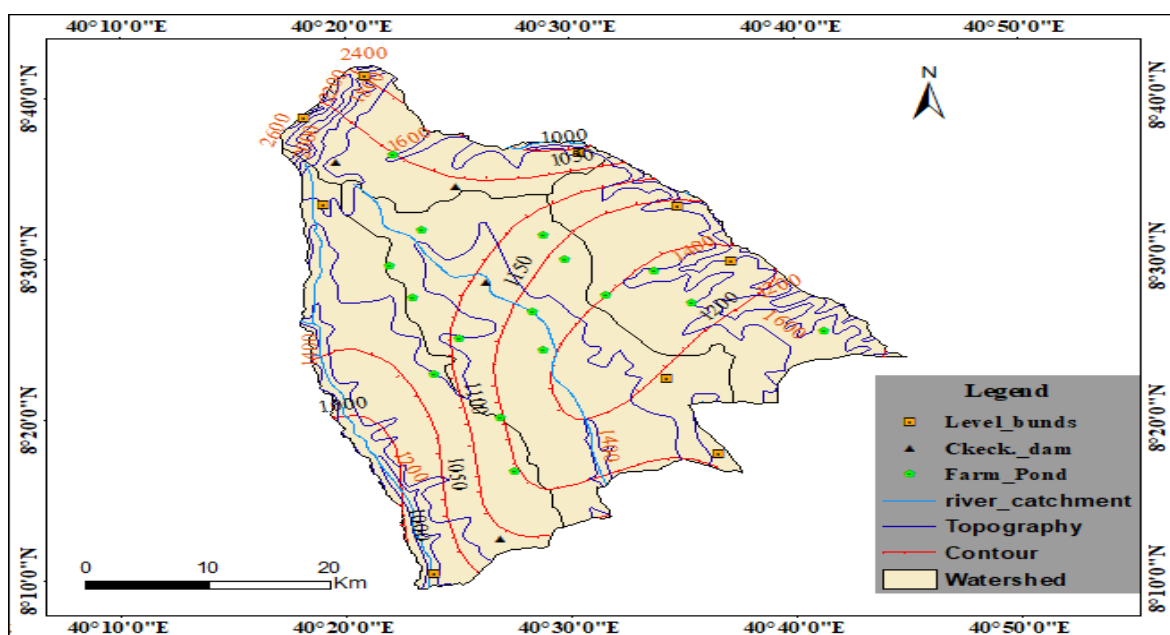


Figure 19: Water harvesting suitability site map of Daro labu District

This study considered the suitability of sites for constructing farm ponds and check dams. To achieve this goal, the suitability criteria for individual RWH structures were finalized on the basis of the result in (figure 19). The suitable sites for RWH structures can also be identified according to the RWH suitability map. In this study, the optimal RWH sites for farm ponds, level bund and check dams were identified and then presented in Figure 19. These sites are located in the high suitability zone because such zone features high runoff depth, as well as slopes and soil texture of high suitability. One of the important criteria for selecting zones suitable for farm ponds is that land use should be focused on agriculture, particularly because farm ponds are necessary when providing supplementary irrigation for crop lands. This part of the study area had been used for agriculture. However, the lack of precipitation in previous years eventually degraded this part of the study area to bare soil. The areas suitable for farm ponds are mostly located in the central north parts of the study area. The total area suitable for farm pond, level bund and check dams were found to be (35.7%, (28% and 24% respectively of the total study area and the rest had not suitable for those the structure. Most of the check dams are located on steep slopes below 15%. These structures are used for the efficient planning and management of water resources in the study area, which in turn can ensure a sustainable water supply in the context of climate change. Sustainable water management strategies, such as that described in this study, are undoubtedly crucial in ensuring that water needs are addressed.

4.4. Selected Crop Water Requirement of Daru Labu District

4.4.1. Gross irrigation requirement of the study area

In order to estimate irrigation water requirements of some selected crops in the potential irrigable sites, the definition of area of influence of the climatic stations using ArcGIS inside and around the study area was assessed. To obtain a spatial coverage of climate data over the study area, each station was assigned to an area of influence using the Thiessen polygons method (FAO, 1997). This method assigns an area of estimated the nearest to each climate station as presented in (Figure 8). Irrigation water requirement of each of the selected crops were calculated using CROPWAT8 software. For the calculation of ET_c / CWR, data from the considered meteorological station was used.

As indicated in appendix table 13, different percentage of area coverage was adopted for each crop based on the assumed benefits of farmers was obtain from them. CROPWAT software assumes 100% efficiency and 24 hours irrigation duration, but in real world, the indicated efficiency and irrigation hours are an achievable due to different uncertainties. Gross irrigation water requirements of tomato, maize, and onion at the identified potential irrigable sites under surface irrigation methods were estimated depend on ETo of the area. Crop water requirements of in the area also depend on the weather condition as a result crop water requirement of a given crop any area was influenced by the climate condition of the area. For this reason, data of twenty years (1999-2018) of the area was used depend on the crop calendar of the study area.

The crop water requirement of the study area is that sampled to determine and estimate with the amount of water harvesting in relation to agricultural production. So that maize, tomato, and onion crop were taken and do its water usage depend on the weather data of the five station.

Table 15: Gross and Net irrigation Requirement of maize, tomato, and onion at Daro Labu District

Station	Crop type	Ig (mm)	In (mm)	CWR (mm)	RWH (Mm ³)	Area (ha)
Mechara	Tomato,	493.8	345.7	322.8	11.83	2396.00
	Onion	371.0	259.7	235.2	11.83	3189.07
	Maize	596.0	417.3	278.7	11.83	1985.14
Micheta	Tomato,	502.0	351.0	332.5	40.15	7998.62
	Onion	355.0	249	227.0	40.15	11310.73
	Maize	615.0	430	277.7	40.15	6528.96
Dumuga	Tomato	436.8	305.7	266.6	26.61	6091.66
	Onion	320.1	224.0	206.1	26.61	8312.52
	Maize	467.7	327.4	249.7	26.61	5689.20
Chancho	Tomato	633.6	443.5	358.2	3.50	548.44
	Onion	360.0	252.0	245.5	3.50	965.25
	Maize	555.7	389.0	329.2	3.50	625.32
Gelemso	Tomato	571.8	399.8	351.6	3.10	543.02
	Onion	365.5	255.8	248.7	3.10	849.52
	Maize	558.1	390.6	296.4	3.10	556.35

NB*:- Ig=gross irrigation, In=net irrigation, CWR= crop water requirement

The climate data of twenty years for each five meteorological station using CROPWAT 8 Model were done. The result obtained that for each meteorology station was listed in

(Table 15). It shows that the total water harvested at Mechara 35.49Mm³ and the crop water requirement of tomato, onion and maize was 493.8 mm, 371.0 mm, and 596 mm of growth irrigation water depth respectively. The area of irrigated by equally distributed water for the three crop was 2398 ha 3189 ha and 1986 ha respectively can irrigated (Table 15). At Micheta station the same for the three crops depend on its specific station weather condition. The water has estimated to harvest was 120.45Mm³. The crop water requirement of tomato, onion, and maize was 502 mm, 355 mm and 615 mm.

Depend on the information obtained area of irrigated under harvesting water estimated to account 7980 ha of tomato, 11310 ha of onion and 6530 ha of maize can be irrigated at the same time (Table 15). There is also the area can be estimated under Dumuga station, Chanco station and Gelemso station for same crop that tomato, accounts 436.8 mm, onion 320.6 mm and maize 467.7 mm of depth of irrigation obtained from the model and the area might be irrigated has been estimated 6091.7 ha, 8312.5 ha and 5689.2 ha were estimated to irrigate under Dumuga station. The next estimated under Chanco meteorological station, the growth irrigation depth of tomato, onion and maize was 633.6 mm, 360 mm and 555.7 mm respectively. It could be estimated to irrigate was 548.4 ha of tomato, 965.3 ha of onion and 625.3 ha of maize might be estimated to irrigate (Table 14).

4.4.2. Net irrigation requirement (NIR) of the study area

The NIR of different crops in the study area was given in (Table 15). The net irrigation requirement for tomato, onion and maize was 369.14, 248.1, and 390.86 mm/season. The lowest onion water requirement was obtained (224 mm) per cropping season at Dumuga station and the highest at Mechara (259 mm) per cropping season. The result also the same with tomato, and maize, that the lower water requirement of tomato, (367 mm) and the highest obtained at Chanch station . This is because of the occurrence of effective rainfall during rainy season (May–September) was high, where as during the growing period of as a result, the irrigation requirement was very high. This indicates the differences in water requirement even within a single district for the same period and hence it shows the significance of requirement of scientific planning for irrigation. The difference in the NIR in Daro Labu District with station might be due to the combined effect of the changes in temperature, sunshine hour percentage, wind and the decrease in effective rainfall (Fig 19).

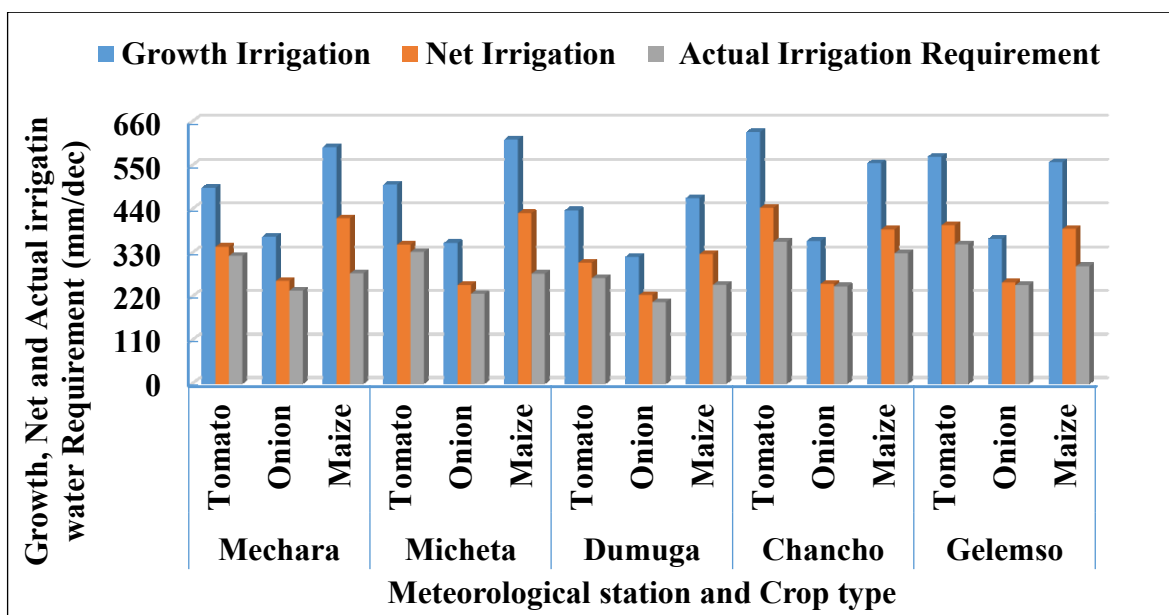


Figure 20: Growth, Net and Actual irrigation water requirement of Tomato, onion and maize at the study area

4.4.3. Actual crop water requirement

The crop actual water requirement of maize, tomato, and onion at Daro Labu District has depend on Evapotranspiration, rainfall, temperature, sunshine hour and wind speed of the area was affected. So that, the crop water requirement of the selected crop under five meteorological station were almost become same with net irrigation and actual irrigation for onion at all station and there is a fluctuation for maize specially on Micheta station (figure 19). There is also obtained minimum crop water requirement under Dhumuga station and the highest under Chanco station due to the difference in Evapotranspiration at the station (figure 20).

5. SUMMARY, CONCLUSION AND RECOMMENDATION

5.1. Summary and Conclusion

The assessment has conducted at Daro Labu District on Rainwater harvesting factor. In this study, geographical information system (GIS) was used to employed and generate a water harvesting. Different site selection criteria affecting the water harvesting in the study area were defined based on a literature review and discussions with relevant factor of influences such as rainfall, slope, soil texture and depth, land use and land cover (LULC) drainage density was considered.

The rainfall runoff depth estimation was done by SCS-CN method that influenced by soil moisture condition (AMC). The depth of five day (5) rainfall with the lengths of dry and growing season of the study area was identified using New LocClim model accordingly, even the study area found under semi-arid there is short dry season and long wet season was considered for the reason that it's the area of bimodal rainfall.

Soil Conservation service and Curve Number model has utilized in the present work by land use map and soil map described in ArcGIS, as input. The amount of runoff represents 20% of the total annual rainfall. In the present study, the methodology for the tenacity of runoff utilizing GIS and SCS approach could do applied in other similar Catchment for arranging of various conservation measures. The good soil and water conservation measures need for planned and implemented in the study area.

In SCN Curve number, method, Antecedent moisture condition of the soil plays a very consequential role because the CN number varies according to the soil and that considered while estimating runoff depth. For a given study, area that Daro Labu District curve number (CN) calculated equal with 82 for AMC -I, 28.4 AMC-II and 87.5 for AMC-III. In conclusion, Soil Conversations Service; Curve Number approach do efficiently proven as a better method, which consumes less time and facility to handle extensive data set as well as larger environmental area to identify site selection of water harvesting structures.

Rainwater harvesting has a great potential to increase crop yields if only farmer capacity to harness this technology is advanced. From the Daro Labu area, the observation that rainfall alone not exceeds the crop water requirements but can be produced about half of the year's production and the farmer can cultivate throughout the year.

The Weighted Overlay (WO) technique used to identify the potential sites for water harvesting in the study area was done with the preprocessing of reclassifying with the aid of raster format of GIS model. This method based on the collection of all the criteria after multiplying weights in rating, thereafter determining weights and unifying rating for each criterion. The study area has classified into four classes in terms of the suitability for the water harvesting namely: very low suitability for water harvesting, moderately suitable for water harvesting, high suitability for water harvesting and very high suitability for water harvesting. The study area was classified into no suitability, low suitability, moderate suitability, high suitability, and very high suitability in terms of water harvesting. It is recommend conducting a fieldwork to investigate the selected sites to test the suitability of soil and the sub-surface layers for water harvesting purposes.

Crop water demand that computed from Copwat8.0 model results, the crop water requirement of the area has about 1440.14 mm of water. The combined potential of rainfall runoff is 8540 m³ of water. This implies that of the available volume of water, only 40% can be utilized. The other 60% can be used for other water needs and or for expansion of the irrigated fields. Also worth noting is that only one season has been considered per year for this analysis.

5.2. Recommendation

Depend on the result obtained and the factor of influences for water harvesting and crop water requirements, the following recommendation was drawn. Water harvesting has been done not only for single purpose it is the work of multi-purpose objective, for crop production, for soil and water conservation, for domestic or consumption. Topography and soil type as well the slope of the area was identified it simple to minimize the risk of water scarcity and soil erosion problem. Water harvesting work used to have the opportunity work for a given community and sources of income generation. Soil texture and LULC were the major influence factor for water harvesting, hence high clay content area, with flat to gentle sloppy area should be considered by reducing workload and cost.

Therefore, rainfall water harvesting should be embraced to increase productivity and improve yields due to the fact that it has a great potential as observed in this assessment work. The advantage of water harvesting is that it also has another opportunity for the farmer to engage in production to increase the livelihood, and also earn from that activity as well.

6. REFERENCE

- Abdulla, F. A. & Al-Shareef, A. W. 2009. Roof rainwater harvesting systems for household water supply in Jordan. *Desalination* 243, 195–207.
- Alamerew E. 2006. Towards Widespread Rainwater harvesting in Ethiopia: ERHA's Experience as a Successful Rainwater Harvesting Capacity Centre (RHCC), *In '10th Southern and Eastern Africa Rainwater Network (Sear Net) International ' Mombasa, Kenya. (Ed. KG Secretariat) Pp.90.*
- Alamerew E, Fentaw B, Ali S., 2002. Traditional Rainwater Harvesting Systems for Food Production: the case of kobo wereda, Northern Ethiopia.
- Alem G. 2009. Rainwater Harvesting in Ethiopia: An overview. Integrated Development for Water Supply and Sanitation. 25th WEDC Conference. Addis Ababa, Ethiopia. pp. 387- 390.
- Alemayeh, A., & Bewket, B. 2016. Local climate variability and crop production in the central high lands of Ethiopia. *Environmental Development*.
<http://dx.doi.org/10.1016/j.envdev.2016.06.002>.
- Ali, M. 2012. State of Water Supply and Consumption in Urban Areas at Household Level: A Case Study of East Wollega Zone, Ethiopia. *British Journal of Humanities and Social Sciences*, Vol.5.<http://www.ajournal.co.uk/HSpdfs/HS> volume
- Amha, R., 2006. Rainwater Harvesting Impact Assessment of Ponds in Alaba *woreda*, Ethiopia. Addis Ababa University.
- Ammar A, Riksen M, Ouessar M, Ritsema C., 2016. Identification of suitable sites for rainwater harvesting structures in arid and semiarid regions: a review. *International Soil Water Conservation Resources* 4(2):108–120
- Angrill, S., Farreny, R., Gasol, C.M., Gabarrell, X., Viñolas, B., Josa, A., Rieradevall, J., 2012. Environmental analysis of rainwater harvesting infrastructures in diffuse and compact urban models of Mediterranean climate. *International Journal of Life Cycle Assessment* 17(1), 25-42.
- Arega, Y., 2003. Guidelines on Water Harvesting Techniques. *World Food Program (WFP). Addis Ababa, Ethiopia*. 141p Arnold.
- Aroka, N., 2010. Rainwater Harvesting in Rural Kenya Reliability in a Variable and Changing Climate. *Stockholm University*.
- Ball, J. 2001. Soil and Water Relationships [<http://www.noble.org/Soils/soilWaterRelationships/Index.htm>] site visited on 22/4/2016.

- Berhanu, B., Melesse, A.M. and Seleshi, Y. 2013. GIS-based hydrological zones and soil geo-database of Ethiopia. *Catena*, 104, pp.21-31.
- Bewket W., 2009. Rainwater Harvesting as a Livelihood Strategy in the Drought- Prone Areas of Amhara region of Ethiopia. *Organization for Social Science Research in Eastern and Southern Africa (OSSREA)*.
- Biazin, B., Sterk, G., Temesgen, M., Abdulkedir, A., & Stroosnijder, L. 2012. Rainwater harvesting and management in rainfed agricultural systems in sub-Saharan Africa- *A review Physics and Chemistry of the Earth, Parts A/B/C*, (47-48), 139-151. <http://dx.doi.org/10.1016/j.pce.2011.08.015>
- Boorman, D. Hollis, J., and Lilly, A. 2010. Hydrology of Soil Types: a hydrological based classification of the soils of the United Kingdom, *IAHS Press, Wallingford, UK, IAHS Report, 126*.
- Bot, A., Nachtergaele, F., & Young, A. 2000. Land resource potential and constraints at regional and country levels (No. 90). FAO.
- Bothale, R. V., Bothale, V. M., Srinivasan G. and Sharma, J R. (2002) Identification of Suitable Sites for Water Harvesting Structures in upper Betwa Watershed through Waris. Regional Remote Sensing Service Centre. ISRO. [<http://www.gisdevelopment.net/application/nrm/water/watershed/watws0013pf.htm>] site visited on 20/5/2005.
- Bouma, J. A., Hegde, S. S., & Lasage, R. 2016. Assessing the returns to water harvesting: A meta-analysis. *Agricultural Water Management*, 163, 100-109. <http://dx.doi.org/10.1016/j.agwat.2015.08.012>
- Bulcock, L.M., Jewitt, G.P.W., 2013. Key physical characteristics used to assess water harvesting suitability. *Joarnal Physics, Chemistry and Earth science* 66, 86–100.
- Chala A, Etissa E, Lemecha G, Hunde H, Desta L, Jateno W, Ayele W. 2003. Progressive Evaluation on Water Harvesting Schemes Implementation in Oromia Region (part I). *Rural and Agricultural Development Supreme Office*.
- Chala A, Demisie A, 2004. Evaluation Report on Benefits of Water Harvesting Schemes Implements in Nine Zones of Oromia Region. *Oromia Irrigation Development Authority*.
- Critchley, W., Siegert, K., Chapman, C. 1991. Water Harvesting Manual. FAO Paper MISC/17/ 91, Rome, 133 pp. Rome.
- Dagnew.E. 2000. The Role and contributions of NGOs in food security in Ethiopia. In: proceedings of the panel discussion on the role and contributions of NGOs in rural

- development in Ethiopia: *organized by Agri-service Ethiopia on the occasion of ASE's 30th Anniversary, 26th of February 2000, Addis Ababa. pp. 21- 22*
- Dechmi F, Playa 'n E, Faci J.M, Tejero M and Bercero A 2003. Analysis of an irrigation district in north-eastern Spain II. Irrigation evaluation, simulation, and scheduling. *Agricultural Water Management* 61: 93– 109.
- Desta, L, Carucci, V, Wendem-Agegnehu, A, Abebe, Y. 2005. Community Based Participatory Watershed Development: a guideline, part 1. Ministry of Agriculture and Rural Development, Addis Ababa, Ethiopia
- Dillon, P., 2005. Future management of aquifer recharge. *Journal of Hydrogeology* 13(1), 313-316.
- Eastman, J. R. 2009. IDRISI Taiga guide to GIS and image processing. *Clark Labs Clark University, Worcester, MA.*
- FAO (Food and Agricultural Organization). 2003a. <http://faostat.fao.org/default.htm>. Accessed on 23/10/2015.
- FAO, 2003b. Land and Water Digital Media Series. Planning of Water Harvesting Schemes, Unit 22. Nations, Rome.
- FAO, 2003. Unlocking the water potential of Agriculture, Rome, Italy.
- FAOWATER. 2012. Hot Issue on Water scarcity; water and poverty, an issue of life and livelihood. Natural Resources and Environment Department;FAOWATER development and management unit.<http://www.fao.org/nr/water/issues/scarcity.htm>
- Farran, M.M. and Elfeki, A.M., 2020. Evaluation and validity of the antecedent moisture condition (AMC) of Natural Resources Conservation Service-Curve Number (NRCS-CN) procedure in undeveloped arid basins. *Arabian Journal of Geosciences*, 13 (6), pp.1-17.
- Feki, F., Weissenbacher, N., Assefa, E., Oltod, E., Gebremariam, M. K., Dalechac, T., Shibrue, B., Sayadia, S., and Langergraber, G. 2014. Rain water harvesting as additional water supply for multi-store buildings in Arba Minch, Ethiopia. *Desalination and Water Treatment*, 53, 1060-1067. <https://doi.org/10.1080/19443994.2014.880156>
- Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, L.L. White IPCC, 2014: climate change impacts, adaptation, and vulnerability.
- Fitsum Y., Hordofa, T., & Abera, Y. 2014. Review of Water Harvesting Technologies for Food Security in Ethiopia: Challenges and Opportunities for the Research System. *Journal of Natural Sciences Research*, 4(18): 40-49.

- Gary W. F., 2011. Water Harvesting for Improved Agricultural Production. Water report No.3. (*FAO proceedings. Cairo*, 21-25).
- Getachew A. 1999. Water Harvesting a Water Security Strategy for Mitigating the Impact of Drought in Ethiopia. Addis Ababa, Ethiopia
- George, B., Shende, S., and Raghuwanshi, N. 2000. Development and testing of an irrigation scheduling model. *Agricultural Water Management*, 46(2), 121–136.
- Girma Mogos., 2009. Identification of potential rain water harvesting areas. Central Rift Valley of Ethiopia using a GIS Based Methodology. *Wageningen University, Netherland*.
- Ghaffarian Hoseini, A., Tookey, J., Ghaffarian Hoseini, A., Yusoff, S.M., Hassan, N.B., 2016. State of the Art of Rainwater Harvesting Systems towards Promoting Green Built Environments: *A Review, Desalination, and Water Treatment* 57(1), 95-104.
- GDRC (Global Development Research Center), 2002. An Introduction to Rainwater Harvesting.
- Gould.J and Erik Nissen-Petersen, 1999. Rainwater catchment systems for domestic supply. Design, construction, and implementation. Intermediate technology publications, ITDG. Southampton, UK. 330P
- Gouranga Kar, Verma HN. 2005. Climatic water balance, probable rainfall, rice crop water requirements, and cold period in AER 12.0 in India. *Agricultural Water Management* 72: 15–32.
- Gowda T.P, Manjunaththa S.B, Yogesh T.C and Satyareddim S.A .2013. Study on Water Requirement of Maize (*Zea mays* L.) using CROPWAT Model in Northern Transitional Zone of Karnataka. *Journal of Environmental Science, Computer Science and Engineering and Technology* 2(1): 105- 113.
- Haile M, Merga S. N., 2002. Workshop on the Experiences of Water Harvesting in the Drylands of Ethiopia: Principles and Practices December 28-30 2001, DCG Report No. 19, Mekelle, Ethiopia.
- Hailemichael A., 2011. Indigenous talents of Konso people to cope up climate change susceptibility, Ethiopia. Arba Minch University, Ethiopia.
- Hamel, P., Fletcher, T.D., Daly, E., Beringer, J. 2012. Water retention by rain gardens: implications for local-scale soil moisture and water fluxes. In: Wong, T.H.F., McCarthy, D.T. 7th edition. *International Conference on Water Sensitive Urban Design, Engineers Australia, Melbourne, Australia*, 2012.

- Hatibu, N., Mahoo, H., 2009. Rainwater harvesting technologies for agricultural production.
- IPCC (Intergovernmental Panel on Climate Change). 2007. Climate Change Synthesis Report Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change
- IPCC (Intergovernmental Panel on Climate Change). 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (editions). Cambridge University Press, Cambridge, UK, and New York, NY, USA, Pp. 582.
- ISRIC (International Soil Reference and Information Centre), 1995. Kenya Soil Survey (KSS), 1995.
- Jarvis A., Reuter, H. I., Nelson, A., and Guevara, E, 2011. Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available at: <http://srtm.csi.cgiar.org> (last access: 20 February).
- Jasrotia, A., Majhi, A., and Singh, S. 2009. Water Balance Approach for Rainwater Harvesting using Remote Sensing and GIS Techniques, Jammu Himalaya, India, Water Resource Management, 1–30.
- Jiang, Z., Li, X., Ma, Y., 2013. Water and Energy Conservation of Rainwater Harvesting System in the Loess Plateau of China. *Journal of Integrative Agriculture* **12**(8), 1389-1395.
- Jones, O.D., Sheridan, G.J., Lane, P.N., 2013. Using queuing theory to describe steady-state runoff-run on phenomena and connectivity under spatially variable conditions. 49, water resources research. Doing: 10.1002/2013 WR0 13803.
- Kebede Ganole, 2010. A GIS-based Surface Irrigation Potential Assessment of River Catchments for Irrigation Development in Dale Woreda, Sidama Zone, SNNP.
- Kidane D, Temesgen M, Abdelkadir A. 2012. Effect of Winged Sub soil and Traditional Tillage Integrated with Fanya Juu on Selected Soil Physico-Chemical and Soil Water Properties in the North western Highlands of Ethiopia. *East African Journal. Of Science* **6** (2):21-32.

- Kihara, F.I. 2002. Evaluation of rainwater harvesting systems in Laikipia district. Greater horn of Africa rainwater partnership (GHARP), *Kenya Rain water Association, Nairobi, Kenya. pp. 5-9.*
- Kuo S, Ho S and Liu C, 2006. Estimation irrigation water requirements with derived crop coefficients for upland and paddy crops in Chia Nan Irrigation Association, Taiwan. *Agriculture Water Management* 82: 433–451.
- Ly S, Charles C, Degré A., 2013. Different methods for spatial interpolation of rainfall data for operational hydrology and hydrological modeling at watershed scale. A review. *Biotechnology, Agronomy and Socio Environ* 17 (2):392–406.
- Li Y, Youyi Huang Y, Ye Q, Zhang W, Meng F, Zhang S. 2018. Multi objective optimization integrated with life cycle assessment for rainwater harvesting systems. *Journal of Hydrology* 558 (8):659–666.
- Ling, E., & Benham, B. L. 2014. *Rainwater Harvesting Systems.*
- Long, W. and Srihann, S., 2004, September. Land cover classification of SSC image: unsupervised and supervised classification using ERDAS Imagine. In *IGARSS 2004. IEEE International Geoscience and Remote Sensing Symposium (Vol. 4, pp. 2707-2712).* IEEE.
- Madan K, Chowdary VM, Kulkarnia Y, Mal BC .2014. Rainwater harvesting planning using geospatial techniques and multi-criteria decision analysis. *Resource Conservation Recycle* 83 (12):96–111.
- Mahmoud, S.H., Alazba, A.A. 2014. The Potential of in situ Rainwater Harvesting in Arid Regions. *Arab. Journal of Geological science* 8, 5167–5179.
- Makurira, H., Savenije, H.H., Rockström, J.2009. Investigating the water balance of on-farm techniques for improved crop productivity in rain fed systems; Makanya catchment, Tanzania. *J. Phys. Chem. Earth* 34, 98.
- Malcozewski, J., 2004. GIS- based land- use suitability analysis: a critical overview. *Program Planning.* 62, 3–65.
- Mati, B. De Bock, T. Malesu, M., Khaka, E., Oduor, A., Meshack, M., Oduor, V., 2006. Mapping the Potential of Rainwater Harvesting Technologies in Africa. A GIS Overview.
- Mbilinyi, B., Tumbo, S., Hatibu, N., 2005. Indigenous knowledge as a decision making tool in rainwater harvesting. *Phys. Chem. Earth* 30, PP 792–798.

- Mbilinyi, B.P., Tumbo, S.D., Mahoo, H.F., Mkilamwinyi, F. 2014. Identification of Suitable. Indices for Identification of Potential Sites for Rainwater Harvesting. *Tanzania Journal of Agricultural Science* 12, 35–46.
- Martyniak L, Dabrowska-Zielinska K and Szymczyk R, 2006. Validation of satellite-derived soil-vegetation indices for prognosis of spring cereals yield reduction under drought conditions: Case study from central-western Poland. *Advances in Space Research* 8: 1–6.
- Melesse Assefa, 2002. Spatially Distributed Storm Runoff Modeling using Remote Sensing and Geographic Information Systems. PhD. Dissertation Agriculture and biology. Engineering Dept., University of Florida, Gainesville, Florida.
- MoA (Ministry of Agriculture), 2002. Manual on Rainwater Harvesting and Extension Packages. *Addis Ababa, Ethiopia*. 167p.
- Mockus, V; 1964. Estimation of direct Runoff from storm rainfall, National Engineering Handbook, Section. 4, Chapter 10, Soil Conservation Service: Washington, DC.
- Moutaz, Al., 2001. Surface water modeling using GIS and remote sensing: A case study in Malewa catchment, Navaisha, Kenya.
- Mourad, K.A. and Yimer, S.M., 2017. Socio-economic Potential of Rainwater Harvesting in Ethiopia. *Sustainable Agriculture Research*, 6 (526-2017-2660).
- Munyao, J.N., 2010. Use of Satellite Products to Assess Water Harvesting Potential In Remote Areas of Africa; A case study of Ungula Island, Zanzibar. *International Institute of Geo information Science and Earth Observation Science and Earth Observation, the Netherlands*.
- Mwenge Kahinda, J. Rockström, J., Taigbenu, A. 2007. Rainwater Harvesting to Enhance Water Productivity of Rain fed Agriculture in the semi-arid Zimbabwe. *Journal of Physics, Chemistry and Earth Science* 1068–1073.
- Mwenge Kahinda, J., Taigbenu, A.E., Sejamoholo, B.B.P. 2009. A GIS-Based Decision Support System for Rainwater Harvesting (RHADESS). *Journal of Physics, Chemistry and Earth Science*, 34, 767–775.
- Mzirai, O.B., Tumbo, S.D. 2010. Macro-catchment Rainwater Harvesting Systems. Challenges and Opportunities to Access Runoff. *Journal of Animal and Plant Science*, 7, 789–800.
- Napoli, M., Cecchi, S., Zanchi, C. 2013. Determining Potential Rainwater Harvesting Sites Using a Continuous Runoff Potential Accounting Procedure and GIS Techniques in Central Italy. *Agricultural Water Management*, pp. 55–65.

- Nega, H. and Kimeu, P.M. 2002. Low-Cost Methods of Rainwater Storage. Results from field trials in Ethiopia and Kenya. Technical Report No.28. RELMA, Nairobi.
- Nemec, 1973. Engineering Hydrology. Mc Graw –Hill publishing company Limited. New Delhi.
- Ngigi, S.N. 2003. Rainwater Harvesting for Improved Food Security. Greater Horn of Africa.
- Ngigia, S., Savenije, H.H, Thome, J. 2005. Agro hydrological Evaluation of on-farm Rainwater Storage Systems for Supplemental Irrigation in Laikipia district, *Kenyan Journal of Agricultural Science*.
- Niehoff, D., Fritsch, U., and Bronstert, A. 2002. Land-Use Impacts on Storm-Runoff Generation: Scenarios of Land-Use Change and Simulation of Hydrological Response in a Micro-Scale Catchment in South West-Germany, *Journal of Hydrology*, 267(1–2), 80–93.
- Nthuni, S. M., Lübker, T., & Schaab, G. 2014. Modelling the potential of rainwater harvesting in western Kenya using remote sensing and GIS techniques. *South African Journal of Geometrics*, 3(3): 285-301
- Oweis, T., Hachum, A., Kijne, J., 1999. Water Harvesting and Supplementary Irrigation for Improved Water Use Efficiency in Dry Areas. SWIM Paper7.
- Oweis, T. and Karrou, M. 2012. Water and Land Productivities of Wheat and Food Legumes with Deficit Supplemental Irrigation in a Mediterranean environment. *Agricultural Water Management*, 107, pp.94-103.
- Parkes, C., Kershaw, H., Hart J., Sibille, R., Grant, Z. 2010. Energy and Carbon Implications of Rainwater Harvesting & Grey water Recycling. Final Report, Science Project Number: SC090018, Environment Agency, Bristol. <http://publications.environment.agency.gov.uk/pdf>.
- Pinzon, T., Rieradevall, J., Gasol, C.M., Gabarrell, X. 2015. Modelling for economic cost and environmental analysis of rainwater harvesting systems. *Journal of Cleaner Production* 87(2015), 613-626
- Prinz, D., Singh, A.K. 2008. Technological and Potential for Improvements of Water Harvesting Study for the World Commission on Dams, Cape Town, South Africa. Pretoria, South Africa.
- Rahmato, D., 1999. Water resource development in Ethiopia: Issues of sustainability and participation. *Forum for Social Studies*.

- Rami H. 2003. Ponds filled with Challenges for Water Harvesting Experiences in Amhara and Tigray. UN OCHA, Ethiopia.
- Rao KHV, Durga, Bhaumik MK. 2003. Spatial Expert Support System in Selecting Suitable Sites for Water Harvesting Structures. A Case Study of Song Watershed, Uttaranchal, India. *Geo-carto International* 18, 43 - 50.
- Reuter, H. I., Nelson, A., and Jarvis, A. 2007. An evaluation of void-filling interpolation methods for SRTM data, *International Journal of Geogr and Information Science*, 21(9), 983–1008.
- Risinger, J., and Turner, J., 2004. Siting a Flood Control Reservoir Using a Geographic Information System in St. Clair County, Illinois: In GEOG*4480 Applied GIS Winter 2004. [http://www.uoguelph.ca/geography/research/hgeog4480_w2004/Group21/index.html] site visited on 9/5/2004.
- Rockstram J. 2002. Potential of Rainwater Harvesting to Reduce Pressure on Freshwater Resources. Dialogue on water, food and environment. International Water Conference, Hanoi, Vietnam, October 14-16.
- Rockström, J., Folke, C., Gordon, L., Hatibu, N., Jewitt, G., De Vries, F.P., Rwehumbiza, F., Sally, H., Savenije, H. and Schulze, R. 2004. A Watershed Approach to Upgrade Rain fed Agriculture in Water Scarce Regions through Water System Innovations: an integrated research initiative on water for food and rural livelihoods in balance with ecosystem functions. *Journal of Physics, Chemistry of the Earth Science*,
- Rossiter, D.G., Zeng, R. and Zhang, G.L., 2017. Accounting for taxonomic distance in accuracy assessment of soil class predictions. *Geoderma*, 292, pp.118-127.
- SCS National Engineering Handbook. 1993. Hydrology, Soil Conservation Service, USDA, Washington DC, Section 4.
- Segers K, Dessein J, Nyssen J, Hailec M, Deckers J, 2007. Wanted by the State Farmers Making Headway - a Case Study in Tigray, Northern Ethiopia. In 'States at work: African Public Services in Comparative Perspective'. African Studies Centre, Leiden, the Netherlands. (AEGIS European Conference on African Studies).
- Sekar, I., Randhir, T.O. 2007. Spatial Assessment of Conjunctive Water Harvesting Potential in Watershed Systems. *Journal of Hydrology*, 334 (1) pp. 39-52.
- Şen, Z., A.A. Alsheikh, A.S. Al-Turbak, A.M. Al-Bassam, A.M. AL-Dakheel, 2011. Climate Change Impact and Runoff Harvesting in Arid Regions.

- Sileshi Bekele, Merrey DJ, Kamara A. B, Van Koppen B, Penning de Varies F, Boelee E, Makombe G, 2005. Experiences and Opportunities for Promoting small-scale /micro Irrigation and Rainwater Harvesting for Food Security in Ethiopia. Colombo, Sri Lanka: IWMI. v. (Working paper 98). P. 86.
- Sileshi Bekele, and Merrey, J. D. 2007. Assessment of small scale irrigation and water harvesting in Ethiopian agricultural development. *International Water Management Institute (IWMI)*, Addis Ababa, Ethiopia
- Sileshi Bekele, 2010. Irrigation Potential in Ethiopia: Constraints and Opportunities for Enhancing the System. *International Water Management Institute (IWMI)*.
- Silveira, L., Charbonnier, F. and Genta, J.L., 2000. The antecedent soil moisture condition of the curve number procedure. *Hydrological Sciences Journal*, 45(1), pp.3-12.
- Sivanappan R.K. 2006. Rain Water Harvesting, Conservation and Management Strategies for Urban and Rural Sectors. In 'National Seminar on Rainwater Harvesting and Water Management 11-12' Nagpur, India.
- Smajstrla, A.G. Beeson Jr, R.C., Haman, D.Z., Knox, G.W., and Yeager, T.H. 2002. Water conservation plant container University of Florida Research Foundation Inc., U.S. Patent 6,415,549.
- Steffen, J., Jensen, M., Pomeroy, C.A., Burian, S.J. 2012. Water Supply and Storm water Management Benefits of Residential Rainwater Harvesting in U.S. cities. *Journal of the American Water Resources Association* 49(4), 810-824.
- Temesgen M, Rockstrom J, Savenije HHG, Hoogmoed W. B., 2007. Assessment of Strip Tillage Systems for Maize production in Semi- arid Ethiopia: Effects on grain yield and water balance. UNESCO- IHE, Wageningen University, the Netherlands.
- Temesgen M, Uhlenbrook S, Belay S, van der Zaag P, Mohamed Y, Wenninger J, Savenije HHG. 2012. Impact Of Conservation Tillage on Hydrological and Agronomic Performance of Fanya juus in the Upper Blue Nile (Abbay) river basin. *Hydrological Earth System*.
- Terencio, D.P.S., Fernandes, L.S., Cortes, R.M.V. and Pacheco, F.A.L., 2017. Improved framework model to allocate optimal rainwater harvesting sites in small watersheds for agro-forestry uses. *Journal of hydrology*, 550, pp.318-330.
- Teshome M. B. 2005. Evaluation of Rainwater Harvesting Systems in Amhara Region, Ethiopia, Haramaya University.

- USDA (United State Department of Agricultura) .1986. Urban hydrology for small Watersheds. *TR-55, United States Department of Agriculture, 210-VI-TR-55, 2nd edition June 1986*
- USDA (United State Deptmt of Agricultura). 1972. Soil Conservation Service, National Engineering Handbook. *Hydrology Section 4. Chapters 4-10. Washington, D.C:*
- Wakeyo, M. B., & Gardebroek, C. 2015. Empty pockets, empty ponds? Adoption of water harvesting technologies in Ethiopia. *Journal of Arid Environments, 120, 75-86.*
<http://dx.doi.org/10.1016/j.jaridenv.2015.04.013>.
- WWC (World Water Council). 2010. <http://www.worldwatercouncil.org/index.php?id=25>.
(Accessed on June. 2012)
- World Water Council.2012. <http://www.worldwatercouncil.org/index.php?id=25> Under Suitability.
- Yohannes, M., & Haile, M. 2010. The potential of in situ rainwater harvesting for water resources conservation on malaria transmission in Tigray, Northern Ethiopia. *Momona Ethiopian Journal of Science, 2(2): 49-63.*
- Zhang, Q., Li, S., Gu, and S., Tan, X. 2009. Water quality in the upper Han River basin, China: the impacts of land use/land cover in riparian buffer zone. *Journal of hazardous materials, 165(1-3), pp.317-324.*

7. APPENDICES

7.1. Rainfall data

Appendix Table 1: Corrected Rainfall of Mechara Meteorology Station (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1999	0.00	31.00	14.60	58.00	141.00	72.00	59.00	201.00	89.41	12.54	9.20	0.00	687.75
2000	2.30	0.00	24.60	87.00	139.00	95.50	165.00	227.00	67.34	7.36	3.73	3.00	821.83
2001	0.00	0.00	11.60	126.00	162.00	43.00	241.00	109.00	80.80	9.32	5.32	1.70	789.74
2002	0.00	11.00	44.60	139.00	150.20	95.50	146.40	87.00	117.20	30.00	11.70	0.00	832.60
2003	3.70	160.30	34.50	114.90	52.00	115.10	89.50	165.00	160.00	8.80	34.70	12.90	951.40
2004	0.00	11.70	0.00	35.80	201.80	5.30	204.00	137.80	115.80	4.70	0.00	21.30	738.20
2005	90.50	116.80	58.60	122.80	151.60	158.40	261.30	157.70	0.00	19.40	62.90	17.30	1217.30
2006	0.00	272.60	82.90	109.40	151.60	112.60	254.50	40.80	40.80	84.60	92.80	75.50	1318.10
2007	35.00	83.10	18.50	123.70	123.70	20.90	20.90	128.80	128.80	4.30	4.30	109.00	801.00
2008	2.57	0.60	5.60	121.02	55.90	97.00	187.40	109.10	93.80	101.01	36.30	65.10	875.40
2009	0.00	169.40	52.50	88.70	205.20	85.30	150.90	148.50	242.70	25.00	19.10	1.10	1188.40
2010	0.00	0.25	22.70	43.20	154.20	100.90	118.60	252.00	261.80	16.93	76.90	0.00	1047.48
2011	0.00	0.00	0.20	95.60	67.30	43.30	178.30	97.70	182.40	0.00	18.30	19.70	702.80
2012	36.20	0.60	10.30	201.30	211.70	96.70	133.00	206.10	135.90	25.80	71.80	0.00	1129.40
2013	0.00	0.00	11.60	190.40	131.80	47.00	68.90	200.50	125.30	17.20	35.50	0.00	828.20
2014	0.00	0.00	28.20	39.70	128.70	83.20	85.70	215.20	106.50	56.20	0.70	15.10	759.20
2015	9.20	34.90	69.50	214.10	212.10	114.40	219.50	73.00	105.30	48.30	30.30	20.20	1150.80
2016	0.00	3.20	68.30	69.70	205.70	40.40	118.10	109.60	197.60	74.80	20.10	0.00	907.50
2017	0.00	3.30	24.30	181.40	160.60	189.30	40.10	129.30	61.80	48.20	60.10	6.70	905.10
2018	0.00	6.00	12.00	132.37	128.00	84.56	98.25	170.00	78.00	38.00	5.00	0.00	752.18
mean	8.97	45.24	29.76	114.70	146.71	85.02	142.02	148.26	119.56	31.62	29.94	18.43	920.22
80% Dep. RF	0.00	0.00	11.00	115.00	150.00	95.3	140.9	101	60	6	1	1	

Appendix Table 2: Corrected Monthly Rain fall data of Micheta meteorology station (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1999	0.00	31.00	14.60	58.00	141.00	72.00	59.00	201.00	89.41	12.54	9.20	0.00	687.75
2000	2.30	0.00	44.24	87.00	139.00	75.50	165.00	227.00	67.34	7.36	3.73	3.00	821.47
2001	0.00	0.00	11.70	126.00	162.00	43.00	241.00	109.00	80.80	9.32	5.32	1.70	789.84
2002	0.00	11.00	110.60	139.00	150.20	95.50	146.40	87.00	117.20	30.00	11.70	0.00	898.60
2003	3.70	160.30	34.50	114.90	52.00	115.10	89.50	165.00	160.00	8.80	34.70	12.90	951.40
2004	0.00	11.70	0.00	35.80	201.80	85.30	204.00	137.80	115.80	154.70	0.00	21.30	968.20
2005	90.50	116.80	258.60	122.80	151.60	158.40	261.30	157.70	0.00	19.40	62.90	17.30	1417.30
2006	0.00	272.60	182.90	9.40	9.40	12.60	254.50	40.80	40.80	84.60	92.80	275.50	1275.90
2007	35.00	83.10	118.50	123.70	123.70	20.90	20.90	128.80	128.80	4.30	4.30	109.00	901.00
2008	2.57	0.60	5.60	121.02	55.90	97.00	187.40	109.10	93.80	147.50	36.30	65.10	921.89
2009	0.00	169.40	152.50	88.70	205.20	85.30	150.90	148.50	42.70	25.00	19.10	1.10	1088.40
2010	0.00	0.25	22.70	43.20	154.20	100.90	118.60	252.00	61.80	16.93	76.90	0.00	847.48
2011	0.00	0.00	0.20	95.60	67.30	43.30	178.30	97.70	12.40	0.00	18.30	19.70	532.80
2012	36.20	0.60	17.30	211.30	211.70	96.70	133.00	206.10	35.90	125.80	71.80	0.00	1146.40
2013	0.00	0.00	10.60	190.40	131.80	47.00	68.90	200.50	5.30	127.20	35.50	0.00	817.20
2014	0.00	0.00	28.20	39.70	128.70	83.20	85.70	215.20	106.50	56.20	80.70	15.10	839.20
2015	9.20	34.90	68.50	214.10	212.10	114.40	219.50	73.00	105.30	48.30	130.30	20.20	1249.80
2016	0.00	3.20	68.30	69.70	205.70	40.40	118.10	109.60	197.60	74.80	20.10	0.00	907.50
2017	0.00	3.30	124.30	181.40	160.60	189.30	40.10	129.30	61.80	48.20	60.10	6.70	1005.10
2018	0.00	6.00	102.00	132.37	128.00	84.56	98.25	170.00	78.00	38.00	5.00	0.00	842.18
Mean	8.97	45.24	68.79	110.20	139.60	83.02	142.02	148.26	80.06	51.95	38.94	28.43	945.47
80% Dep. RF	0.00	0.00	10.00	119.00	59.00	85.00	80.00	100.00	61.00	5	5	0	945.47

Appendix Table 3: Corrected Monthly Rainfall data of Dumuga meteorology station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1999	0.00	0.11	25.57	115.23	147.38	161.40	118.54	180.76	88.73	26.88	44.35	4.02	912.97
2000	0.30	9.08	54.21	78.33	89.12	49.39	80.30	204.61	89.51	50.32	0.27	0.29	705.74
2001	1.64	0.00	37.09	98.75	80.48	86.63	215.32	224.56	89.36	6.65	21.08	0.26	861.81
2002	25.92	0.07	53.23	126.98	125.83	216.43	120.47	99.81	198.08	7.14	10.64	5.25	989.85
2003	26.79	30.90	20.26	142.10	205.10	185.64	174.09	176.13	104.78	4.39	4.49	0.00	1074.67
2004	9.49	1.14	51.51	52.45	83.88	99.30	104.09	140.11	153.80	9.70	0.45	6.15	712.07
2005	0.00	0.00	10.98	124.70	138.04	72.26	320.94	136.13	137.09	58.37	6.05	17.64	1022.20
2006	0.73	0.18	22.30	50.60	111.86	83.06	319.58	77.88	138.02	33.04	0.44	1.12	838.81
2007	2.65	2.65	97.19	99.70	26.23	46.17	75.89	184.72	133.93	16.37	0.04	3.41	688.95
2008	2.48	0.06	5.69	129.74	2.29	118.10	36.86	132.57	183.04	5.43	1.20	59.12	676.58
2009	18.70	14.64	51.94	118.84	8.92	161.49	349.26	98.00	107.55	15.29	12.68	5.07	962.37
2010	12.90	11.56	54.52	72.99	230.21	141.27	137.86	101.22	68.59	77.78	11.67	0.00	920.57
2011	0.16	13.88	9.45	25.93	127.45	136.40	62.57	62.57	80.47	18.59	0.51	15.02	552.99
2012	1.85	8.36	13.42	144.16	175.42	154.75	89.43	139.24	120.76	35.29	12.04	0.04	894.76
2013	0.15	3.75	3.49	66.74	126.26	79.45	379.75	106.16	209.12	42.38	88.96	0.48	1106.70
2014	15.69	0.16	73.15	69.83	34.40	65.87	235.45	21.49	108.90	19.29	9.23	22.00	675.45
2015	4.13	11.28	24.74	102.41	39.04	127.86	49.54	170.58	145.78	21.07	6.25	0.42	703.10
2016	1.63	12.04	20.38	85.66	44.75	226.98	124.80	216.85	287.22	6.64	46.26	13.11	1086.30
2017	1.06	0.00	51.23	116.30	71.42	137.93	105.72	80.65	122.34	54.24	4.95	11.89	757.74
2018	4.95	0.93	16.50	86.78	86.08	119.89	69.46	103.47	132.85	251.05	105.65	12.06	989.68
Mean	6.56	6.04	34.84	95.41	97.71	123.51	158.50	132.88	135.00	38.00	19.36	8.87	856.67
80% Dep. RF	0.00	0.00	15.00	65.00	82.00	136.00	116.00	102.00	108.00	15.00	1.04	0.00	856.67

Appendix Table 4: Corrected Monthly Rainfall Data of Chancho Meteorology Station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annu(mm)
1999	12.07	4.21	22.76	78.24	28.57	208.21	100.33	104.39	249.80	22.48	0.00	0.94	831.99
2000	8.31	3.38	104.67	350.70	66.86	128.11	70.94	279.96	301.69	79.76	1.51	0.00	1395.88
2001	7.78	1.00	59.25	155.33	149.67	292.56	51.90	278.56	60.68	1.34	6.54	2.86	1067.48
2002	35.72	4.06	94.54	76.86	133.96	103.22	154.92	185.60	13.31	0.14	10.00	0.00	812.34
2003	12.53	10.1	39.02	91.49	76.40	117.54	243.56	224.99	72.43	0.87	4.54	20.59	914.02
2004	5.57	9.6	114.92	67.92	188.52	97.75	85.47	233.16	215.09	0.00	2.09	0.00	1020.25
2005	0.11	25.6	115.23	147.38	161.40	98.55	480.76	188.73	26.88	44.35	4.02	0.30	1293.28
2006	0.00	20.3	142.10	105.10	185.64	174.08	276.13	104.78	94.39	4.49	4.49	9.25	1120.71
2007	1.14	0.1	52.46	83.88	99.30	94.09	140.11	153.80	289.72	0.45	6.15	0.00	921.22
2008	0.00	11.0	124.71	138.04	72.26	104.94	136.13	137.09	58.37	6.05	17.64	0.73	806.94
2009	0.18	22.3	50.61	71.86	83.06	219.58	97.87	138.02	133.04	0.44	1.12	2.65	820.73
2010	2.65	7.2	99.70	46.23	46.17	175.88	184.72	133.93	16.37	0.04	3.41	2.48	718.78
2011	0.06	5.7	299.75	2.29	118.10	186.86	202.57	183.04	105.43	1.20	2.00	0.00	1107.00
2012	14.64	11.9	58.84	8.92	161.49	149.26	208.00	207.55	105.29	12.68	5.07	12.90	956.57
2013	13.88	9.5	225.93	46.52	136.40	108.24	162.57	180.47	180.59	0.51	15.02	1.85	1081.43
2014	8.36	13.4	144.16	15.42	226.75	189.43	209.24	120.76	35.29	12.04	0.04	0.15	975.07
2015	3.75	3.5	66.74	126.26	209.45	79.75	126.16	209.12	42.38	9.00	0.48	0.00	876.59
2016	0.16	73.2	169.83	44.40	65.87	95.45	24.49	108.90	195.29	9.20	0.00	4.13	790.86
2017	0.00	51.2	186.30	71.42	137.93	105.72	180.65	422.34	54.24	4.95	0.00	4.95	1219.73
2018	0.93	16.0	46.78	86.08	219.90	129.46	103.47	132.85	251.05	10.65	12.06	0.00	1009.24
Mean	6.39	15.17	110.91	90.72	128.39	142.93	162.00	186.40	125.07	11.03	4.81	3.19	987.01
80% Dep. RF	0.00	0.00	43.00	43.00	128.00	95.00	94.00	105.00	53.00	0.00	0.00	0.00	987.01

Appendix Table 5: Corrected Monthly Rainfall Data of Gelemso Meteorology Station

Year	Jan	Febr	Mar	Apri	May	June	July	August	Sept	Oct	Nov	Dec	Total
1999	37.6	0	101.3	248.5	150	32	236.1	110.9	76.6	23.3	25.4	6.2	1047.9
2000	0	14.5	75.7	129.7	169.4	93.8	148.7	110.4	151.5	69.8	2.3	20.8	986.6
2001	0	19.2	148.7	67.2	237.2	42	80.9	69.6	170.2	74.6	0	7.6	917.2
2002	22.6	39	34.1	156.5	80.1	64.8	110.1	244.4	176.2	134.8	0	1.4	1064
2003	0	16.8	85.9	272.6	29	96.4	114	102.1	140.6	130.8	6.2	71.4	1065.8
2004	8.1	112.2	155.4	191	65.4	158.4	100.1	207	97.9	26.8	0	11.2	1133.5
2005	18.9	57	174.8	77.6	99	241.5	58.6	33.9	10.9	6.2	99	41.5	918.9
2006	58.6	33.9	10.9	176.2	17.7	167	29.4	192.7	75.1	78.1	98.4	11.3	949.3
2007	81.5	52.7	0	57.9	117	119.3	55.6	140.8	39.5	114.9	29.9	10.3	819.4
2008	87.6	2.8	10.1	19.7	56.5	11.5	51.8	149.1	46.8	42.6	110.5	15.4	604.4
2009	1.8	132.1	23.4	23	15.1	195.8	137.8	227.3	48.6	166.3	98	3.5	1072.7
2010	55.8	54.4	0	2.7	25.1	155.6	155.1	46	90.8	115.5	123.8	11.7	836.5
2011	68.9	164.9	0	0.2	240.5	71.2	154.5	194.9	55.1	65.9	14.9	2.3	1033.3
2012	51.5	88.4	4.4	79.2	127.5	267	122.1	30.2	88.4	0	1.2	0	859.9
2013	3.7	85.3	236.5	32.3	6.8	137.4	141.5	174	59.3	113.2	11.6	27.4	1029
2014	97.2	63.4	34.6	160	117.2	188	229.1	24.2	164.4	249	10.3	48.1	1385.5
2015	0	0	135.2	31.9	209	59.9	216.7	218.2	19.2	10.9	202	9.9	1112.9
2016	85.7	2	42.8	7.2	78.6	78.5	103	230.5	0	0	160.1	16.7	805.1
2017	5.5	8	5.3	95.1	156.8	50.4	155.6	123.9	210.3	94.8	94.6	0	1000.3
2018	0	130.4	155.1	33	154.1	98.8	5.5	101.3	10.1	152.6	117.4	0	958.3
Mean	34.25	53.85	71.71	93.08	107.60	116.47	120.31	136.57	86.58	83.51	60.28	15.84	980.03
80% Dep. RF	0	0	0	31	147	102	146	24	11	16	10	1	980.25

7.2. Mean Climatic Data and ETo of Five Meteorological Station

Appendix Table 6: Mean Monthly Climate Data of Mechara Station

Station Name	Time of Record	Parameter	J January	February	March	April	May	June	July	August	September	October	November	December
Mechara	1999-2018	T _{max} (°C)	28.15	30.0	29.65	28.62	26.98	27.60	28.22	27.79	27.36	27.5	28.3	27.5
	1999-2018	T _{min} (°C)	14.6	15.8	15.4	15.6	15.6	14.8	14.7	14.9	15.5	15.5	14.8	14.3
	1999-2018	R.H (%)	43	58	57	62	66	77	69	69	69	64	63	57
	1999-2018	W. S (Km/hrs.)	38.4	33.9	36.9	38.8	25.7	17.1	24.4	25.2	22.5	25.4	30.3	23.1
	1999-2018	S. Sh (hrs./d)	7.03	6.5	6.61	5.88	6.27	6.85	6.12	5.74	5.30	5.76	6.8	6.5
	1999-2018	ETo (mm/d)	3.26	3.6	3.8	3.7	3.6	3.5	3.5	3.5	3.4	3.3	3.2	3.0

Appendix Table 7: Mean Monthly Climate data of Micheta Station

Station Name	Time of Record	Parameter	January	February	March	April	May	June	July	August	Sept	Oct	Nov	Dec
Micheta	1999-2018	T _{max} (°C)	27.89	31.49	28.87	27.94	27.71	27.85	26.64	26.43	26.59	26.68	26.57	26.43
	1999-2018	T _{min} (°C)	14.20	16.83	16.06	15.83	15.64	15.32	15.02	14.97	14.31	14.59	14.36	13.93
	1999-2018	R.H (%)	48.91	50.51	52.61	61.08	70.03	70.82	76.06	76.56	72.76	64.84	60.72	52.07
	1999-2018	W. S (Km/hrs.)	32.06	28.33	30.06	27.89	23.39	23.88	23.41	22.24	20.10	22.99	26.09	25.69
	1999-2018	S. Sh (hrs./d)	8.18	7.14	7.54	5.62	6.16	6.02	5.40	5.31	5.07	6.34	5.90	6.91
	1999-2018	ETo (mm/d)	3.34	3.70	4.24	3.58	3.60	3.48	3.31	3.37	3.26	3.38	3.06	3.03

Appendix Table 8: Mean Monthly Climate Data of Dumuga Station

Station	Time of Record	Parameter	January	February	March	April	May	June	July	August	September	October	November	December
Dumuga	1999-2018	T _{max} (°C)	26.96	24.13	24.38	23.74	24.41	24.68	22.55	22.49	23.36	24.66	24.67	24.85
	1999-2018	T _{min} (°C)	15.32	14.76	13.82	14.95	11.19	15.61	15.03	14.60	14.25	13.80	15.56	15.14
	1999-2018	R.H (%)	55	48	54	64	61	62	77	81	74	69	64	59
	1999-2018	W. S (Km/hrs.)	2.17	2.30	3.90	3.21	2.10	2.55	2.18	1.87	2.04	2.15	2.16	3.12
	1999-2018	S. Sh (hrs./d)	7.69	5.40	5.66	7.67	7.60	8.50	8.51	8.53	7.54	8.01	10.35	9.62
	1999-2018	ET _o (mm/d)												

Appendix Table 9: Mean Monthly Climate data of Chancho Station

Station	Time of Record	Parameter	January	February	March	April	May	June	July	August	Sept	October	Nov	Dece
Chancho	1999-2018	T _{max} (°C)	22.37	29.47	28.05	29.29	28.57	27.18	25.82	26.12	26.68	25.58	26.99	27.33
	1999-2018	T _{min} (°C)	16.50	15.79	15.24	14.02	15.77	14.49	14.20	15.05	17.06	14.71	16.28	16.12
	1999-2018	R.H (%)	43.30	44.70	53.00	88.60	59.00	87.70	56.70	61.80	74.00	85.00	34.00	66.80
	1999-2018	W. S (Km/hrs.)	21.30	22.70	24.00	25.20	25.90	25.40	22.10	18.80	19.90	21.00	21.50	21.20
	1999-2018	S. Sh (hrs./d)	11.01	10.14	10.34	8.83	9.34	8.77	5.67	6.18	7.42	8.52	10.40	11.24
	1999-2018	ET _o (mm/d)	3.26	3.59	3.91	3.77	3.63	3.34	3.20	3.34	3.49	3.53	3.31	3.42

NB: Tmax= Maximum temperature, Tmin= Minimum temperature, R.H= Relative humidity, W.S=Wind speed, S. Sh= Sun shine & Reference Evapotranspiration

Appendix Table 10: Mean Monthly Climate Data of Galemso Station

Station Name	of Record	Parameter	January	February	March	April	May	June	July	August	September	October	November	December
Galemso	1999-2018	T _{max} (°C)	26.72	27.69	25.32	24.56	25.82	25.57	26.34	26.20	26.47	26.14	26.55	26.08
	1999-2018	T _{min} (°C)	13.35	11.78	12.84	13.43	14.08	13.37	16.24	17.47	13.84	11.98	12.30	11.84
	1999-2018	R.H (%)	68.00	63.00	43.00	62.00	33.00	63.43	92.00	63.00	62.90	57.00	51.00	61.00
	1999-2018	W. S (Km/hr s.)	14.50	12.20	11.40	12.30	11.30	9.80	9.50	14.40	20.50	17.60	24.90	17.40
	1999-2018	S. Sh (hrs./d)	6.68	7.10	7.56	7.02	6.27	7.35	6.98	6.81	6.77	7.45	7.66	7.05
	1999-2018	ET _o (mm/d)	3.14	3.55	3.59	3.61	3.22	3.47	3.59	3.57	3.59	3.53	3.38	3.08

Appendix Table 11: Seasonal wet and dry rainfall using excel sheet for the computation of expected runoff depth

Date	RF (mm)	AMC	CN	S(mm)	Q	Date	RF	AMC	CN	S (mm)	Q (mm)
05/01/09	0	1	66.6	127.38	0	30/07/2	24.1	1	66.6	127.38	0.0
10/01/09	0	1	66.6	127.38	0	05/08/2	32.5	1	66.6	127.38	0.4
15/01/09	0	1	66.6	127.38	0	10/08/2	77.7	3	91.43	23.81	55.0
20/01/09	0	1	66.6	127.38	0	30/07/2	32.5	1	66.6	127.38	0.4
25/01/09	0	1	66.6	127.38	0	04/08/2	3.4	1	66.6	127.38	0.0
30/01/09	0	1	66.6	127.38	0	09/08/2	25.6	1	66.6	127.38	0.0
05/02/09	0	1	66.6	127.38	0	14/08/2	34.3	1	66.6	127.38	0.6
10/02/09	0	1	66.6	127.38	0	19/08/2	2.6	1	66.6	127.38	0.0
15/02/09	0	1	66.6	127.38	0	24/08/2	0	1	66.6	127.38	0.0
20/02/09	0	1	66.6	127.4	0	29/08/9	12.8	1	66.6	127.38	0.0
25/02/09	0	1	66.6	127.4	0	03/09/9	27.9	1	66.6	127.38	0.0
02/03/09	0	1	66.6	127.4	0	08/09/9	7.2	1	66.6	127.38	0.0
07/03/2/9	0	1	66.6	127.4	0	13/09/9	16.5	1	66.6	127.38	0.0
12/03/09	0	1	66.6	127.4	0	18/09/9	9.3	1	66.6	127.38	0.0
17/03/09	0	1	66.6	127.4	0	23/09/9	24.9	1	66.6	127.38	0.0
22/03/09	15.1	1	66.6	127.4	0	28/09/9	19.4	1	66.6	127.38	0.0
27/03/09	0	1	66.6	127.4	0	03/10/0	64.3	3	91.43	23.81	42.5
01/04/09	10.62	1	66.6	127.4	0	08/10/0	37.3	2	82	55.76	8.3
06/04/09	11.7	1	66.6	127.4	0	13/10/0	2.5	1	66.6	127.38	0.0
11/04/09	7.3	1	66.6	127.4	0	18/10/0	19.2	1	66.6	127.38	0.0
16/04/09	1	1	66.6	127.4	0	23/10/0	0	1	66.6	127.38	0.0
21/04/09	75.7	3	91.43	23.8	53	28/10/9	0.5	1	66.6	127.38	0.0
26/04/09	14.7	1	66.6	127.4	0	02/11/9	0	1	66.6	127.38	0.0
01/05/09	0.7	1	66.6	127.4	0	07/11/9	0	1	66.6	127.38	0.0
06/05/09	3.4	1	66.6	127.4	0	12/11/9	0	1	66.6	127.38	0.0
11/05/09	33.4	1	66.6	127.4	0	17/11/9	4.2	1	66.6	127.38	0.0
16/05/09	12.7	1	66.6	127.4	0	22/11/9	44.9	3	66.6	127.38	2.6
21/05/09	4.5	1	66.6	127.4	0	27/11/9	0	1	66.6	127.38	0.0
26/05/09	1.2	1	66.6	127.4	0	02/12/9	42.3	3	66.6	127.38	2.0
31/05/09	5.1	1	66.6	127.4	0	07/12/9	2.4	1	66.6	127.38	0.0
05/06/09	1.9	1	66.6	127.4	0	12/12/9	3.5	1	66.6	127.38	0.0
10/06/09	10.3	1	66.6	127.4	0	17/12/9	3.6	1	66.6	127.38	0.0
15/06/09	4.6	1	66.6	127.4	0	22/12/9	0	1	66.6	127.38	0.0
20/06/09	20.2	1	66.6	127.4	0	27/12/9	4.2	1	66.6	127.38	0.0
25/06/09	17.4	1	66.6	127.4	0	01/01/9	44.9	3	91.43	127.38	2.6
30/06/09	35.7	3	91.43	23.8	17	06/01/9	0	1	66.6	127.38	0.0
05/07/09	22.8	1	66.6	127.4	0	11/01/9	42.3	3	91.43	127.38	2.0
10/07/09	28.2	1	66.6	127.4	0	16/01/9	2.4	1	66.6	127.38	0.0
15/07/09	24.1	1	66.6	127.4	0	21/01/9	3.5	1	66.6	127.38	0.0
20/07/09	32.5	1	66.6	127.4	0	26/01/9	3.6	1	66.6	127.38	0.0
25/07/09	77.7	3	91.43	23.8	55		1014.				187.4

Appendix Table 12: Crop Water Requirement of Tomato, onion and maize at Mechara Station

Crop Water Requirements

ETo station: Mechara Crop: Tomato
 Rain station: Mechara Planting date: 02/09

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Sep	1	Init	0.60	2.00	18.0	10.8	6.0
Sep	2	Init	0.60	2.00	20.0	8.5	11.6
Sep	3	Init	0.60	2.01	20.1	5.6	14.5
Oct	1	Deve	0.66	2.22	22.2	0.1	22.0
Oct	2	Deve	0.79	2.66	26.6	0.0	26.6
Oct	3	Deve	0.92	3.05	33.6	0.0	33.6
Nov	1	Deve	1.05	3.43	34.3	0.0	34.3
Nov	2	Mid	1.11	3.54	35.4	0.0	35.4
Nov	3	Mid	1.11	3.52	35.2	0.0	35.2
Dec	1	Mid	1.11	3.50	35.0	0.0	35.0
Dec	2	Mid	1.11	3.47	34.7	0.0	34.7
Dec	3	Late	1.05	3.34	36.7	0.0	36.7
Jan	1	Late	0.95	3.06	30.6	0.0	30.6
Jan	2	Late	0.88	2.88	11.5	0.0	11.5
					393.9	25.0	367.7

Crop Water Requirements

ETo station: Mechara Crop: Onion
 Rain station: Mechara Planting date: 02/09

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Sep	1	Init	0.70	2.84	25.6	10.8	13.6
Sep	2	Init	0.70	2.86	28.6	8.5	20.1
Sep	3	Deve	0.71	2.78	27.8	5.6	22.1
Oct	1	Deve	0.78	2.94	29.4	0.1	29.3
Oct	2	Deve	0.87	3.13	31.3	0.0	31.3
Oct	3	Mid	0.95	3.29	36.1	0.0	36.1
Nov	1	Mid	0.96	3.20	32.0	0.0	32.0
Nov	2	Mid	0.96	3.06	30.6	0.0	30.6
Nov	3	Late	0.96	3.04	30.4	0.0	30.4
Dec	1	Late	0.96	3.02	30.2	0.0	30.2
					302.1	25.0	275.8

Crop Water Requirements

ETo station: Mechara Crop: Maize

Rain station: Mechara Planting date: 02/09

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Sep	1	Init	0.30	1.22	11.0	10.8	0.0
Sep	2	Init	0.30	1.22	12.2	8.5	3.8
Sep	3	Deve	0.41	1.60	16.0	5.6	10.4
Oct	1	Deve	0.65	2.45	24.5	0.1	24.3
Oct	2	Deve	0.89	3.21	32.1	0.0	32.1
Oct	3	Mid	1.11	3.86	42.4	0.0	42.4
Nov	1	Mid	1.15	3.81	38.1	0.0	38.1
Nov	2	Mid	1.15	3.66	36.6	0.0	36.6
Nov	3	Mid	1.15	3.63	36.3	0.0	36.3
Dec	1	Late	1.12	3.52	35.2	0.0	35.2
Dec	2	Late	0.95	2.98	29.8	0.0	29.8
Dec	3	Late	0.76	2.42	26.6	0.0	26.6
Jan	1	Late	0.62	2.01	8.0	0.0	8.0
					348.9	25.0	323.6

Appendix Table 13: Crop Water Requirement of Tomato, onion and maize at Michata Station

Crop Water Requirements

ETo station: Micheta Crop: Tomato

Rain station: Micheta Planting date: 09/09

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Sep	1	Init	0.60	1.98	4.0	2.4	4.0
Sep	2	Init	0.60	1.96	19.6	8.8	10.8
Sep	3	Init	0.60	1.98	19.8	5.8	14.0
Oct	1	Deve	0.60	2.02	20.2	0.1	20.1
Oct	2	Deve	0.69	2.34	23.4	0.0	23.4
Oct	3	Deve	0.82	2.69	29.6	0.0	29.6
Nov	1	Deve	0.95	3.01	30.1	0.0	30.1
Nov	2	Mid	1.06	3.25	32.5	0.0	32.5
Nov	3	Mid	1.09	3.32	33.2	0.0	33.2
Dec	1	Mid	1.09	3.31	33.1	0.0	33.1
Dec	2	Mid	1.09	3.30	33.0	0.0	33.0
Dec	3	Late	1.08	3.39	37.3	0.0	37.3
Jan	1	Late	1.00	3.24	32.4	0.0	32.4
Jan	2	Late	0.90	3.02	30.2	0.0	30.2
Jan	3	Late	0.85	2.95	2.9	0.0	2.9
					381.2	17.1	366.5

Crop Water Requirements

ETo station: Micheta Crop: Onion

Rain station: Micheta Planting date: 09/09

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Sep	1	Init	0.30	1.17	2.3	2.4	2.3
Sep	2	Init	0.30	1.19	11.9	8.8	3.2
Sep	3	Deve	0.31	1.17	11.7	5.8	5.8
Oct	1	Deve	0.52	1.85	18.5	0.1	18.4
Oct	2	Deve	0.80	2.72	27.2	0.0	27.2
Oct	3	Mid	1.09	3.71	40.8	0.0	40.8
Nov	1	Mid	1.16	3.98	39.8	0.0	39.8
Nov	2	Mid	1.16	4.01	40.1	0.0	40.1
Nov	3	Late	1.14	3.78	37.8	0.0	37.8
Dec	1	Late	0.91	2.87	28.7	0.0	28.7
Dec	2	Late	0.65	1.98	13.8	0.0	13.8
					272.7	17.1	258.0

Crop Water Requirements

ETo station: Micheta Crop: Maize

Rain station: Micheta Planting date: 01/09

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Sep	1	Init	0.60	1.98	19.8	12.1	7.7
Sep	2	Init	0.60	1.96	19.6	8.8	10.8
Sep	3	Deve	0.68	2.23	22.3	5.8	16.5
Oct	1	Deve	0.81	2.72	27.2	0.1	27.1
Oct	2	Deve	0.95	3.22	32.2	0.0	32.2
Oct	3	Mid	1.07	3.51	38.6	0.0	38.6
Nov	1	Mid	1.08	3.43	34.3	0.0	34.3
Nov	2	Mid	1.08	3.31	33.1	0.0	33.1
Nov	3	Mid	1.08	3.30	33.0	0.0	33.0
Dec	1	Late	1.07	3.24	32.4	0.0	32.4
Dec	2	Late	0.99	2.99	29.9	0.0	29.9
Dec	3	Late	0.90	2.83	31.1	0.0	31.1
Jan	1	Late	0.85	2.74	8.2	0.0	8.2
					361.7	26.8	334.9

Appendix Table 14: Crop Water Requirement of Tomato, onion and maize at Dumuga Station

Crop Water Requirements

ETo station: Dumuga Crop: Tomato

Rain station: Dumuga Planting date: 07/09

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Sep	1	Init	0.60	2.27	9.1	8.9	0.0
Sep	2	Init	0.60	2.20	22.0	24.0	0.0
Sep	3	Init	0.60	2.17	21.7	16.0	5.8
Oct	1	Deve	0.61	2.20	22.0	0.1	21.8
Oct	2	Deve	0.73	2.59	25.9	0.0	25.9
Oct	3	Deve	0.87	3.15	34.6	0.0	34.6
Nov	1	Deve	1.02	3.72	37.2	0.0	37.2
Nov	2	Mid	1.08	4.01	40.1	0.0	40.1
Nov	3	Mid	1.08	3.92	39.2	0.0	39.2
Dec	1	Mid	1.08	3.84	38.4	0.0	38.4
Dec	2	Late	1.03	3.57	35.7	0.0	35.7
Dec	3	Late	0.92	3.15	34.7	0.0	34.7
Jan	1	Late	0.85	2.85	11.4	0.0	11.4
					372.0	49.0	324.8

Crop Water Requirements

ETo station: Crop:
 Rain station: Planting date:

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Sep	1	Init	0.70	2.65	2.6	2.2	2.6
Sep	2	Init	0.70	2.56	25.6	24.0	1.7
Sep	3	Deve	0.72	2.60	26.0	16.0	10.1
Oct	1	Deve	0.79	2.85	28.5	0.1	28.4
Oct	2	Deve	0.87	3.11	31.1	0.0	31.1
Oct	3	Mid	0.94	3.40	37.4	0.0	37.4
Nov	1	Mid	0.94	3.48	34.8	0.0	34.8
Nov	2	Late	0.94	3.54	35.4	0.0	35.4
Nov	3	Late	0.94	3.44	34.4	0.0	34.4
Dec	1	Late	0.94	3.35	10.0	0.0	10.0
					266.0	42.3	225.9

Crop Water Requirements

ETo station: Crop:
 Rain station: Planting date:

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Sep	1	Init	0.30	1.13	4.5	8.9	0.0
Sep	2	Init	0.30	1.10	11.0	24.0	0.0
Sep	3	Deve	0.32	1.17	11.7	16.0	0.0
Oct	1	Deve	0.52	1.86	18.6	0.1	18.5
Oct	2	Deve	0.74	2.66	26.6	0.0	26.6
Oct	3	Deve	0.98	3.57	39.3	0.0	39.3
Nov	1	Mid	1.10	4.06	40.6	0.0	40.6
Nov	2	Mid	1.10	4.13	41.3	0.0	41.3
Nov	3	Mid	1.10	4.02	40.2	0.0	40.2
Dec	1	Mid	1.10	3.91	39.1	0.0	39.1
Dec	2	Late	1.00	3.47	34.7	0.0	34.7
Dec	3	Late	0.81	2.77	30.4	0.0	30.4
Jan	1	Late	0.63	2.12	19.1	0.0	19.1
					357.0	49.0	329.6

Appendix Table 15: Crop Water Requirement of Tomato, onion and maize at Chancho Station

Crop Water Requirements

ETo station: Chancho Crop: Tomato

Rain station: Chancho Planting date: 05/09

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Sep	1	Init	0.60	2.07	12.4	6.6	6.9
Sep	2	Init	0.60	2.10	21.0	6.5	14.5
Sep	3	Init	0.60	2.11	21.1	4.3	16.7
Oct	1	Deve	0.63	2.21	22.1	0.1	22.0
Oct	2	Deve	0.74	2.63	26.3	0.0	26.3
Oct	3	Deve	0.87	3.03	33.3	0.0	33.3
Nov	1	Deve	1.00	3.41	34.1	0.0	34.1
Nov	2	Mid	1.09	3.63	36.3	0.0	36.3
Nov	3	Mid	1.10	3.61	36.1	0.0	36.1
Dec	1	Mid	1.10	3.58	35.8	0.0	35.8
Dec	2	Mid	1.10	3.55	35.5	0.0	35.5
Dec	3	Late	1.06	3.44	37.9	0.0	37.9
Jan	1	Late	0.94	3.08	30.8	0.0	30.8
Jan	2	Late	0.85	2.78	19.4	0.0	19.4
					402.3	17.6	385.8

Crop Water Requirements

ETo station: Chancho Crop: Onion

Rain station: Chancho Planting date: 05/09

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Sep	1	Init	0.70	2.42	14.5	6.6	9.0
Sep	2	Init	0.70	2.45	24.5	6.5	18.0
Sep	3	Deve	0.71	2.51	25.1	4.3	20.8
Oct	1	Deve	0.78	2.75	27.5	0.1	27.4
Oct	2	Deve	0.85	3.01	30.1	0.0	30.1
Oct	3	Mid	0.92	3.19	35.1	0.0	35.1
Nov	1	Mid	0.94	3.20	32.0	0.0	32.0
Nov	2	Mid	0.94	3.14	31.4	0.0	31.4
Nov	3	Late	0.95	3.12	31.2	0.0	31.2
Dec	1	Late	0.95	3.09	30.9	0.0	30.9
Dec	2	Late	0.95	3.07	9.2	0.0	9.2
					291.6	17.6	275.1

Crop Water Requirements

ETo station: Chancho Crop: Maize
 Rain station: Chancho Planting date: 05/09

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Sep	1	Init	0.50	1.73	10.4	6.6	4.9
Sep	2	Init	0.50	1.75	17.5	6.5	11.0
Sep	3	Deve	0.53	1.88	18.8	4.3	14.4
Oct	1	Deve	0.69	2.42	24.2	0.1	24.1
Oct	2	Deve	0.85	3.01	30.1	0.0	30.1
Oct	3	Mid	1.02	3.53	38.8	0.0	38.8
Nov	1	Mid	1.07	3.63	36.3	0.0	36.3
Nov	2	Mid	1.07	3.56	35.6	0.0	35.6
Nov	3	Mid	1.07	3.53	35.3	0.0	35.3
Dec	1	Late	1.07	3.48	34.8	0.0	34.8
Dec	2	Late	0.97	3.13	31.3	0.0	31.3
Dec	3	Late	0.82	2.68	29.5	0.0	29.5
Jan	1	Late	0.70	2.29	16.0	0.0	16.0
					358.6	17.6	342.1

Appendix Table 16: Crop Water Requirement of Tomato, onion and maize at Gelemso Station

Crop Water Requirements

ETo station: Gelemso Crop: Tomato
 Rain station: Gelemso Planting date: 07/09

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Sep	1	Init	0.60	2.15	8.6	0.1	8.5
Sep	2	Init	0.60	2.16	21.6	0.0	21.6
Sep	3	Init	0.60	2.15	21.5	0.0	21.5
Oct	1	Deve	0.61	2.17	21.7	0.0	21.7
Oct	2	Deve	0.71	2.51	25.1	0.0	25.1
Oct	3	Deve	0.83	2.90	31.9	0.0	31.9
Nov	1	Deve	0.96	3.28	32.8	0.0	32.8
Nov	2	Mid	1.05	3.57	35.7	0.0	35.7
Nov	3	Mid	1.07	3.50	35.0	0.0	35.0
Dec	1	Mid	1.07	3.39	33.9	0.0	33.9
Dec	2	Mid	1.07	3.28	32.8	0.0	32.8
Dec	3	Late	1.04	3.24	35.6	0.0	35.6
Jan	1	Late	0.94	2.93	29.3	0.0	29.3
Jan	2	Late	0.83	2.61	23.5	0.0	23.5
					388.9	0.1	388.9

Crop Water Requirements

ETo station: Gelemso Crop: Onion

Rain station: Gelemso Planting date: 07/09

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Sep	1	Init	0.60	2.15	8.6	0.1	8.5
Sep	2	Init	0.60	2.16	21.6	0.0	21.6
Sep	3	Init	0.60	2.15	21.5	0.0	21.5
Oct	1	Deve	0.67	2.40	24.0	0.0	24.0
Oct	2	Deve	0.84	2.96	29.6	0.0	29.6
Oct	3	Deve	1.01	3.52	38.8	0.0	38.8
Nov	1	Mid	1.09	3.76	37.6	0.0	37.6
Nov	2	Mid	1.09	3.70	37.0	0.0	37.0
Nov	3	Late	1.07	3.51	35.1	0.0	35.1
Dec	1	Late	0.91	2.90	29.0	0.0	29.0
					282.7	0.1	282.6

Crop Water Requirements

ETo station: Gelemso Crop: Maize

Rain station: Gelemso Planting date: 07/09

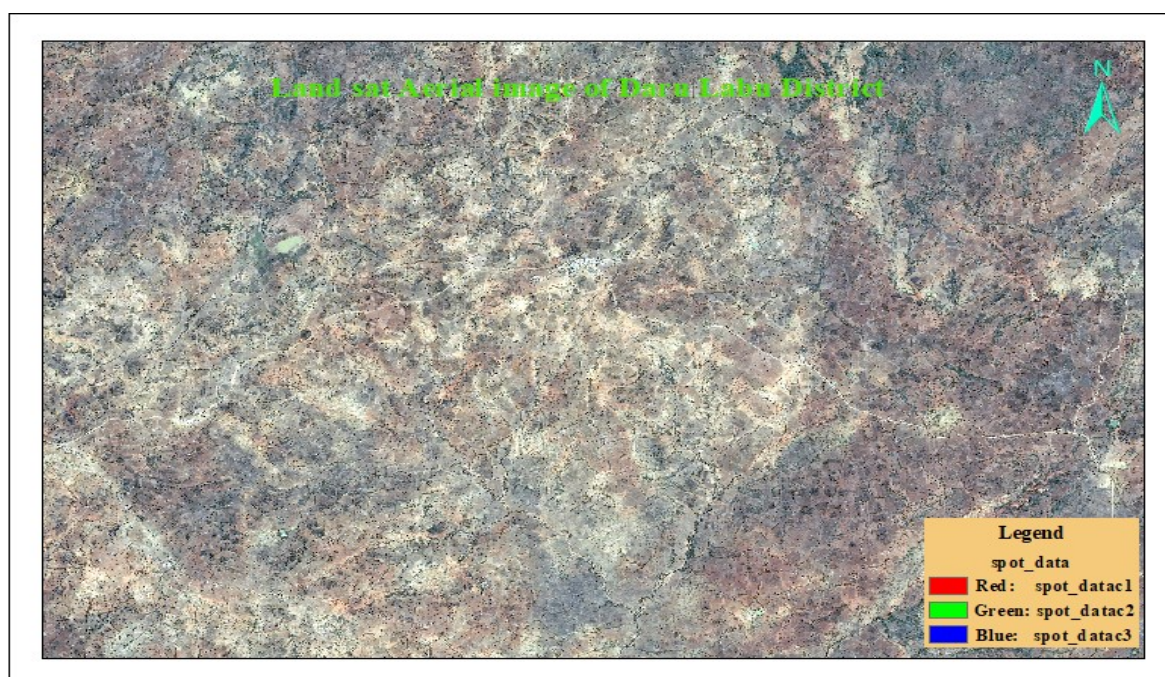
Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Sep	1	Init	0.30	1.08	4.3	0.1	4.2
Sep	2	Init	0.30	1.08	10.8	0.0	10.8
Sep	3	Deve	0.32	1.16	11.6	0.0	11.6
Oct	1	Deve	0.52	1.85	18.5	0.0	18.5
Oct	2	Deve	0.75	2.66	26.6	0.0	26.6
Oct	3	Deve	1.00	3.48	38.3	0.0	38.3
Nov	1	Mid	1.12	3.83	38.3	0.0	38.3
Nov	2	Mid	1.12	3.77	37.7	0.0	37.7
Nov	3	Mid	1.12	3.66	36.6	0.0	36.6
Dec	1	Mid	1.12	3.55	35.5	0.0	35.5
Dec	2	Late	1.01	3.11	31.1	0.0	31.1
Dec	3	Late	0.81	2.51	27.6	0.0	27.6
Jan	1	Late	0.62	1.93	17.4	0.0	17.4
					334.2	0.1	334.1

Appendix Table 17: Soil Texture classification and its normal range of infiltration rate

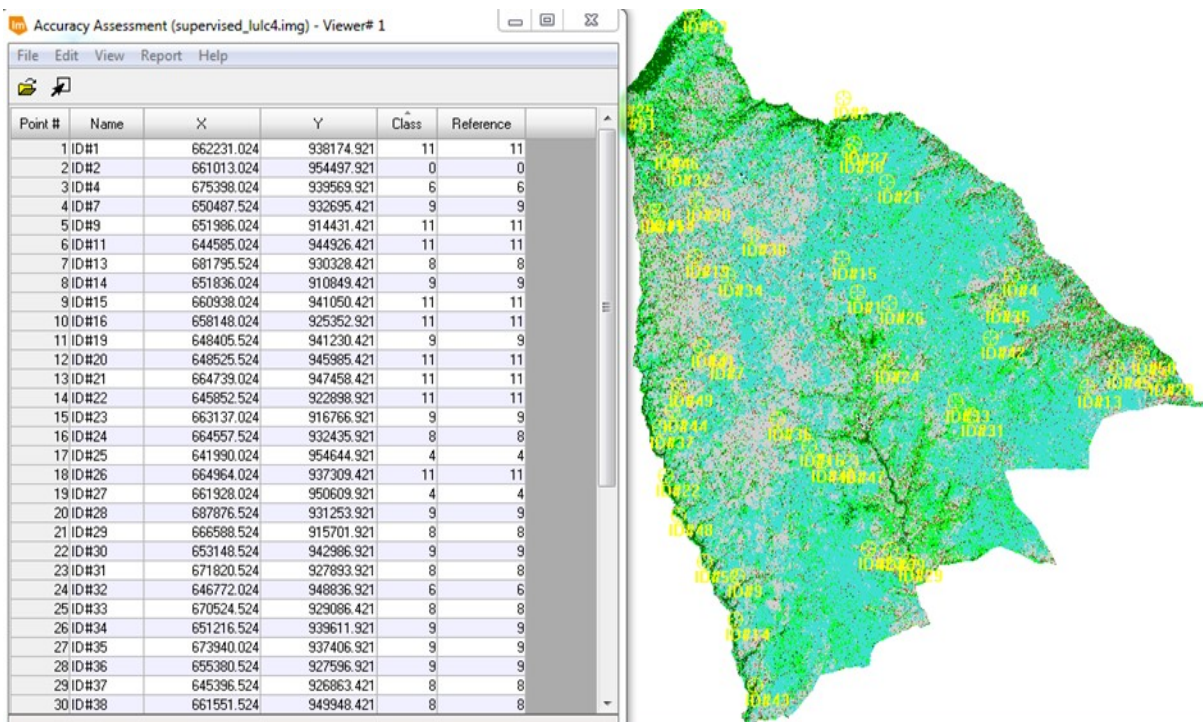
Soil texture	Representative, I (mm hr ⁻¹)	Normal range of I (mm hr ⁻¹)	Category
Sandy	50	20 – 250	Rapid
Sandy loam	20	10 – 80	Moderate rapid
Loam	10	10 – 20	Moderate
Clay loam	8	2 – 15	Moderately slow
Silty clay	2	0.3 – 5	Slow
Clay	0.5	0.1 – 8	Very slow

Appendix Table 18: SCS-Curve Number for HSG under AMC II Conditions

S/N	Land Use	Hydrologic Soil Group			
		A	B	C	D
1	Agriculture Land	76	86	90	93
2	Vegetation Land	49	69	79	84
3	Wood & Shrubs	41	55	69	73
4	Forest	26	40	58	61
5	Built Up	71	80	85	88



Appendix Figure 1: Band of Aerial Spot image map of Daro Labu District



Appendix Figure 2: Accuracy assessment of supervised land classification of the study area