JIMMA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY
HYDRAULIC AND WATER RESOURCES ENGINEERING DEPARTMENT
HYDRAULIC ENGINEERING MASTER OF SCIENCE IN HYDRAULIC ENGINEERING

GEOGRAPHICAL INFORMATION SYSTEM BASED SURFACE IRRIGATION POTENTIAL ANALYSIS
(CASE STUDY OF KETO CATCHMENT, WESTERN ETHIOPIA)

THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF JIMMA UNIVERSITY, JIMMA INSTITUTE OF TECHNOLOGY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN HYDRAULIC ENGINEERING.

BY

ENDALE WAKTOLE

November, 2016
Jimma, Ethiopia

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BY

ENDALE WAKTOLE

ADVISOR: - DR. Ing.TAMENE ADUGNA (PhD)

CO-ADVISOR: - MR. WAKJIRA TAKALA (MSc)

November, 2016

Jimma, Ethiopia

APPROVAL PAGE

A thesis entitled with "**GIS BASED SURFACE IRRIGATION POTENTIAL ANALYSIS OF KETO BASIN: CASE STUDY OF WESTERN ETHIOPIA**" has been approved by the following assessment boards: Advisors, Examiners, Department Head, Chairman, Coordinator and Director of graduate studies in partial fulfillment of the requirement for the degree of Master of Science in Hydraulic engineering.

Submitted by:

<u>Endale Waktole</u>	_____________ /	_____________
Name	Signature	Date
Approved by:		
<u>Dr. Ing/Tamene Adugna</u>	_____________ /	_____________
Major advisor	Signature	Date
<u>Wakjira Takala MSc</u>	_____________ /	_____________
Co-advisor	Signature	Date
_________________	_____________ /	_____________
External examiner	Signature	Date
_________________	_____________ /	_____________
Internal examiner	Signature	Date
_________________	_____________ /	_____________
Chairman	Signature	Date
_________________	_____________ /	_____________
Department Head	Signature	Date
_________________	_____________ /	_____________
SGS Co-coordinator	Signature	Date

ABSTRACT

Although Ethiopia has a large potential to develop irrigation, only 7.84% of the 3.7 million hectares of land potentially available has been developed. To examine the underlying causes, this study evaluates the suitability of surface water irrigation in Keto River catchment. The study area covers an area of about 1058.592 square kilometers. This study was initiated with the objective of analyzing the water and land resources potential of river catchments in this River basin for irrigation development by using Geographic Information System. The hydrological, meteorological, Digital elevation model, soil, Land use, land cover map data were gathered from different organization of government and other concerned sectors. First elevation data of the study area were delineated as 30m resolution, then, characteristics of flow direction, contours and radius of elevation noticed. The potential irrigable land was identified by using slope, land use/cover and soil in arc GIS software, spatial analysis tool to analyze their suitability individually, then application of the weighted overlay tool was provided to condense overall suitability factors as specific outcome, and suitability was conducted implementing FAO criteria for surface irrigation. Analysis of the water resource potential of the study area was carried out by using hydrological data after filling different gaps observed using techniques like the average mean method and distance power method to screen them for further application. Here, there was, flow duration curve developed, flood frequency tested, low flow analyzed to differentiate between variability existed between time series of the records. The reservoir requirements of the catchment were dealt with dependable flow by mass curve technique. Also crop water requirement of most widely growing crops of the study area viz. Potato and Maize were computed from climatic data as an input depending on the preference of agro climatic condition of the study area using CROPWAT model, version 8. Potential irrigable land was identified out of the total catchment area considering suitability outcomes for river catchments and selected crops agro ecology. The Gross irrigation demand of selected crops for each month is computed for low flow analysis of 80%, 85%, 90%, 95%, and a 100% exceedence. The result suggests that the irrigation potential of the area considering the analysis of possible low flows and crop gross irrigation requirement is 0.014ha.

Key Terms: *Calibration, cropwat model, GIS, Potential irrigation, soil analysis tool.*

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CCA	Cultivable command Area
CIR	Cunsumptive irrigation requirement
CN	Curve Number
DMC	Double Mass Curve
DC	Demand curve
DEM	Digital Elevation Model
ESRI	Environmental Systems Research Institute
FAO	Food and Agricultural Organization
GCA	Gross command Area
GIS	Geographical Information System
GPS	Geographical Positioning System
IDP	Irrigation Development Program
LULC	Land Use Land Cover
MC	Mass Curve
Mm3	Million-meter cube
NOAA	National Oceanic and Atmospheric Administration
NMSA	National Meteorological service Agency
RP	Return Period
R^2	Regression coefficient
SCS	Soil Conservation Service
SRTM	Shuttle Radar Topography Mission
SWAT	Soil and Water Assessment Tool
SUFI2	Sequential Uncertainty Fitting version 2
WGEN	Weather Generator
WUE	Water Use Efficiency
UTM	Universal Transverse Mercator


x

CHAPTER ONE: INTRODUCTION

1.1. Background

Water and land are two most valuable and vital resource essentially required for Irrigation sustenance of life and not only this one but also for the economic and social progress of the country throughout the world.

Surface irrigation is the oldest and most used irrigation methods. For all kinds of rural land are involved with different land cover/use types, its suitability evaluation for surface irrigation also provides guidance in cases of conflict between rural land use and urban or industrial expansion, by indicating which areas of land cover /uses are most suitable for irrigation (FAO, 1985).

In Ethiopia, no matter how government is pushing to diversify into manufacturing, textile and energy generation, yet her economy is based on agriculture even attracted significant foreign investment in commercial agriculture. The five year economic plans have achieved high single digit growth rates through government led infrastructure expansion and commercial Agriculture development (IWMI, 2007).

To feed Ethiopian population on a sustainable basis, traditional rain fed agricultural practices must be supplemented by irrigated practices. Irrigation agriculture becomes more important to meet the human needs. It allows double cropping and enables stabilization of supply and production of vegetables and fruits. Only around 5% of Ethiopia's irrigable land are irrigated and less than 5% of total renewable water resources are withdrawn annually, so there is considerable scope for expansion (Wim G.M, 2000).

GIS and Satellite remote sensing provides efficient data and effective method for land, soil and land use cover mapping, drainage system, groundwater and surface water exploration. A GIS stores and manages all data, including the classified vegetation index drive from NOAA (National Oceanic and Atmospheric Administration) data and other information such as land use, rivers, reservoirs, and Lakes and soon, derived from Land sat data being great tool for determining the actual irrigated area (IAHS, 1997). Ethiopia has an important opportunity in water-led development, but it needs to address critical challenges in the planning, design, delivery, and maintenance of its irrigation systems if it is to capture its full potential. Therefore, this study urges to analyze the surface irrigation potential of Keto sub catchment. This has very productive water and land resources for implementation of irrigation practice to provide communities, economic development, food self-sufficiency, employment, investment and other human needs. No matter how demand for land and water resource for irrigation development is increasingly enhanced, there are so many bottlenecks towards available data. Unemployed, Planners, investors, and needy farmers are facing hindrance due to absence of data resource separately as per requirement for implementation of irrigation practices. Year to year local inventory have been carried out at both Zonal and Woreda levels but, it has great problem when examine by real nature due to different errors and mistakes, carelessness of inventory person, poor organization, and inappropriate documentation. Furthermore, data present if any is that of the total cultivable area from general zonal over all land resources. The same is true for water resource that only presence of rivers and their tributaries have known. Compared to traditional methods, the investigation of irrigable land of remote sensing and GIS (Geographical Information System) techniques has evident advantages as objectivity, time saving and low cost (IAHS, 1997).

To ensure adequate management and planning of irrigation system well-arranged and appropriate potential database is crucial. As a result, the advantage of using GIS in a single platform has also facilitated for better data analysis and their interpretation (Gopalan, 2001).

Consequently, this study is initiated to solve fore-addressed problems by organizing different data of the study area and was arranged in advance, land and water resources; separating irrigable land for surface irrigation by utilizing selective agents namely; land use/covers, slope and soil by making use of arc GIS spatial tools. A Potential water resource for surface irrigation was identified through stream flow and rainfall data after both hydrological and hydro meteorological analyses have conducted. As far as most dominantly growing crops of the area were selected depending on the local agro ecology and patterns, crop water requirements were computed thus, the surface irrigation potential of the Keto basin was analyzed for the general catchment land.

1.2. Statement of the problem

The study area is found within needy rural communities, those enormous dwellers are being host for food self- insufficiency, dependency, and un-employment. Ethiopian Ministry of Water resource in collaboration with New York Consultants have been conducted Baro Akobo river basin integrated development master plan study and estimated total arable land of the overall basin to be 1,11,830 Km^2 or1,118, 3,000 ha (ULG, 1997).

Although the study area has different tributaries, streams and partial irrigable land and rain fed agricultural practices, now a day there is no properly identified potential irrigable land and water resources data available for a particular area of proper implementation and future planning of surface irrigation. Also data present if any are prone to different constraints and uncertainties lacking easily understandable information on Potential land and water resources separately with an understandable image of this productive and virgin land. As a result, this study would desired identified possible irrigable land and water resource potential of the area so that proper irrigation practices in line with rain fed agriculture would be carried out. Even, though investors can work on irrigation oriented economic development would be provided with clear data, then, improved community's livelihood would be managed.

1.3. Objectives of study area

1.3.1. General objective

The main objective of this thesis work is to conduct flow analysis by arc swat and to undertake GIS based surface irrigation potential analysis of Keto sub basin for further irrigation development with respect to the available land and water resources.

1.3.2. Specific objective

More specifically, this study addresses the following issues:

1) To identify potential irrigable land and characterize its nature of utility for surface irrigation.
2) To estimate potential surface Water resources for irrigation and determine Crop Water requirements of very common crops of the area.
3) To recommend Storage volume requirement, whether the available water resource would meet the demand of potential irrigable land.

1.4. Research Questions

Based on the itemized objectives, the following questions were used to escort the research process and finally answered from the findings of the study.

a) What type method is used to identify potential irrigable land?

b) What is the important procesure to estimate potential surface water resource for irrigation & crop water requirement?

c) How much volume of available water resource will meet demand of potential irrigable land of Keto catchment?

1.5. Significance of the study and scope

The study is believed to contribute to the efforts working towards attaining economically feasible and socially desirable use of irrigation water and land to the initiatives striving to identify better strategies for irrigated production. These contributions will have application to already irrigated and further irrigable lands, and the ultimate beneficiaries of the study are primarily the poor rural community.

This study can also provide a good input at times of planning for future irrigation projects aimed at foreseeing their future development and impacts. Available water resource and the irrigation land need to be well documented for planning purposes.

This study concentrates on qualitative as well as quantitative assessment of the existing physical resources those are land and water with respect to its suitability for irrigation. The study also focuses on surface water resources and does not include other criteria‘s rather than land and water resources.

CHAPTER TWO: LITERATURE REVIEW

2.1. Water Resource Development in Africa

Africa's River systems have been the target of development planners since the 1960s, and many of the major rivers of the continent have been controlled for irrigation, for power generation and flood control. Indeed, *river basin development planning* has been widely adopted in Africa, and often enough water resource development has come to be synonymous with river basin development (Adam, 1992).

Integrated river basin planning was pioneered in the U.S., and the basic objective was to coordinate water resource development in a given basin so that individual development schemes do not work at cross-purposes (Adam, 1992). The river basin, and not the individual farmstead, served as the unit of planning, the assumption being that what was good for the basin was good for the individual farm. Such planning exercise requires a powerful interventionist state, a strong central planning authority and an over reliance on physical engineering to solve all development and conservation issues.

River basin planning was adopted in Africa, essentially in truncated form, in part because it appealed to the authoritarian interventionist states that were then in power in many countries in the continent. Moreover, African governments and their willing donor agencies, which bank rolled many of the costly river basin schemes on the continent in the 1960s and 70s, were frequently seduced by the technological promise of large-scale water projects (Moris, 1990).

The problem of food security has been keenly felt especially in the Sahel countries and Ethiopia, both of which have become increasingly drought prone. The food crises of the 1960s, 1970s and 1980s have drawn attention to the issue of environmental vulnerability and the need for its mitigation. In many of the drought prone countries, the concentration of the human population is relatively high and cannot be adequately supported by rain-fed agriculture alone. Thus, where rainfall is insufficient or un-reliable and rain-fed agriculture cannot fully support food production, water management schemes have been considered to be sound investments. Such investments, it is argued, will help stabilize agricultural production and promote food security (Moris, 1990).

But many water projects in Africa are performing poorly or have failed outright, often with damaging environmental consequences. In many instances, the benefits have gone to a small segment of the urban elite and not to the masses of needy peasants and Pastoralists. Some of the reasons for this sorry record include poor planning and design on the one hand, and the lack of involvement of the primary stakeholders in policy formulation and project management on the other (FAO).

The loss of traditional farming and grazing land, population displacement and relocation, and the long term and, at times, irreparable damage to the environment are but some of the costs that communities have had to pay for the failure of water projects (Moris, 1990).

2.2. Water Resource Development in Ethiopia

The development of water resources for agricultural purposes on the one hand and rural water supply schemes, on the other are the focus of our discussion in this section. Of the two subsectors, the first have attracted high levels of investment, and the second was neglected until the post-Imperial period. Even today, rural water supply programs, which affect the majority of the country's population, have not been given sufficient attention.

Modern water development schemes are a relatively new phenomenon in the country. The Imperial government took the first initiative in water resource development in the second half of the 1950s. Large-scale water projects for agricultural purposes and power generation were constructed from the end of the 1950s, and were concentrated in the Awash valley as part of the agro-industrial enterprises that were expanding in the area at the time. They subsequently spread to the Rift Valley and the Wabe Shebelle basin. Essentially, the government's interest at the time centered almost entirely on large-scale and high technology water projects: hydro-power dams, irrigation schemes, and water supply projects in Addis Ababa and a few major towns. Since then, all large-scale schemes in the country have been constructed on the initiative of the government, and managed by state (www.Ethiopia.com).

Ethiopia is endowed with a substantial amount of water resources. The surface water resource potential is impressive, but little developed. The country possesses twelve major river basins, which form four major drainage systems viz. Nile basin, Rift valley basin, Shebelli juba and North East coast (Sileshi Bekele, 2007).

Integrated development master plan studies and related river basin surveys undertaken at the end of the 1990s indicate that the aggregate annual runoff from nine Ethiopian river basins is about 122 km3. The Abbay, Baro-Akobo and Omo- Gibe basins account for about 76 percent of the total runoff from an area that is only 32 percent of the total area of the country. Most of the rivers in Ethiopia are seasonal and about 70 percent of the total runoff is obtained during the period June to August.

Table 2.1: Areas and annual run-off by river basin

Major drainage system	River basin	Area (ha)	As % of total area	Annual Runoff (km3/yr)	As % of total runoff
Nile basin		36881200	32.4	84.55	69
	Abbay(Blue Nile)	19981200	17.6	52.60	42.9
	BaroAkobo	7410000	6.5	23.6	19.3
	Setittekeze/Atbara	8900000	7.8	7.63	6.2
	Mereb	590000	0.5	0.72	0.6
Rift valley		31764000	27.9	29.02	23.7
	Awash	11270000	9.9	4.60	3.7
	Denakil	7400000	6.5	0.86	0.7
	Omo gibe	7820000	6.9	17.96	14.7
	Central lake	5274000	4.6	5.60	4.6
Shebelli-Juba		37126400	32.7	8.95	7.3
	Wabi-shebelle	20021400	17.6	3.15	2.6
	GenaleDawa	17105000	15.1	5.80	4,7
North east cost		7930000	7.0	0.00	0.0
	Ogaden	7710000	6.8	0.00	0.0
	Gulf of Aden	220000	0.2	0.00	0.0
Total		133701600	100.0	122.52	100.0

(Sileshi Bekele, 2007).

All the lakes, except Lake Tana which is the source of Abbay River in the Nile Basin, are found in the Rift Valley and among these lakes only Ziway has fresh water while the others are all saline. Rising water levels in Lake Tana and Lake Awassa after intense rainfall have been creating concern.

Ethiopia has many small, medium and large reservoir dams constructed for hydropower generation, irrigation and drinking water supply. Small dams are less than 15 m high and have a capacity of less than 3 million m3. The height of the medium and large dams in Ethiopia is 15−50 m and their capacity ranges from 4 to 1 900 million m3. In total, there are nine medium and large dams with a total capacity of almost 3.5 km3.Two large dams are used for hydropower generation only, one dam is used both for hydropower generation and irrigation supply, two dams are used for irrigation supply only and the remaining four for water supply to the city of Addis Ababa and the town of Gondar. Small dams (micro-dams) constructed for irrigation supply are concentrated in the Amhara and Tigray regional states (IWMI, 2007).

Irrigation Development in Ethiopia

At the close of the last millennium, Ethiopia was irrigating fewer than 200,000 hectares (ha) of farmland, although a total of 3.7 million ha had been classified as potentially irrigable. This gross underdevelopment of capacity to grow food and industrial crops has spurred the IDP (Irrigation

Development Program) to put an additional 273,829 ha under irrigation, an increase of 135 per cent of current irrigated farmlands, within its 15-year plan period of 2002–2016.

Table 2.2: Target for irrigation Development program (2002_2016) of oromia

Description	Small-scale schemes	Large-and medium-scale schemes	Total area
Short-term1st 5 years: (2002-2006)	40,319	13,044	53,363
Medium-term2nd 5 years: (2007- 2012)	40,348	39,701	80,049
Long-term3rd 5 years: (2012-2016):	46,471	94,729	141,200
Total area to be developed during (2002-2016)	127,138	147,474	274,612
Currently developed (approximate)	98,625	98,625	197,250
Grand total irrigated area of 2016	225,763	246,099	471,862

(IWMI, 2007).

2.3. Evolution and development of irrigation in Ethiopia

Irrigation in Ethiopia dates back several centuries, if not eras, while "modern" irrigation was started by the commercial irrigated sugar estate established in the early 1950s by the Imperial Government of Ethiopia and the Dutch company Ethiopia. Various sources give different estimates of irrigated area, but recent sources indicate that the area equipped for irrigation was nearly 290 000 ha in 2001, which is 11 percent of the economical irrigation potential of 2.7 million ha (World, 2005).

The global water crisis has drawn worldwide attention to the urgency of achieving a more efficient use of water resources, particularly in agriculture, to increase crop production and achieve world food security (IWMI, 2009).

Irrigation development has been identified as an important tool to stimulate economic growth and rural development, and is considered as a cornerstone of food security and poverty reduction in Ethiopia. While a lot of effort is being exerted towards irrigation development, little attempt is being made to quantify the contribution of irrigation to national income. Enhancing public and private investment in irrigation development has been identified as one of the core strategies to delink economic performance from rainfall and to enable sustainable development (IWMI, 2009).

2.4. Irrigation Potential in the Baro Akobo river basin

Baro Akobo River Basin Baro Akobo river basin has an area of 75,912 Km2, covering parts of the Benishangul-Gumz, Gambella, Oromia, and SNNPR. The basin has a lower elevation of 390

m. And highest elevation of 3244 m. The total mean annual flow from the river basins is estimated to be 23.6 BMC. Twenty-two large-scale potential irrigation sites are identified in the basin, with an estimated irrigable area of 1,019,523 hectares. The Baro-Akobo basin is the second most important basin, next to Genale Dawa, as far as irrigation potential is concerned.

Table2. 3 Large scale irrigation potential in Baro-Akobo river basin

S/No	Project description	Sub basin	River	Potential(ha)
1	Baro RB, Itang Dam, Gravity	Lower basin	Baro	66,581
2	Baro RB, Itang River, Pumping	Lower basin	Baro	41,267
3	Baro RB, Gambela Dam	Lower basin	Baro	17,335
4	Baro, RB, River Pumping, gravity Conveyance	Lower basin	Baro	17,338
5	Baro, LB, Itang Dam, Gravity Lower basin	Lower basin	Baro	61,900
6	Baro, LB, Pumping		Baro	15,832
7	Baro, LB, Gambela Dam		Baro	57,018
8	Baro, LB, River pumping		Baro	57018
9	Alwero project, Abobo, Dam Gravity		Alwero	13,600
10	Alwero, Chiru Dam		Alwero	17,054
11	Gilo, RB, Gilo-1 Dam		Gilo	81,346
12	Gilo, LB, River pumping		Gilo	79,652
13	System 2+Relift Station	Lower basin	Baro	57,495
14	System 3+ Low lift	Lower basin	Baro	41,016
15	System 3A+ High lift	Lower basin	Baro	67740
16	System 4+ Low Lift	Lower basin	Baro	41,016
17	System 4A+High lift	Lower basin	Baro	67,740
18	Alwero, RB Dumbong		Alwero	23192
19	Alwero, Chiru and Dumbong Dams		Alwero	34,665
20	Gilo, LB, River pumping		Gilo	65,538
21	Gilo, LB, Gilo 2 Dam		Gilo	33,855
22	Gilo, RB, Gilo 2 Dam		Gilo	61,325

(IWMI, 2007).

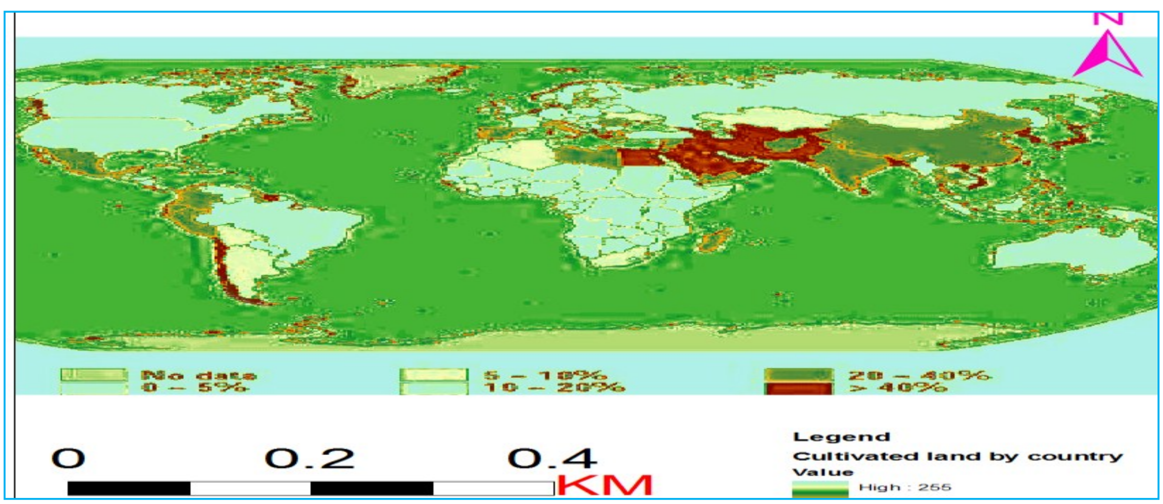


*Figure 2. 1*Area equipped for irrigation as percentage of cultivated land by country (Source: FAOSTAT, 2002.)

2.5. Hydrological Models

A hydrologic model is an approximation of the actual system, with a structure that is a set of equations linking measured inputs and output variables (Chow et al., 1988). Hydrologic models can be categorized in to two broad classes. (1) Physically-based models that are based on solving governing equations such as conservation of mass and momentum equations. (2) Conceptual models that use simple mathematical equations to describe the main hydrologic processes such as evapotranspiration, surface storage, percolation, snowmelt, base flow, and runoff. The other classification is deterministic and stochastic hydrological models. The deterministic hydrological model as it is the most commonly used modeling approach in hydrology, it can be further classified as lumped, and semi distributed and distributed models (Aghakouchak, 2010 and Nethanet, 2013).

2.6. SWAT model description

The Soil and Water Assessment Tool (SWAT) is a physical process based model to simulate continuous-time landscape processes at catchment scale (Arnold et al., 1998; Neitsch et al., 2005). The catchment is divided into hydrological response units (HRU) based on soil type, land use and slope classes. The hydrology computation based on dailyprecipitation, runoff, evapotranspiration, percolation and return flow is performed at each HRU. The SWAT model has two options for computing surface runoff: (i) the Natural Resources Conservation Service Curve Number (CN) method (USDA-SCS, 1972) or (ii) the Green and Ampt method (Green and Ampt, 1911).

2.7. Application of SWAT

SWAT can be used to simulate a single watershed or a system of multiple hydrological connected watersheds. Each watershed is first divided in to sub basins and then in hydrologic response units (HRUs) based on the land use and soil distribution. Hence, it is applicable for:

- Simulation of processes at land and water phase
- Spatially distributed (different scales)
- Simulation of changes (climate, land use, management etc.)
- Estimation of water quantities, including different runoff components
- Water quality: nutrients, sediments, pesticides, etc.

All the above descriptions are daily time step and at different spatial scales and more or less readily available data sets.

2.8. Application of GIS

2.8.1. GIS in Agriculture

A Geographical information systemapplied to an agricultural landscape can effectively capture, store, analyze and display information that is geographically based. Of its many benefits, GIS can improve our understanding of farming areas, help promote agricultural development and assist in identifying and handling issues important to strengthening farming (www.agf.gov.bc.ca/gis).

In agro meteorology, to describe a specific situation, we use all the information available on the territory: water availability, soil types, forest and grasslands, climatic data, geology, population, land-use, administrative boundaries and infrastructure (highways, railroads, an electricity or communication systems). Within a GIS, each informative layer provides to the operator the possibility to consider its influence to the final result. However more than the overlap of the different themes, the relationship of the numerous layers is reproduced with simple formulas or with complex models. The final information is extracted using graphical representation or precise descriptive indexes. (Marachi, 2000).

2.8.2. Application of GIS in Hydrology

GIS has become a useful and important tool in hydrology and to hydrologists in the scientific study and, management of water resources. Climate change and greater demands on the water resource requires a more knowledgeable disposition of arguably one of our vital resource. As every hydrologist knows, water is constantly in motion. Because water in its occurrence varies spatially and temporally throughout the hydrologic cycle, its study is using GIS is especially practical**.**

GIS systems previously were mostly static in their geospatial representation of hydrologic features. Today, GIS platforms have become increasingly dynamic, narrowing the gap between historical data and current hydrologic reality.

Hydrologists use GIS technology to integrate various data and applications into one, manageable system. The suite of tools contained in Arc Hydro facilitates the creation, manipulation, and display of hydro features and objects within the ArcGIS environment (Marachi, 2000).

2.8.3. Application of GIS for Irrigation potential analysis

Geographic information system is a tool for data input, storage, retrieve, manipulate, analyzing, and output the spatial data (Marble, 1984).

It can play a major role in spatial decision making considering different parameters:

A) Topography

Topography is generally uniform and quite well adapted to irrigation development surrounding Baro sub-basin Keto. Which was extracted from DEM 30m by 30m resolution.

The best features for a gravity system are: (1) a gradient that facilitates uniform water distribution, allows optimum length of runs, and permits adequate control; (2) relief that is economically feasible to correct without permanent damage to the land and that will permit uniform water distribution for optimum production, salinity control, minimal drainage problems, and water conservation; (3) relief that allows field size and shape to be tilled efficiently, permits water conservation and, when irrigated, results in a minimal nonproductive area; and (4) no rock or vegetative cover, or cover that can be removed readily without permanent damage to the land within limitations imposed by prevailing economic conditions.

Selection of the proper irrigation system may minimize or eliminate many of the limitations imposed by topography.

Topographic Characteristics

Land classification factors most affected by topographic qualities are gradient, land grading, field size and shape, and cover. They greatly influence the suitability of land for irrigation. The position of the land is a more important factor for irrigable area determination.

2.8.4. Land Suitability evaluation

Suitability is a measure of how well the qualities of a land unit match the requirements of a particular form of land use.

Land suitability is the fitness of a given type of land for a defined use. The land may be considered in its present condition or after improvements. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses (www.fao.org/docrep).

2.8.5. Structures of suitability classification

According to FAO 1976 the structure of the suitability classification is described recognizing qualitative and the current or potential suitability in four categories of decreasing generalization. Each category retains its basic meaning within the context of the different classification and as applied it different types of land use.

Land suitability orders

It indicates whether land is assessed as suitable or not suitable for the use of under consideration.

There are two major orders, namely suitable and not suitable by the symbols: **Order S suitable**: It implies land expected to yield benefits which justify the inputs, without unacceptable risk of damage to land resources.

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

Land suitability classes

It reflects the degree of suitability. The classes are numbered consecutively in the sequence of decreasing degree of suitability within the order.

Class S1 Highly Suitable: Land has no significant limitations to sustain application of a given use or only minor limitations that will not significantly reduce productivity and will not raise inputs above an acceptable level.

Class S2 Moderately suitable: Land has limitation which in aggregate is moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantages to be gained from the use, although still attractive, will be appreciably inferior to the expected on class S1 land.

Class S3 Marginally suitable: - Land is having limitations which in the aggregates are severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified.

Class N1 Currently Not suitable: Land having limitation which may be surmount in time, but cannot be corrected with existing knowledge of current acceptable cost.

Class N2 permanently not suitable: Land has limitation which appears severe as to preclude any possibilities of successful sustained use of the land in the given manner.

2.8.6. Land Slope analysis

Land suitability is the fitness of a given type of land for a defined use. The land may be classified in its present condition or after improvements for its specified use. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defining uses (FAO, 1984).

Water supply, water quantity and Seasonality is the important factor to evaluate the land suitability for irrigation according to the volume of water during the period of a year, which it is available (FAO, 1985).

Slope, S, measures the rate of change of elevation in the direction of steepest descent, slope is the means by which gravity induces the flow of water and other materials, so it is of great significance in gradational process of land escape evolution and soil development.

Table 2. 4: Slope ranges from irrigated land

Slope	Percent	Factor of rating
Horizontal	0-2	S1
Very Flat	2-5	S2
Flat	5-8	S3
Steep	>8	N

(FAO, 1996).

Slope shapes

Concave: -The top slope is 2 times the steepness entered while the bottom slope is 0%.

Convex: -The top slope is 0%, while the bottom slope is 2m times the steepness entered.

S-Shape: _Top and bottom slopes are 0%, while the midpoint has a slope of 2m times the steepness entered (www.milford.nserl.purdue.edu).

Uniform - The slope steepness is constant over the slope length.

2.8.7. Land use, land cover and suitability

The FAO Framework land suitability categories are Orders (Suitable or Not Suitable), Classes, and Subclasses. The land suitability classes are highly Suitable (S1), Moderately Suitable (S2), marginally Suitable (S3), marginally not Suitable (N1) and Permanently Not Suitable (N2). A greater or smaller number of Classes can be used as required. A lower case letter is used to designate Subclass, indicating the reason for downgrading the land from S1 (no Subclasses) to a lower class.

Land use requirements and limitations: These are factors that may or may not be 'class determining' and that are required for, or limit, the performance of a LUT on a land Characteristics, inputs and land improvements interact to satisfy or influence the requirement or limitation.

Land qualities: These are descriptors of land in relation to land use. For example, water availability or Water deficiency implies a relationship between water supply and water requirement, but as an attribute of the land. Land qualities represent complex hierarchical interactions ranging from water availability, nutrient availability, to crop, yielding ability, drain ability, erode ability, etc. In general, land qualities are the interactions affecting the performance of a land use type (LUT).

Measures of suitability: The land suitability classes can be defined in terms of various physical, financial or economic indicators.

Irrigation Suitability

The basic physical factors in determining the suitability of land for irrigation are soil, topography, drainage, water quality and quantity, and climate.

Water and climate differ from the others in that they are usually uniform throughout the specific area to be investigated (www.milford.nserl.purdue).

2.8.8. Soil Suitability

The soil is a major factor in the suitability of land for sustained irrigation. Its primary influence is in the productive capacity, but it may also influence production and development costs.

The most desirable soil qualities for diversified crop production under sustained irrigation includes; 1) a water-holding capacity adequate to retain and provide optimum moisture for crops between irrigations with the proposed irrigation system; (2) an internal drainage adequate to maintain an aerated root zone and an acceptable salt level; (3) an infiltration rate adequate to replenish soil moisture depleted from evapo transpiration without excessive losses with the proposed irrigation system; (4) an adequate depth to allow optimum root development; (5) a tillable surface; (6) non injurious amounts of exchangeable sodium, or soluble phytotoxic substances; and (7) amendable by an adequate supply of plant nutrients. Several soil characteristics must be evaluated to determine soil suitability for irrigation. The primary factors are soil-moisture relationships, toxicity, fertility, depth of gravel and cobble, depth to soil horizons that restrict root development or water movement and the erosion hazard.

2.8.9. Weighted overlay Analysis

Weighted overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis. Within a single raster we need to define the weight age values to the classes based on the relevance in the site suitability (Janss and Rietved, 1990). The weighted overlay function weight the individual input raster on a defined scale (1 to 10 or 1 to 9). The more favorable locations for each input criterion will be classified to the higher values. I the weighted overlay tool, the influences assigned to all the input raster must equal to 100 percent. The equation for the weighted overlay function can be given as follows. Weighted overlay assumes that more favorable factors result in the higher values in the output raster, therefore, identifying these locations as being the best. The optimal site for irrigation requires a weighing of factors like, soil, slope, and land use land cover to conduct suitability analysis (Yang Yi, 2003).

2.9.10. Contour lines

A contour line is the imaginary horizontal line that connects all points in a field which have the same elevation. It is an imaginary but can be visualized by taking the example of a lake. The water level of a lake may move up and down, but the water surface always remains horizontal. The level of the water on the shoreline of the lake makes a contour line because it reaches points which are all at the same elevation.

Interpretation of contour lines on a map

The arrangement of the contour lines on a map gives a direct indication of the changes in the field's topography. In hilly areas, the contour lines are close together while they are wider apart on flat slopes. A closer the contour lines, the steeper the slope. A wider the contour lines, a flatter the slope. On a hill, the contour lines form circles; whereby the values of their elevation increase from the edge to the Centre. In a depression, the contour lines also form circles; the values of their elevation, however, decrease from the edge to the center.

Mistakes in the contour lines

Contour lines of different heights can never cross each other. Crossing contour lines would mean that the intersection point has two different elevations, which is impossible.

2.9. Command area

The Gross command area is defined as the total area which can be irrigated by a canal system on the presumption that unlimited quality of water is available. The canal is usually aligned along the watershed in between two drainage valleys, so that water can flow from it on both sides under gravity to the maximum possible area. However, the area to which water can flow from the canal will be restricted by the drainage boundaries which can be irrigated by a canal system.

The entire gross commands are, however, cultivable area because; it also includes un-cultivable such as areas of habitation, roads, ponds, hillocks, barren land. (Zazueta, 1995).

Cultivable command area

It is the portion of the gross command area which is cultivable. It may be obtained by subtracting the uncultivable area from the gross command area. (FAO, 1986).

$$C.C.A = G.C.A - Uncultivable\ area$$

2.10. Runoff Characteristics of streams

A study of annual hydrograph of streams enables one to satisfy stream into three classes as perennial, intermittent and ephemeral. Perennial stream is one which always carries some flow. There is a considerable amount of groundwater flow throughout the year. Even during dry seasons, the water table will be above the bed of the stream.

An intermittent stream has limited contribution from the ground water. During the wet season the water table is above the stream bed and there is contribution of base flow to the stream flow. However, during the dry season the water table drops to a level lower than that of the stream bed and stream dries up. Expecting for an occasional storm which can produce a short duration flow, the stream remains dry for the most part of the driest month.

An ephemeral stream is one which does not have any base flow contribution. The annual hydrograph of such river shows series of short duration spikes marking flash flows in response to the storms. The stream became dry soon after the end of the storm flow. Typically, an ephemeral stream does not have any well-defined, channel. Most of the rivers in arid zones are of the ephemeral kind.

2.11. Runoff Volume

Total quantity of surface water that can be expected in a given period from a stream at the outlet of its catchment is known as yield or the volume of the catchment in that period. Depending upon the period chosen we have annual yield and seasonal yield satisfying yield of the catchment in any year and specified season respectively.

Flow duration curve

It is well known that the stream flow varies over a water year. One of the popular methods of studying this stream flow variability is through flow duration curves. A flow duration curve of the stream is a plot of discharge against the percentage of time the flow was equaled or exceeded. This curve is also known as discharge frequency curve.

The stream flow data are arranged in a descending order of discharges, using class intervals if the number of individual values is very large. The data can be daily, weekly, en daily or monthly values. If N number of data points is used in this listing, the plotting position of any discharge (class value) Q is given by one of the following methods:

Different methods of computing plotting position

Methods	Probability(P)
California	$\frac{m}{N}*100$……………………..(1)
Hazen	$\frac{m-0.5}{N}$ …………..…………(2)
Chegodayev	$\frac{m-0.3}{N+0.4}$ ………….……….(3)
Weibull	$\frac{m}{N+1}$ ………………………....(4)
Gringorten	$\frac{m-3/4}{N+0.25}$ ……………………..(5)

2.12. Low flow Analysis

Characterization of magnitude, frequency and duration of low stream flows and droughts is vital for assessing the reliability of flows for all in a stream and withdrawal uses and for defining resource shortages and drought.

The objective of the low flow analysis is to estimate the frequency of probability with which stream flow in a given reach will be less than various levels. Thus the FDC (Flow Duration Curve) is an important tool for low flow analysis. Most of the time, the flow exceeded 95% of the time, Q_{95} is a useful index of water availability that is often used for design purposes (Guta.W, 2011).

2.13. Reservoir capacity determination

The reservoir capacity is a term used to represent the reservoir storage capacity. The Storage capacity of a reservoir is the maximum difference between the cumulative supply and demand during the period of driest year of available records. Its determination is performed using historical inflow records in the stream at the proposed structure site.

Mass curve to determine storage capacity

An MC (mass curve) is a plot of accumulated flow in a stream against time. A mass curve continuously rises, as it shows accumulated flows. The slope of the curve at any point indicates the rate of flow at that particular time. If there is no flow during certain periods, the curve will be horizontal during that period.

A demand curve on the other hand is a plot between accumulated demand and time. If the demand is at constant rate, then the demand curve is straight line having its slope equal to the demand rate. However, if demand is not constant, then the demand will be curved indicating a variable rate of demand.

2.14. Water requirement

Water requirement is the quantity of water, regardless of its source, required by a crop or diversified patterns of crops in a given period of time for its normal growth under field conditions at a place. (Sileshi Bekele, 2007).

Water requirement includes the losses due to evapo transpiration (ET) or consumptive use (CU) plus the losses during the application of irrigation water (unavoidable losses) and the quantity of water required for special operations such as land preparation, transplanting, leaching, etc.

$WR = ET(CU) + Application\ losses + special\ needs$ …………………………………….. *(6)*

The combination of two processes whereby liquid water is lost on the one hand from the soil surface by evaporation and on the other hand, from the crop by transpiration is referred to as evapo transpiration.

Consumptive use (CU) is the evapo transpiration from a vegetated area plus the water used directly by plants in the metabolic process of building the plant tissues. As the water used in the metabolic process is negligibly smaller (usually, less than 1% of the total loss), it is the usual practice to neglect the difference between evapo transpiration and consumptive use and the two terms are generally used synonymously.

Water requirement is, therefore a ‘demand’ and the ‘supply’ would consist of contributions from any of the sources of water, the major source being the irrigation water (IR) and effective rainfall (ER) and soil profile contribution (S) including that from shallow water tables.

$WR = IR + ER + S$ **………………………………………………………………… (7)**

The field irrigation requirement of a crop therefore, refers to the water requirement of crops, exclusive of effective rainfall and contribution from the soil profile, and given as:

$IR = WR - (ER + S)$ **……………………………………………………………… (8)**

2.15. Evapo-transpiration (ET)

Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Apart from the water availability in the top soil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. This fraction decreases over the growing period as the crop developed and the crop canopy shades more and more of the ground area. When the crop is small, water is Predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process.

The evapo transpiration (ET) rate is normally expressed in millimeters (mm) per unit time. The rate expresses the amount of water lost from a cropped surface in units of water depth. The time unit can be an hour, day, decade, month, or even an entire growing period of years.

Reference crop evapo transpiration (ETo)

The evapo transpiration rate from a reference surface, not short of water, is called the ETo Reference Crop Evapo transpiration). The reference surface is a hypothetical grass reference crop with specific characteristics.

The concept of the reference evapo transpiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development, and management practices. As water is abundantly available at the reference evapo transpiration surface, soil factors do not affect ET. Relating ET to a specific surface provides a reference to which ET from other surfaces can be related.

$$ETO = \frac{0.408\,\Delta\,(Rn - G) + \frac{\gamma 900}{T+27.3} u2(es - ea)}{\Delta + \gamma(1 + 0.34u2)} \quad \text{-- (9)}$$

Where

ETo is reference evapo transpiration [mm/day]

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

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

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

u^2 is wind speed at 2m height [m/s]

es is saturation vapor pressure [k Pa]

ea is actual vapor pressure [k Pa]

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

ΔSlope vapor pressure curve [k Pa/ O C]

γPsychrometric constant [k Pa/ O C]

Crop evapo transpiration under standard conditions

The ETc (Crop Evapotranspiration under standard condition) is the evapo transpiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions.

Crop evapo transpiration can be calculated from climatic data and by integrating directly the crop resistance, albedo and air resistance factors in the Penman-Monteith approach. As there is still a considerable lack of information for different crops, the Penman-Monteith method is used for the estimation of the standard reference crop to determine its evapo transpiration rate, i.e. ETo. Experimentally determined ratios of ETc/ETo, called crop coefficients (Kc), are used to relate

$ETc = Kc * ETo$.. (10)

Differences in leaf anatomy, stomata characteristics, aerodynamic properties, and even albedo cause the crop evapo transpiration to differ from the reference crop evapo transpiration under the same climatic conditions. Due to variations in the crop characteristics throughout its growing season, Kc for a given crop changes from sowing till harvest.

Crop evapo transpiration under non-standard conditions

The crop evapo transpiration under non-standard conditions (ETc) is the evapo transpiration from crops grown under management and environmental conditions that differ from the standard conditions. The crop evapo transpiration under non-standard conditions is calculated by using a water stress coefficient Ks and/or by adjusting Kc for all kinds of other stresses and environmental constraints on crop evapo transpiration.

ETo can be computed from meteorological data. As a result of an Expert Consultation held in May 1990, the FAO Penman-Monteith method is now recommended as the sole standard method for the definition and computation of the reference evapo transpiration. The FAO PenmanMonteith method requires radiation, air temperature, air humidity, and wind speed data.

2.16. Irrigation efficiencies

Efficiency is the ratio of the water output to the water input, and is usually expressed as a percentage. Input minus output is nothing but losses, and hence, if losses are more, the output is less and therefore, efficiency is less. Hence, efficiency is inversely proportional to the losses. Water is lost in irrigation during various processes and, therefore, there are different kinds of irrigation efficiencies, as given below:

Conveyance efficiency: It is the amount of water delivered into the fields from the output point of the channel, to the water entering into the channel and its starting point. It may be represented by ηc. It takes the conveyance or transit losses into consideration.

Application efficiency: It is the ration of quantity of water stored in the root zone of the crops to the quantity of water actually delivered to the field. It may be represented by ηa. It may also be known by on farm efficiency, as it takes into consideration the water lost in the farm.

Storage efficiency: Is the ratio of water stored in the root zone during irrigation to the water needed in the root zone prior to irrigation i.e. field capacity-existing moisture content.

Efficiency of water use: Is the ratio of water beneficially used, including leaching water, to the quantity of water delivered.

2.17. Consumptive irrigation requirement

It is an amount of irrigation water required in order to meet the evapo transpiration needs of the crop during its full growth. It is, therefore, nothing but the consumptive use itself, but exclusive of effective precipitation, stored soil moisture, or ground water, when the last two are ignored, then we can write

$CIR = CU - RE$……………………………………………………………………….. (11)

Net irrigation requirement

It is an amount of irrigation water required in order to meet the evapo transpiration need of the Crop as well as other needs such as leaching. Therefore, $NIR = CU - Re + Losses$

2.18. Effective precipitation

Out of given precipitation, the only effective part is available for plant use, which is stored as available water in the soil within the root zones of crop grown. The water, which flows away as surface runoff, or percolate below the root zone is lost so far as the current crop is concerned. Very light shower may get evaporated from the surface and while reducing evaporation, they may contribute little to available water.

Meteorological parameters are characteristics of rainfall (amount, frequency, intensity and distribution over the area and in time), air temperature, radiation, relative humidity and wind velocity. Other, non-meteorological parameters are: land characteristics (topography, slope, type of use), soil type (depth, texture, structure, bulk density, salt and organic matter content), management factors (type of tillage, degree of leveling, use of soil conditioners, type of layout, bund, terracing, ridging), crops (nature of crops, depth of root system, degree of ground cover, stage of growth, crop rotations) and characteristics of groundwater and irrigation channels (Valher, 2013).

2.19. Duty of Water

The duty of water is the relationship between the volume of water and the area of crop it measures. It may be defined as the number of hectares of land irrigated for full growth of a given crop by supply of 1m3/sec of water continuously during the entire base period (B) of that crop.

Duty at various places

Duty of water for crop is the number of hectares of land, which the unit flow of water for (X) days can irrigate. Therefore, the more water requirements of a particular crop at a particular location, the lesser number of hectares of land it will irrigate. If the water requirement of a particular crop at a particular location is more, then the lesser number of hectares of land it will irrigate. Hence, if water consumed by a crop of a given base period is more, its duty will be less. As a result, the duty of water at the head of water course will be less than the duty of water on the field; because, when water flows from the head of water courses and reaches the field, some water is lost en routes as transit losses. Duty of water therefore varies from one place to another, and increases as one move downstream from the head of the main channel towards the head of the branches or water courses.

2.20. Previous studies

In 1987, FAO (Food and Agricultural Organization) conducted a study to assess the land and water resources potential for irrigation for Africa on the basis of river basins and countries. It was one of the first GIS-based studies of its kind at continental level. It proposed natural resources based approach to assessing irrigation potential. Its main limitation was in the sensitivity of the criteria for defining land suitability for irrigation and in the water allocation scenarios needed for the computation of the potential as cited by (Meron.T, 2007).

GIS based irrigation suitability assessment had been carried out on Abbaya-Chamo Basins, Southern Rift Valley of Ethiopia. The study defined suitability criteria in terms of parameters like topography, climate, land use pattern, soil, water availability, agricultural practices, investment and social economic practices (Wagesho, 2004).

The analysis had been carried out on the surface irrigation suitability of the southern Abay basin by implementing GIS techniques considering soil, slope and land cover /use factors to find suitable land for irrigation with respect to location of available water resource. Also the determination of the combined effects of factors have tested by arc GIS tool, weighted overlay to define whether they are suitable for irrigation or not (Meron.T, 2007)].

GIS based surface irrigation potential assessment of river catchment for irrigation development in SNNP, Sidama zone, Dale woreda had been conducted in 2010. The study utilized the slope, soil, land cover/use, distance between water supply, and the potential command area for identification of suitable sites for irrigation. (Kebede, 2010).

Also GIS based watershed analysis had been dealt for Tillamook Bay, Oregon. This study, conducted a watershed analysis and decision support system for watershed by utilizing stream flow records, aerial photo, and DEM (Patrice Angelle Melancon, 1999).

CHAPTER THREE: MATERIALS AND METHODS

3.1. Description of study area

The study area is located in the western part of Ethiopia covering about 1058.592km²or 105859.2ha. The area incorporates parts of three administrative zones: West wollega in the (East and central western), Illuababor in the south west, Kellem wollega (West, South west and some parts of North West). With a general slope the northwest to southwest.

Keto is one of the sub basins of the Baro Akobo river basin. It is located in the western direction of the country, between 8° 78' 17'' and 8° 95'' 19' latitude and 34° 49' 39'' and 35° 05' 27" longitude and west Oromia region.

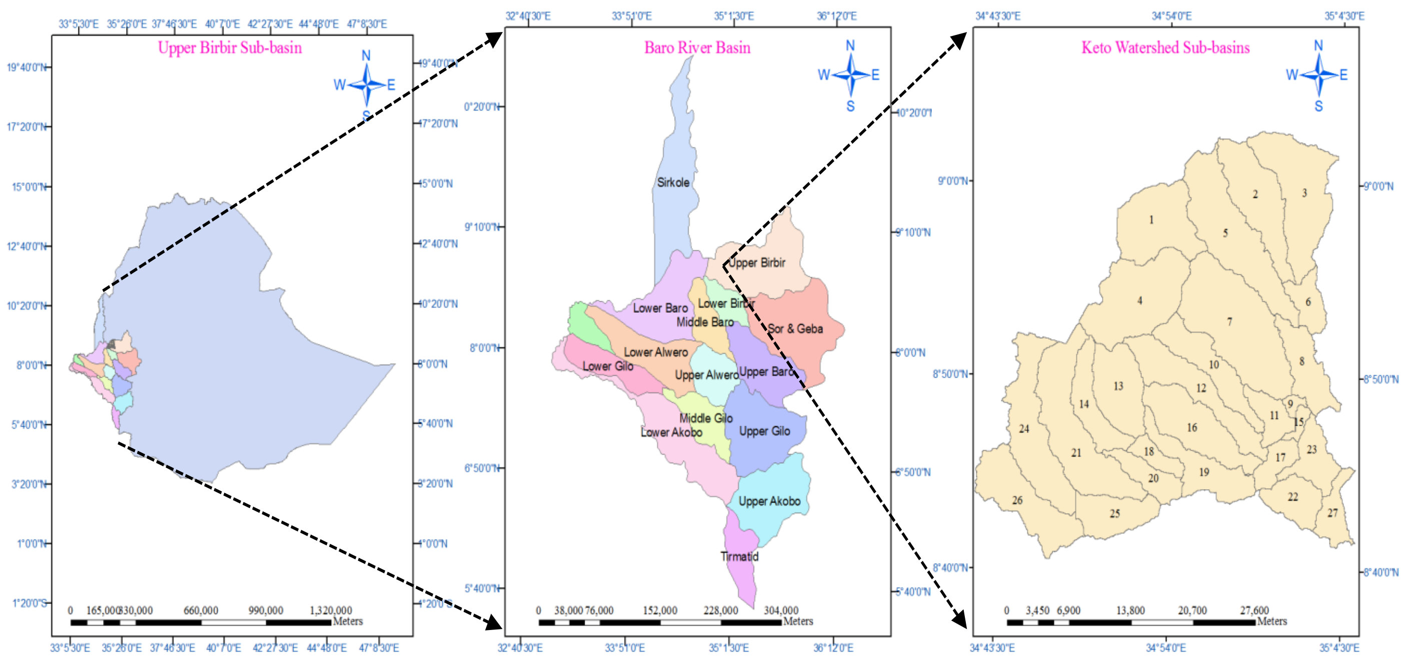


Figure 3. 1 Local map of the study area.

A) Topography

Most interior and central of the sub basin towards south west is plain. However, the central part is intensively cultivated than south western area and the same is true for western components found between 1000-1800meters are virtually cultivated and with deciduous shrubs and sparse trees. The highest altitude is in the North east part of the catchment around Illuababor, rising to 2033 meters is almost forest and agro forestry coverage.

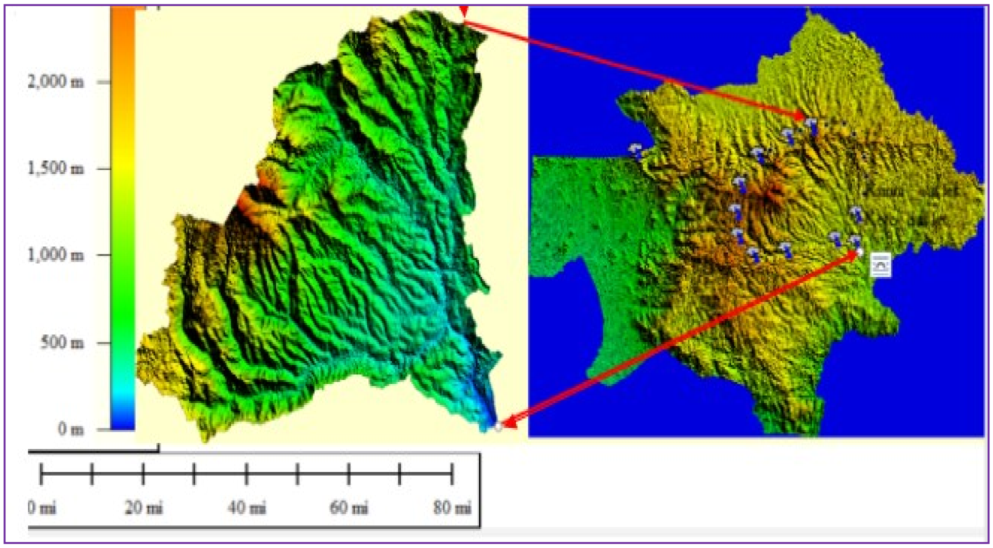


Figure 3. 2: Topography of Keto and Dembidollo by Global mapper 11

B) Geology

The Study area is dominant with pre Cambrian era crystalline rocks consisting of granite, Biotitic gneiss and clay shell inter bedded with quartzite overlapped with quaternary deposits of various origins (Mesgana.B, 2013).

Out of Baro Akobo sub basins Keto is categorized under high and mid altitude areas. The land surface whose elevation lies at 1000-2033 is characterized by mountainous terrain in the southeastern two-third. Also Presence of unconsolidated sedimentary porous medium and fracture and crush zones in the basement complex rocks are the two types of aquifers found in the catchment (ULG, 1997).

Keto sub catchment has a high extent of shield group: Trap series Miocene alkali basalt, tuffs, agglomerates and Paleocene: Oligocene, Miocene alkali olivine basalt and tuffs, rare rhyolites, dolerite sills and gabro-dia base intrusive. Generally, among Baro Akobo river sub basins upper Berber is the only catchment with Shield, groups, namely: Trap series Miocene, alkali basalts and agglomerates (Mesgana.B, 2013).

C) Sedimentation

It has been observed in various part of the world that the annual soil erosion frequently exceeds 1mm, the equivalent of approximately 2000 t/year/Km2 and can average33mm. Not all eroded soils reaches the river and accumulated in reservoirs; generally, there is re-deposition between source and reservoir. This effect is measured as the delivery ratio of sediment yield of catchment to the total soil loss upstream. The delivery ratio is the function of the catchment shape, slope, etc. It usually decreases with the increasing catchment area. From two most commonly known and large rivers of the study area, average annual sediment load of Keto River are estimated to be 324 t/yr/Km2 (ULG, 1997).

D) Climate

The study has to do with three agro ecological zones viz. Dega, Weina Dega and Kolla. More than 50% is Semi-high land, and the rest are Low land and Highland respectively.

- **Rainfall**

Rainfall amount varies widely throughout Ethiopia and are determined principally by two main factors: the direction of moisture bearing seasonal air currents and elevation. Generally speaking, rainfall variability increases as rainfall amount decrease. Since rainfall amount tends to decrease with altitude, this in turn implies rainfall variability increase when passing from highland to lowland areas.

Some part of the highest value of annual rainfall occurs southwestern Ethiopian highlands are found in this catchment, Illu ababor province Gore. Here the mean maximum annual rainfall is 2695mm. However, for the remaining parts of the study area annual rainfall is between 1700-1900 and 900-1400 maximum annual and minimum annual rainfall respectively, higher elevation receiving more than lower elevations.

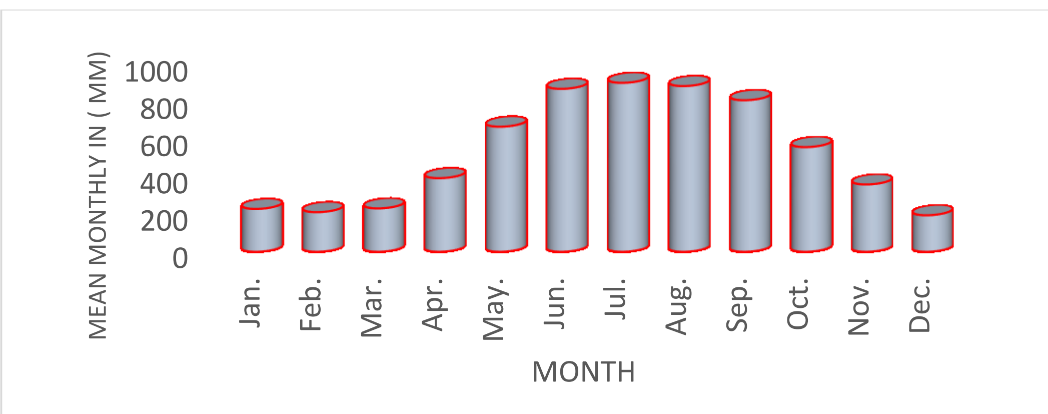


Figure 3. 3 Study area mean monthly RF

E) Temperature

Temperature is greatly influenced by the rapidly changing altitude. Whereas in the case of the study area the existing highest altitude is 2033, the area around Gore and the rest are quite similar having, 1555, 1880, 1850, 1650, 1750m a.s.l. For Ayira, Alge, Dembi dollo, Begi and Bure respectively. As a result, Dembi dollo have minimum mean annual of 11ºC o and 32ºC which is the maximum mean annual characterizes Ayira.

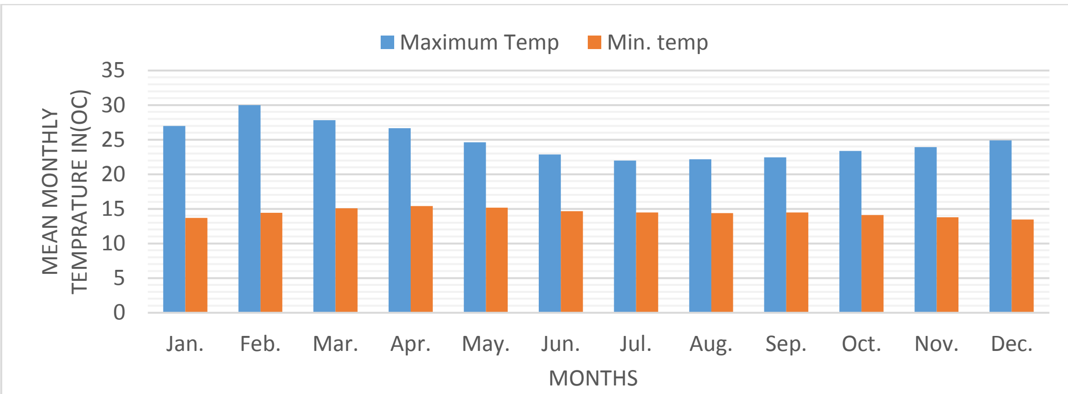


Figure 3. 4: Study area mean monthly temperature

F) Hydrology

Keto is one of the sub basins of Baro Akobo basin, in main rivers. There is also so has a stream of this main river kunni, Keto river confluences near Geba around Illuababor and unite Baro.

Stream flow data gained from NMSA was collected from hydrometric stations in the sub basin. However, most of them are not located at proper site enough to contribute for large drainage areas.

Figure 3. 5: Kuni stream flow gauging station

The observation of the stream flow began in 1985 for main river, Keto having annual Average annual river flow of about 4522.6 m3/s, including upstream catchment drainages.

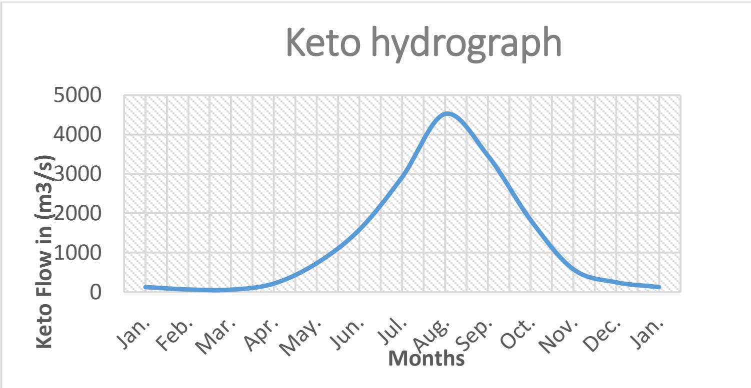


Figure 3. 6: Keto hydrograph

The above graph indicated that Main River of the study area are perennial; there is a considerable amount of ground water flow throughout the year. This further bears witness that during the dry season the water table becomes above the bed of the stream. Also the stage hydrograph of the other sub catchment River namely, Kuni reveal that is also perennial.

G) Cropping Pattern

The sub basin has Dega, Weinadega (>55%) and Kolla Sub agro climatic regions that both positively and negatively affects the proper development of crop plants. Since the total growing period of crops does not surpass four to five months, the crop could cultivate even twice on similar plot. Most part of the study area is prominent of having high amount of annual rainfall. No shortfall encounter for crop to develop properly without drying. Rainy season is cognized by the period from mid-March to September. Whereas, from October to February is known by season of irrigation in the area irrigation is practical. The crop planting date is arranged as accustomed by local farmers for the optimum emergence of crops.

Table 3.1: Major crops cultivate in and around picked out areas of the sub basin

Region	**Types of crops grown**				
Dembi Dollo	Maize	Potato	Tomato	sorghum	Soya bean
Ayira	maize	Potato	Banana	Orange	
Dale Sadi	maize	Potato	Onion	Sorghum	
Gimbi	Maize	potato	Avocado	etc.	

3.2. **Materials**

The study was carried out by utilizing the following different materials and data:

- GPS and Digital Camera.

The Geographical positioning system was used to find the location of study area main rivers and stream as well as coordinates of gauging stations. While, a digital camera was used for collecting partial relief and natural features of the study area.

Figure 3. 7: while taking coordinate point by GPS (Geographical Positioning System)

The thesis was basically based on surface analysis of Keto Sub-basin to prioritize and locate potential land surface irrigation area of watershed. To asses' surface irrigation potential analysis conditions, DEM data (30m by 30m resolution) obtained from Ministry of water, Irrigation and Electricity were used. The digitization dendritic stream pattern was carried out in GIS environment. For each sub-basin, watershed and basin boundary was delineated with help of Arc SWAT software. Arc GIS version 9.3 and Arc SWAT 2009 version software was used for creating, managing and generation of different layer and maps. Excel spreadsheet**:** Microsoft office excel 203,207and 2013 were used to analyze hydrological, meteorological data and other relevant numerical thesis works. Microsoft office excel 203 used for exchange excel file into database file (DBF) prepare for GIS and SWAT, PCPSTAT, DEW02 were program calculator was used for mathematical calculation.

Geographical information system technology has been used as a tool for analysis. GIS has emerged as a powerful tool for handling spatial and non-spatial geo-referenced data for preparation and visualization of input and output, and for interaction with models.

The software used to analyze and arrange data was arc GIS 9.3, Arc SWAT 2009, CROPWAT model, CLIMWAT 2/LOCCLIM, and Global mapper 11.

Stream flow data

Stream discharges of five gauging stations, namely, Keto (Near Chanka), Kuni (near Chanka), and Merdafo near (Dale sadi) were obtained from the Ethiopia ministry of water, Irrigation and Electricity.

Meteorological data

Meteorological data of Dembi dollo, Ayira, Begi, Bure and Gore were collected from NMSA to compute irrigation requirement for the chosen crops using CROPWAT 8.

Soil data

For soil suitability analysis, FAO (1997) soil map with a scale of 1:1000, 000 were used and soil laboratory result in case of textural classes was found from Oromia research institute, Dale sedi district research centre.

3.3. Methodology

3.3.1. Watershed delineation

The delineation process demands a digital elevation model in ESRI (Environmental Systems Research Institute) grid format. Therefore, the Digital Elevation model was clipped from DEM of Ethiopia as 30 by 30m resolution by using shape file of the study area and depicted as follows:

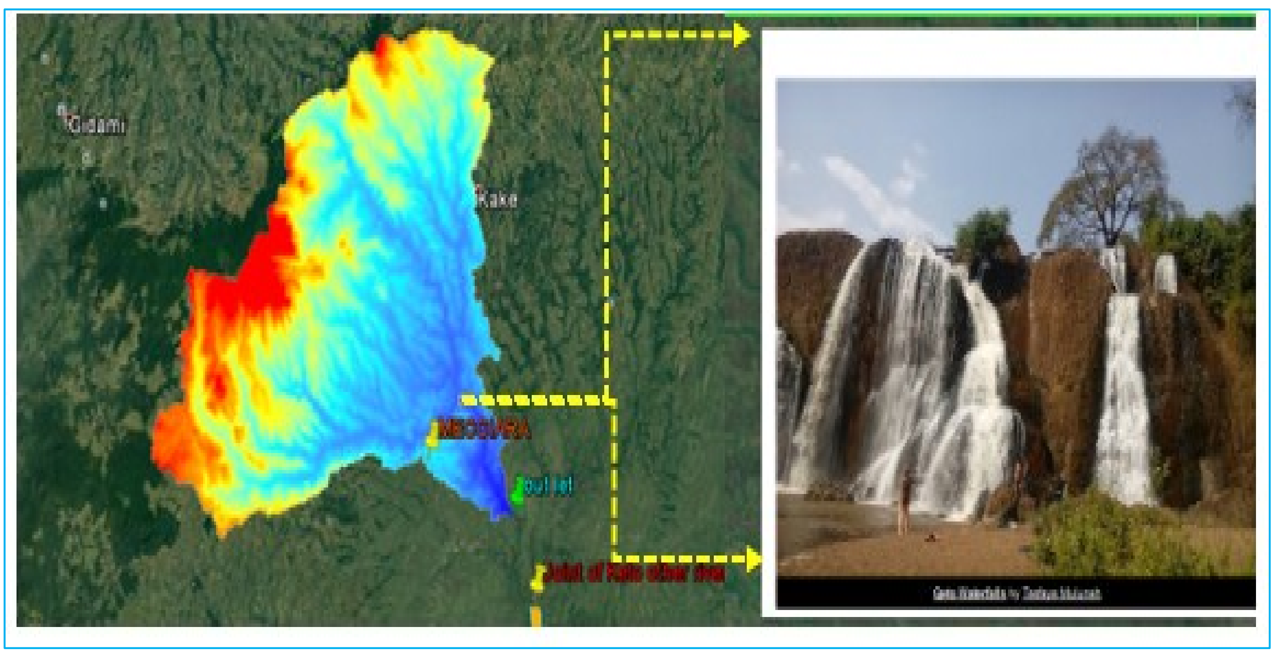


Figure 3. 8: Keto DEM on google earth and Water falls

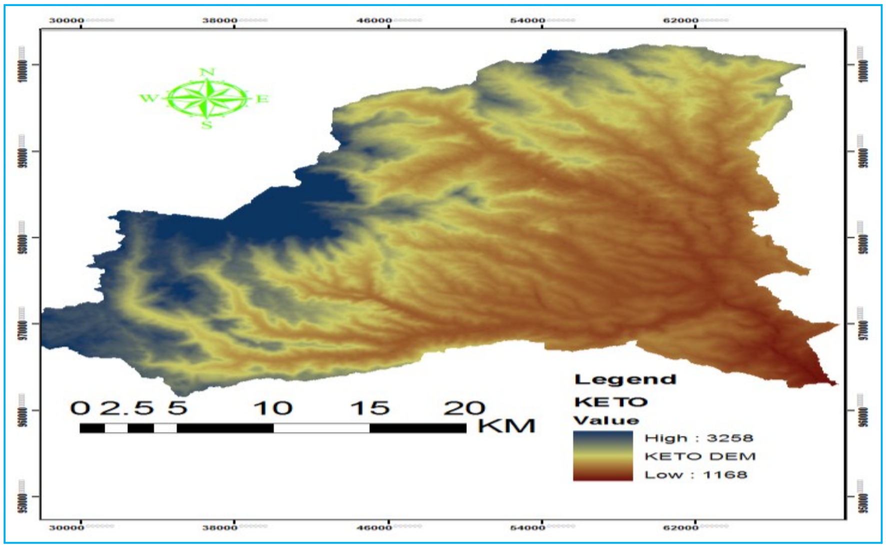


Figure 3. 9: DEM of the study area

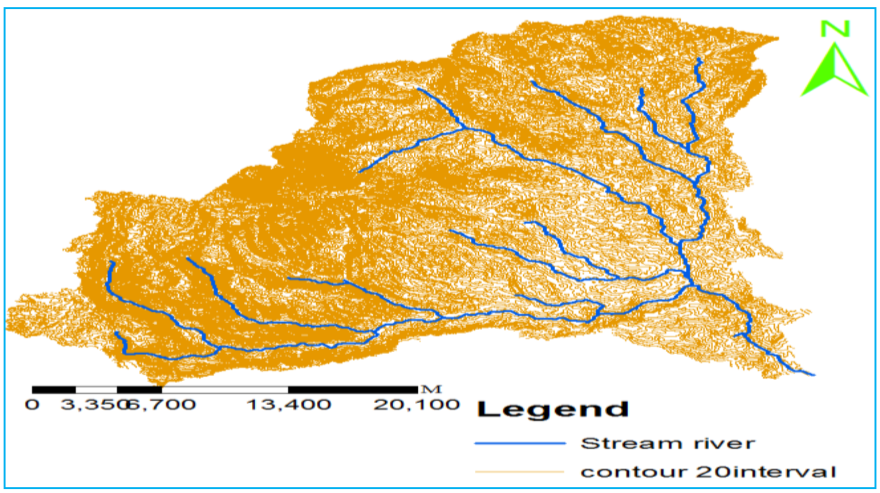


Figure 3. 10: Study area 20m contour intervals

3.3.2. Analysis of potential irrigable land

Description of the potential irrigable site for surface irrigation was accomplished by looking at land use/cover, slope, soil, and command area. Each and every component was tested first by the spatial tools of arc swat, arc GIS and eventually weighted to bring about the potential irrigable land.

Land use/Cover

Land cover and land use are often used interchangeably. However, they are actually quite different. The GLCN (2006) defines land cover as the observed (bio) physical cover, as seen from the ground or through remote sensing, including vegetation (natural or planted) and human construction (buildings, roads, etc.) which cover the earth's surface. Water, ice, bare rock or sand surfaces also count as land cover. However, the definition of land use establishes a direct link between land cover and the actions of people in their environment. Thus, a land use can be defined as a series of activities undertaken to produce one or more goods or services.

Different LULC (Land Use Land Cover) at different scales are present including land use/cover by FAO at scale1:1000, 000 for the whole Ethiopia, Also Ministry of Water, Mines and irrigation have attempted at similar scale. However, both data were collected as feature resulting from many land cover/uses and even complex enough to identify between different locations land cover. Therefore, this study utilized Africa LULC prepared by USGS (United State Geological Survey) and clipped that of the study area.

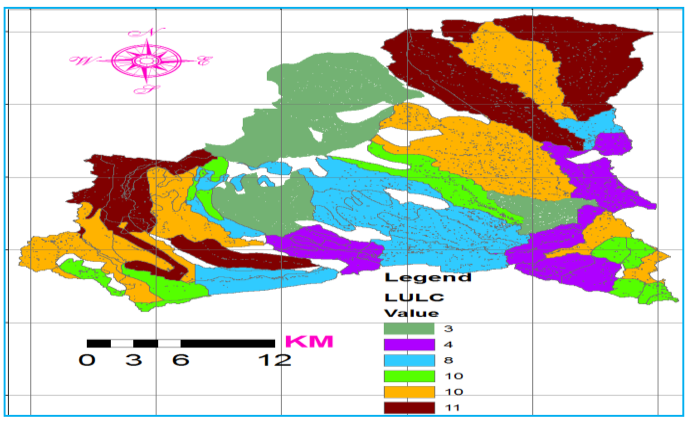


Figure 3. 11: LULC Map of the study area

- **Soil suitability analysis**

For assessment of soil suitability for irrigation, FAO soil map (1997) at scale 0f 1:1000, 000 was used. Also the soil textural nature found in and around the study area was obtained from the Oromia Research institute, west wollega district office. Several FAO guides like (FAO, 1990).Were used for grading soil suitability.

Table 3.2: FAO soil suitability ranking guide

Factors	**Grading**			
	S1	S2	S3	N
Soil texture	L-Si CL,C	80-100	-	-
Soil depth(cm)	>100	SL	50-80	<50
Salinity	<8mmhos/cm	8-16mmhos/cm	-	-
Alkalinity	<15ESP	15-30ESP	-	-
Drainage Class	Well	Imperfect	Poor	Very poor

(FAO, 1976).

Soil Analysis in Arc GIS

Before all soil map was converted into raster by using the conversion tool, then reclassified depending on their factors of grading. Weighted overlay analysis was conducted by using the overlay tool in Arc GIS 9.3 to determine its suitability for surface irrigation. First of all, the evaluation scale was selected in the weighted overlay dialog box as 1 to 9 (1 is for most suitable and 9 are less suitable and raster was added by adding a weighted overlay dialog box. So that the soil factor that is highly suitable for surface irrigation was given the value 1, moderately suitable was given the value 2 and marginally suitable was given the value 3. However, for soil factor which is not suitable for irrigation no value was given, but "restricted" and it is possible by using Arc swat interface with Arc GIS overlay or identify suitable soil profile for irrigation value.

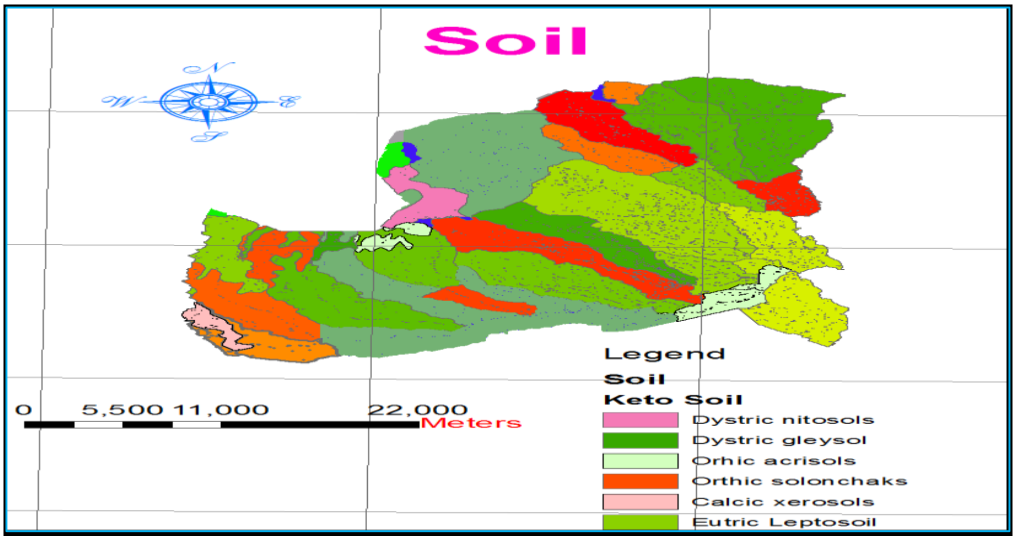


Figure 3. 12: Soil Map of the study area

3.3.3. Derivation of slope map and its Analysis

To bring slope map of the study area Digital elevation model of the area was used. Then by using Arc Swat or application of spatial analyst tools (surface analyst) in the Arc GIS slope map was derived from Digital elevation model. No matter how there are so many written materials on slope suitability measures for surface irrigation practices, for the study area, the slope derived from DEM was classified depending upon FAO (1994, land and water bulletin) classification system using Arc GIS reclassification tool rating the standard suitability range manually 0-5, 5-8, >8 for Highly suitable, Moderately suitable and not suitable respectively for surface irrigation.

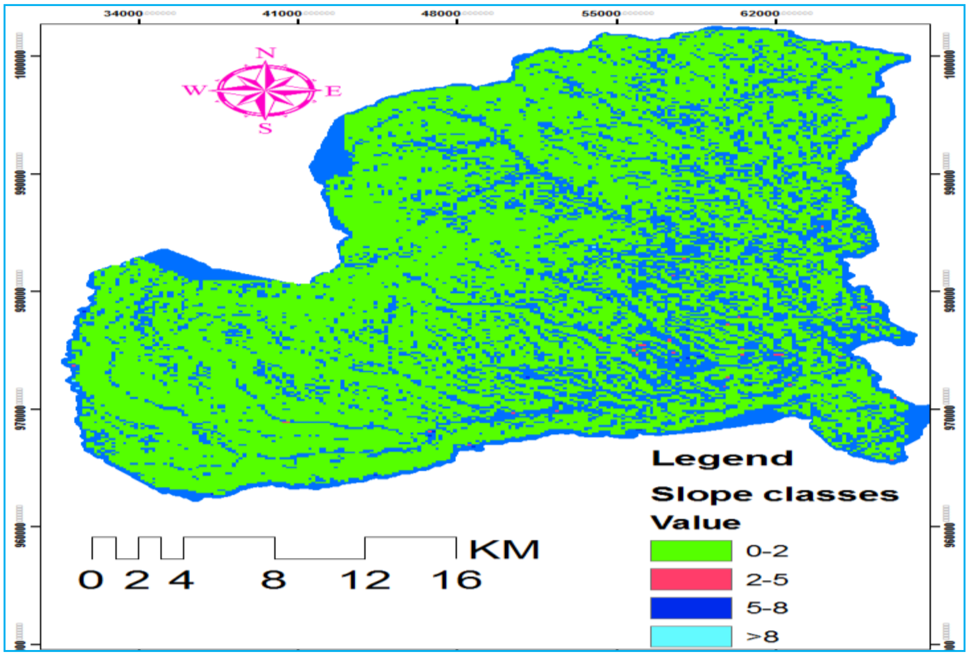


Figure 3. 13: Slope map of the study area

3.3.4. Weighing of Irrigation suitability factors to find the potential irrigable site

Potential irrigable land of the study area was gained by facilitating slope, soil and LULC raster data within arc GIS, spatial analysis tool known arc tool box module. After raster reclassification was implemented according to required suitability criteria, arc tool so called model builder was created on the arc map window then, suitability agents were provided as an input to find the most weighted suitable land (Wale et al., 2013). To create a suitability raster for irrigate site.

Suitability Model

$$S = \sum_{i=1}^{m} wici \prod_{j=1}^{n} rj \quad \text{..........} \quad \textbf{(12)}$$

$$S = \left(WsCs.Wlu.WslCsl.\prod_{j=i}^{n} rj \right), \text{ And weights, } S = (0.60Cs.0.25lu.0.15Csl)\prod_{j=1}^{n} rj$$

and Scale 1:9 for step 1

Where

Ws and Cs: Weight and criteria for slope

Wlu and Clu: Weight and criteria for land use

Wsl and Csl: Weight and criteria for Land soil

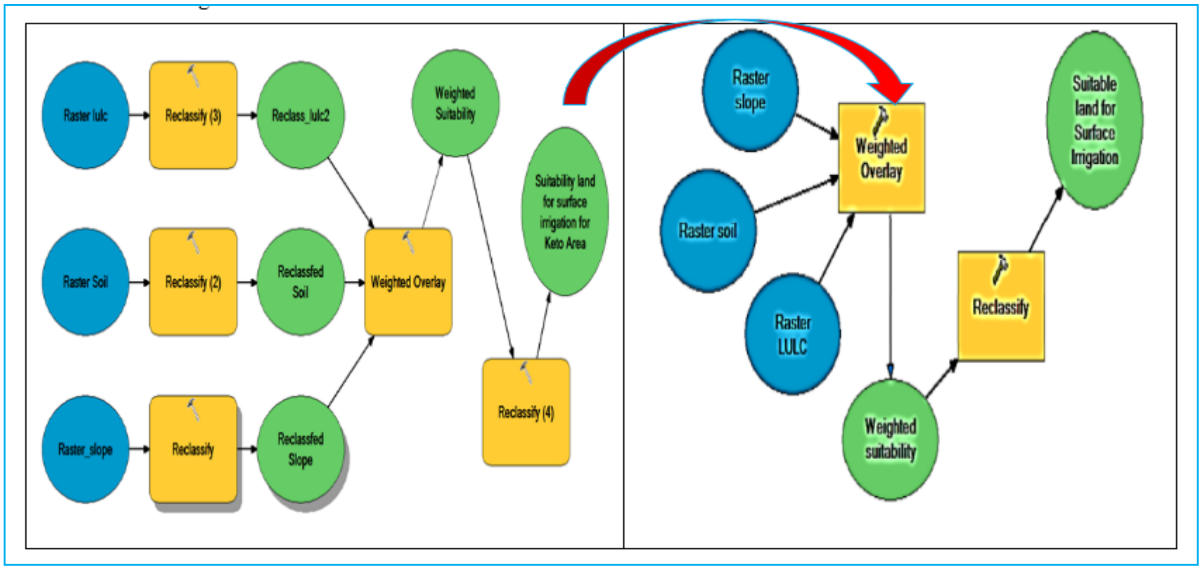


Figure 3. 14: Irrigation Suitability Model of Keto Area

3.3.5. Analysis of Hydro-meteorological data

First adequacy of data and length of records was identified. Thirty-one stream flow data and Thirty-one Years Rainfall, and other climatic parameter data were used for analysis.

Summary of corrected Hydrological and meteorological data is found in Appendix 7 & 8.

Adequacy of Rain-gauge stations

The optimal number of stations that should exist to have an assigned percentage of error in the estimation of mean rainfall was obtained by statistical analysis as:

$$N = (Cv / \in)2 \text{ .... } \mathbf{(13)}$$

Where N, optimum number of stations, $\in$ allowable degree of error in the estimate of the mean rainfall and Cv, Coefficient of variation of the rainfall values at the existing m stations (%).

If there are m stations in the catchment each recording rainfall value P1, P2…., Pi…. Pm in a known time, the coefficient of variation CV is calculated as:

$$Cv = \frac{100 * \delta m}{Pm} \text{ .... } \mathbf{(14)}$$

$$\delta m - 1 = \sqrt{\left[\sum \frac{(Pi - pm)2}{m - 1} \right]}$$, Standard deviation

Pi=Precipitation magnitude in i^{th} station

$Pm = \frac{1}{m}\left(\sum Pi\right)$, Mean precipitation in calculating the number of stations it is usual to take

E=10% According to WMO recommendations, at least 10% of the total rain-gauges should be of self-recording type (H.M. Raaghunath, 2006).

For 10% errors in the estimation of mean rainfall, the optimum number of stations in the catchment was two (2). Therefore, the analysis revealed that existing rainfall stations in the study area are more than enough. However, since there is no station with self-recording system for accurate measurement, the existing three stations, namely, Dembi dollo, Ayira and Gore with 1331.1, 1637.2, and 1915.2 (mm) annual rainfall respectively was used for further water resource potential investigation.

3.3.6. Test for consistency of record and checking the consistency of Data

A consistent record is one where the characteristics of the record have not changed with time. Adjusting for gauge consistency involves the estimation of an effect rather than a missing value. An inconsistent record may result from any one of a number of events; specifically, adjustment may be necessary due to changes in observation procedures, changes in exposure of the gauge, changes in land use that make it unreasonable to maintain the gauge at the old location, and where vandalism frequently occurs. Double-mass-curve analysis is the method that is used to check for an in consistency in a gauge record. The curve is a plot on arithmetic graph paper of cumulative rainfall collected at a gauge where measurement condition may have changed significantly against the average of the cumulative rainfall for the same period of record collected at several gauges in the same region.The method for checking consistency of a hydrological or meteorological record is considered to be an essential tool for taking it for analysis purposes. It is determined by plotting the cumulative values of observed time series of station for which consistency need to be checked on y-coordinate versus cumulative value of observed time series of group of stations on x-axis. The station affected by trend or a break in slope of the curve would indicate that conditions have changed that location. The data series, which is inconsistency, will be adjusted to consistent values by proportionality. Therefore, the station to be adjusted for Consistency by using the equation:

$$Si = \frac{Yi}{Xi} \qquad \textbf{(15)}$$

Where, Si: is the slope of section i,

Yi: is the change in the cumulative catchment for gauge Y between the end pointof the section i,
Xi: is the change in the cumulative catchment for the sum of the regional gages between the endpoints of sections i.

3.3.7. Estimation of Mean Rainfall

Raingauge represents only point for sampling of the areal distribution of a rainfall. In practice, though, hydrological analysis it requires recollection of the rainfall over an area. Arithmetic average, Isohyetal and Thiessen polygon methods are in use to translate the point rainfall values at different stations into an average value over a catchment. Among those methods Thiessen polygon methods is a good network of representative rain gauge. The merit of Thiessen polygon method is that easy to realize, allows for the uneven distribution of rain gauges and the disadvantage is that it does not take in to account the effect of geographical nature on rainfall.
does not take in to account the effect of geographic nature on rainfall. Thiessen polygon method is one way of calculating areal precipitation. The method gives weight to point data in proportion to space among stations. Lines are drawn among adjacent stations on map. The area of each polygon in side sub basin area was calculated by GIS Geometry calculator. Thiessen polygon of Keto watershed used as weight of station studies with in that polygon.

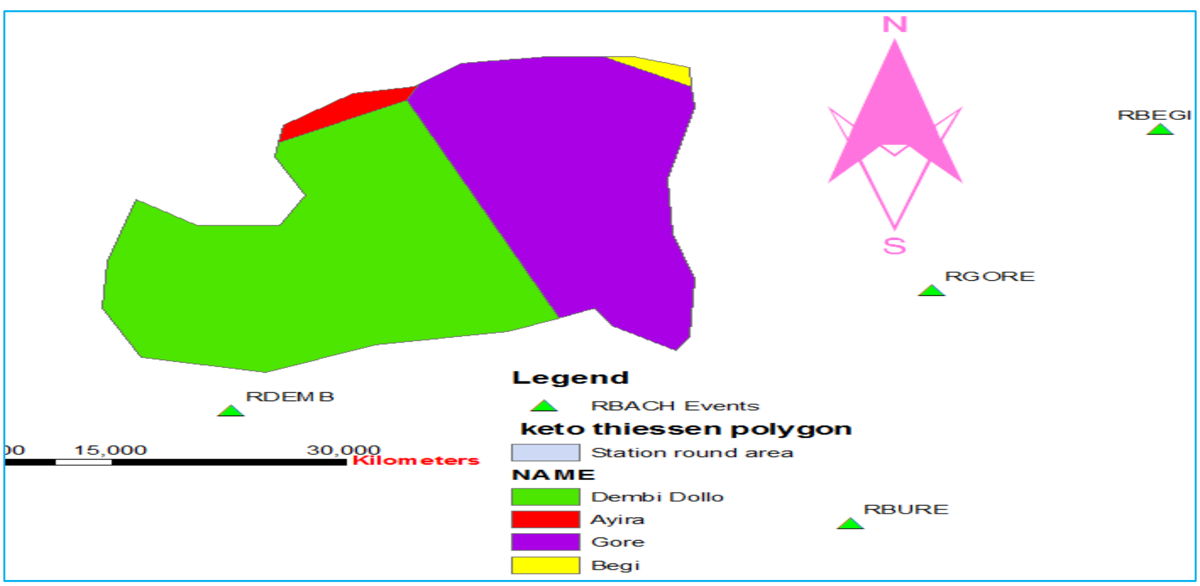


Figure 3. 15: Thiessen polygon of Keto watershed

3.3.8. Thiessen polygon of Keto watershed

Thiessen polygon is drawn by using ArcGIS Software. To determine mean areal rainfall, amount of rainfall at each station multiplied by area of its polygon and the sum of products is divided by total area of catchment. Each polygon area is assumed to be influenced by the rain gauge station inside it, i.e., P1, P2, P3 … Pn are the rainfall at the individual stations, and A1, A2, A3 … An are the area of the polygon surrounding this stations, respectively, the average depth of rainfall for the entire basin is given by

$$Pavg = \frac{\sum PiAi}{AT} \quad \text{………………………………………………………………... ……………………} (16)$$

Table 3.3: Coordinate and area of Thiessen Polygon of Keto Watershed

Name of RF station	XPR	YPR	ELEVATION(m)	Area(KM^2)
Dembi Dollo	82731.728	956879.76	1850	745.603093
Gore	114184.603	972556.46	2033	500.601343
Ayira	95522.293	1000000	1555	44.481128
Begi	2353.094	993458.74	1650	24.715366

Filling Missing rainfall data

Missing record of rainfall stations was estimated by using the Distance power method. Here, the rainfall at a station was estimated as a weighted average of the observed rainfall at the neighboring stations.

Let (*Di*) be the distance of the estimator station from the estimated station. If the weights are an inverse square of distance, the estimated rainfall at the station (*A)* is:

$$PA = \sum \frac{Pi}{Di2} \Big/ \sum \frac{1}{Di2} \quad \text{……………………………………………………………………..……} (17)$$

Where, x and y are the coordinates of the station whose data is estimated and xi, and Yi are the coordinates of stations whose data are used in estimation.

3.3.9. Assessment of water resource potential

The available surface water of the study area was approximated by using stream flow discharges obtained from the Ministry of Water, irrigation and Electricity and Climatic data was from NMSA.

Table 3.5: hydrolometric stations inside and around the study area

S/No	River	Site	Start date	End date	Latitude (UTM)	Longitude (UTM)	Drainage area(Km^2)
1	Keto Chanka	Near Chanka	1985	2015	965961.23	67968.82	1128.2
2	Kuni	Near Chanka	1988	2015	970221.5	*71132.25*	146.6

Table 3.6: Climatic data stations around the study area

Name	Latitude	Longitude	Elevation
Alge	8.53333	35.6667	1880
Ayira	9.1	35.55	1555
Begi	9.333	34.5333	1650
Dembi dollo	8.156667	34.8	1850
Bure	8.23333	35.1	1750
Gore	8.1333	35.53333	2033

3.3.10. Low flow Analysis

Low flow was estimated from a time series of gauging data by arranging all daily discharges and dividing by the number of days in the record. It is normally calculated for a specific month or seasons.

3.3.11. Flood frequency studies

The estimation of flood peak was conducted by commonly used frequency distribution function for the predication of extreme flood values known Gumbel's extreme value distribution.

A practical annual data series of extreme events of flow records was used. Then arranged in descending order and ranked to get return period as summation of one divide by order number and exceedence probability by dividing hundred for return period. Finally, mean annual peak flow was computed by squaring each and annual flood value. After the required expected year of flood was determined (for this study, 25 and 100 years), the outcome of the expected peak flood was calculated as product of standard deviation and summation of mean peak discharge and frequency factor. The Gumbel's equation is expressed as:

$$QT = Q_{mean} + K\delta Q \qquad (18)$$

Where

QT= the Annual peak river flow of (T) year return period

Q_{mean}= Mean of the annual peak flow, K=Frequency factor and σ is a standard deviation peak flow which is given by:

$$\delta = \sqrt{\sum (Q - Q_{mean}) 2} \Big/ (N-1)$$

$$K = \frac{YT - Yn}{Sn}$$

$$YT = In\left(1 - \frac{1}{T}\right)$$

Where,

YT= Reduced variant

Yn = Reduced mean, it is a function of the sample size **N** only

Sn= Reduced standard deviation which is also a function sample size only**.**

3.3.12. Flow duration curve

For analysis of flow by flow duration curve, the monthly discharges of each main and Sub River catchment was screened and arranged in descending order and given class interval. Then, the percentage of time the flow was equaled or exceeded was computed by dividing class interval for the sum of one (1) and number of data multiplied by 100. Mathematically expressed as Californian formulae:

$$P_p = \frac{m}{n} * 100 \quad \textbf{(19)}$$

Where

m is the rank of a value in a list arranged from largest to smallest,

n is the total number of observations

For instance, the highest value would have a rank of 1 while the lowest value would have a rank of n.

3.3.13. Storage Capacity Determination

For storage capacity determination, MC (Mass Curve) was used. Accumulated flow was plotted against time to identify rate of flow at that particular time. Also demand was calculated from both low flow (95% dependable flow) and mean monthly flow considering 20% for the downstream release. The accumulated demand curve was plotted against time on the same graph with mass curve. Then, the line was depicted parallel to the demand curve and tangential lines and measured so that reservoir capacity required for satisfying the given demand determined from largest maximum vertical intercepts occurred between the demand curve and tangent lines.

3.3.14. Computation of crop water requirement

Three climatic data, namely: annual Rainfall, Maximum and minimum temperature used for this study was collected from the NMSA (National Metrological service Agency) and the rest like Relative humidity, Wind speed and Sunshine hours are collected from CLIMWAT model version 2 provided that coordinate of the nearby stations put into the model module. The selection of stations for this study focus on the required data types so as to estimate reference evapo transpiration using FAO penman-Monteith method and their distribution in the existing different climatic regions.
Depending on these criteria the climatic data available for this study comprises five stations present in the sub basin with sparse spatial distribution. To further analyzing of this activity Average monthly data of Thirty one years (31 years) was used. The collected meteorological parameters include: -

- Rainfall (mm)
- Relative humidity (%)
- Maximum & minimum temperature (^{O}C)
- Wind speed (Km/day)
- Sunshine hour (hr.)

Data for crop water requirement

Most selected stations for this study have rainfall data with short missing gap length so that the mean values of data in the available years were simply taken for a missing gap in the analysis period. However, Ayira and Dembi dollo stations somehow have longer missing gaps.
The calculation of the reference evapo transpiration (ETo) with the Penman-Monteith method requires mean daily, ten-day or monthly maximum and minimum air temperature (Tmax and Tmin), actual vapor pressure (ea), net radiation, and wind speed measured. However, for this paper Monthly data were used.

3.3.15. CROPWAT Model

The estimation of crop water requirements was conducted by the selection of appropriate crops that are likely to be grown in the specific climatic condition with their appropriate crop coefficients and the corresponding reference evapo transpiration. According to FAO _56‘ (Richard 1998), the maximum value of the crop coefficient for the dominant crop is 1.15. The irrigation water requirements of climatically classified sub basin regions were quantified from the awareness of the crop water demand. The estimation of ETo for the selected climatic stations was made using Cropwat 8 model and Arc swat process ETo estimation is selected climate stations.

CROPWAT 8.0 for windows is a computer program for the calculation of crop water requirements and irrigation requirements from existing or new climatic and crop data. Furthermore, the program allows the development of irrigation schedules for different management conditions and the calculation of the scheme water supply for varying crop patterns.

It includes updated and new features like:

- Monthly, decade and daily input of climatic data for calculation of ETo
- Backward compatibility to allow use of data from CLIMWAT database
- Possibility to estimate climatic data in the absence of measured values
- Decade *and daily* calculation of crop water requirements based on updated calculation algorithms, including adjustment of crop-coefficient values
- Calculation of crop water requirements and irrigation scheduling for dry crops *and for paddy & upland rice*
- Interactive user adjusts irrigation schedules
- Daily soil, water balance output tables
- Easy saving and retrieval of sessions and of user defined irrigation schedules
- Graphical presentations of input data, crop water requirements and irrigation schedules
- Mislead input sensitive system

For the calculation of crop water requirement, data like Temperature (Maximum and Minimum), humidity, Wind speed and sunshine was loaded in CROPWAT ETo/climate module to calculate ETO using the Penman-Monteith formulae.

- Rainfall (Monthly) data were used to compute effective rainfall
- Crop and soil data: Crop type selected for analysis was both Maize and Potato.

Maize requires deep soil root with high water holding capacity to be grown without irrigation or only with supplemental irrigation (FAO, 1986) (FAO, 1986).

However, in the semi tropical like the study area, the soil is with medium texture (Sandy Clay and sandy clay loam) unless rainfall coincides with the growing period irrigation is must. Equally important, potato is very sensitive to water deficits as water shortages may result in a reduced tuber yield, number, sizes, and loss of tuber quality.

3.3.16. Model Sensitivity analysis, calibration and Validation

Sensitivity analysis is a method of minimizing the number of parameters to be used in The calibration step by making use of the most sensitive parameters largely controlling the behavior of the simulated process. Twenty seven hydrological parameters were tested for sensitivity analysis for the simulation of the stream flow in the study area. The details of all hydrological parameters are found in (Winchell et al. (2007).

Table 3.7: Sensitivity classes by Lenahart et al., (2002)

S.no	Class	Index	Category of Sensitivity
1	I	0.00< I <0.05	Small to negligible
2	II	0.05<I<1	Medium
3	III	0.2<I<1	High
4	VI	I>1	Very high

Model simulations were evaluated by using two objective functions; coefficient of determination (R2) and the Nash Sutcliffe efficiency (NSE) (Nash and sutclife1970).Coefficient of determination (R2) and the Nash Sutcliffe efficiency (NSE) the coefficient of determination is the square of the Pearson product-moment correlation coefficient and describes the proportion of the total variance in the observed data that can be explained by model. The closer the value of R^2 to 1, the ingner is the agreement between the simulated and the measured flow. Nash and Sutcliffe efficiency, NSE indicates the degree of fitness of the observed and simulated plots with the 1:1 line (SANTHI et al, 2001).

Model Inputs and Model setup

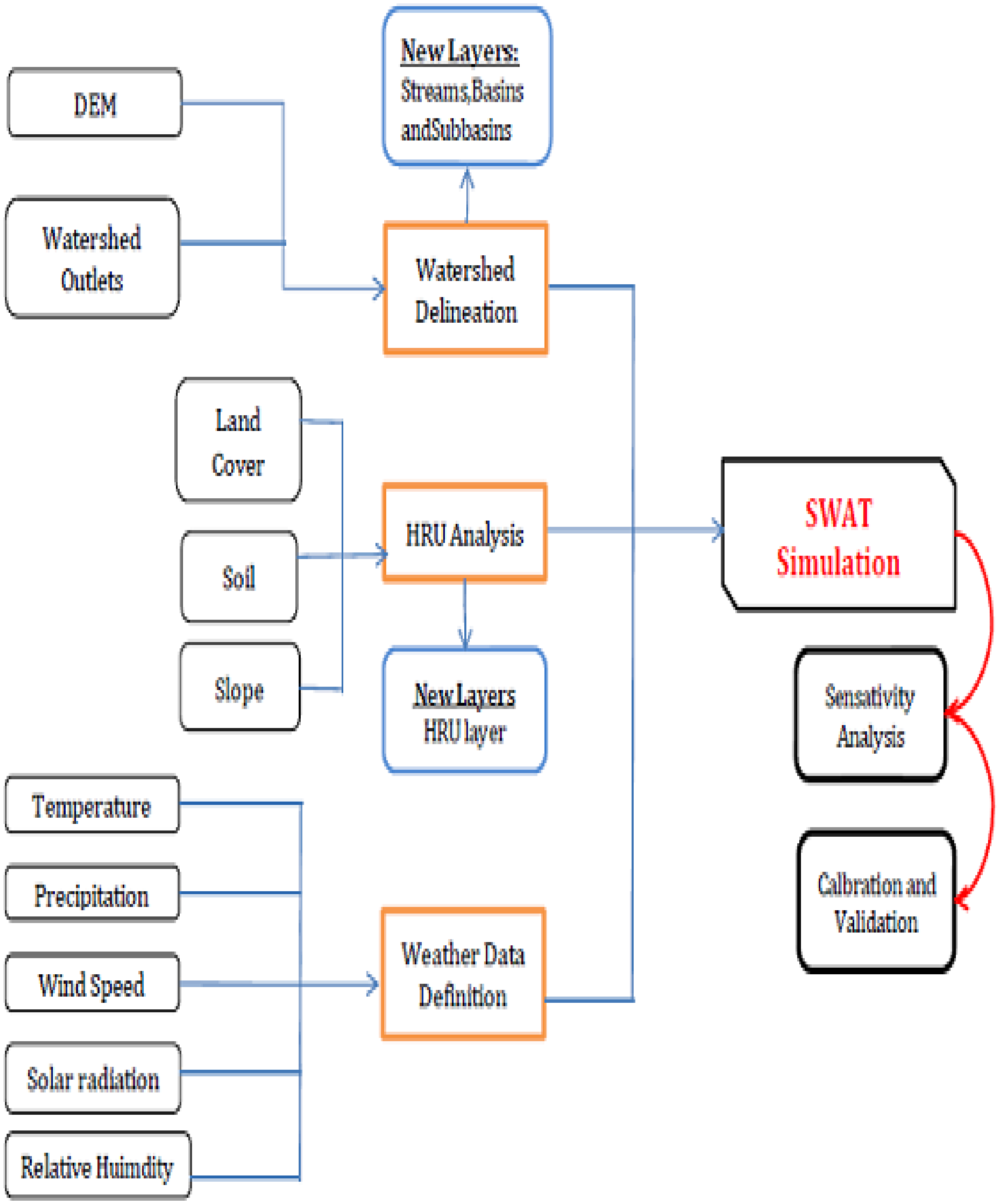


Figure 3.16: Model Inputs and Model setup

CHAPTER FOUR: RESULT AND DISCUSSION

4.1. Testing Stream Flow and Rainfall Data for Consistency

The double-mass curve analysis revealed that there is a good direct correlation between the cumulative stream flow records at the Keto gauging station with the cumulative average stream flows at the two stations (r^2 =0.9995) (Figure 4.1). This indicates that the stream flow data at Keto gauging station is consistent. For the other stations, the consistencies of their stream flow records were checked using a similar procedure and the corresponding double mass curves were presented in Appendix 2. Accordingly; it was found that no significant shift of the slope was observed in their respective plots, and the correlation coefficient of the stations indicated that there is a good direct correlation between the stations' records and their corresponding base stations. Therefore, it was concluded that the stream flow data from all stations can be used for further application.

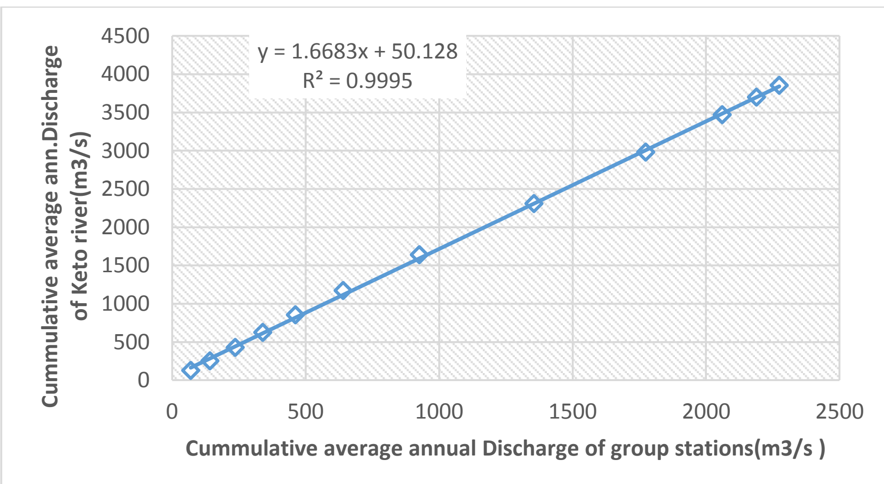


Figure 4. 1 Double mass curve of discharge at Keto station.

The rainfall data was also analyzed and there were missing records as presented in table below. Consequently, missing values were filled to use the data for further application.

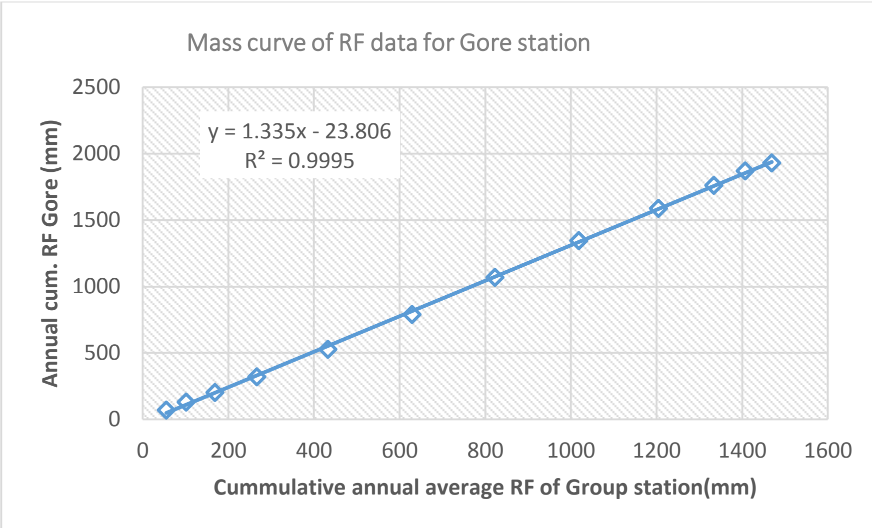


Figure 4. 2 : Double mass curve of RF at Gore station

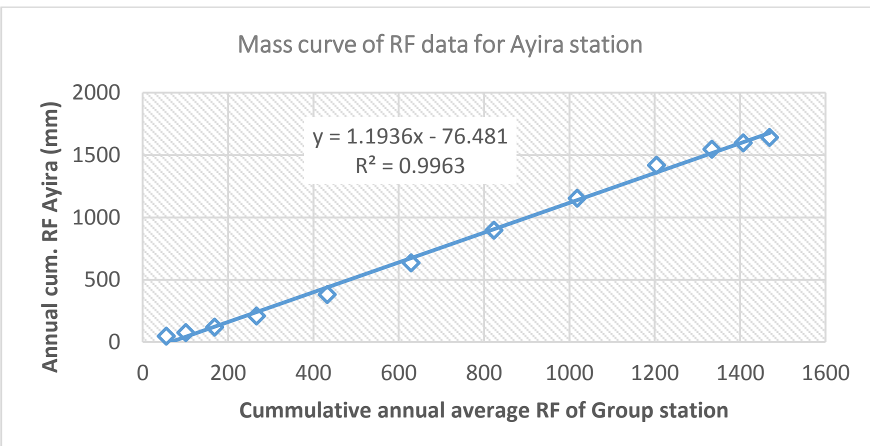


Figure 4. 3: Double mass curve of RF at Ayira station

The meteorological data indicate rainfall at Ayira and Gore has no missing records. On the other hand, the rainfall analysis result shows that there were missing rainfall records at other different stations. As a result, to use these data for the application, those missing values were filled and summarized in Appendix 8. The data of Ayira and Gore were used for filling missing data from other stations. Likewise, outcomes of the double mass curve analysis of the rainfall stations discovered that the rainfall recorded at the five gauging stations, namely Gore, Bure, Begi, Ayira and Dembi dollo are consistent with no change of slope on their respective plots.Therefore,rainfall data recorded at four stations can be used for onward analysis.

Group Double mass curve of Rainfall at study area

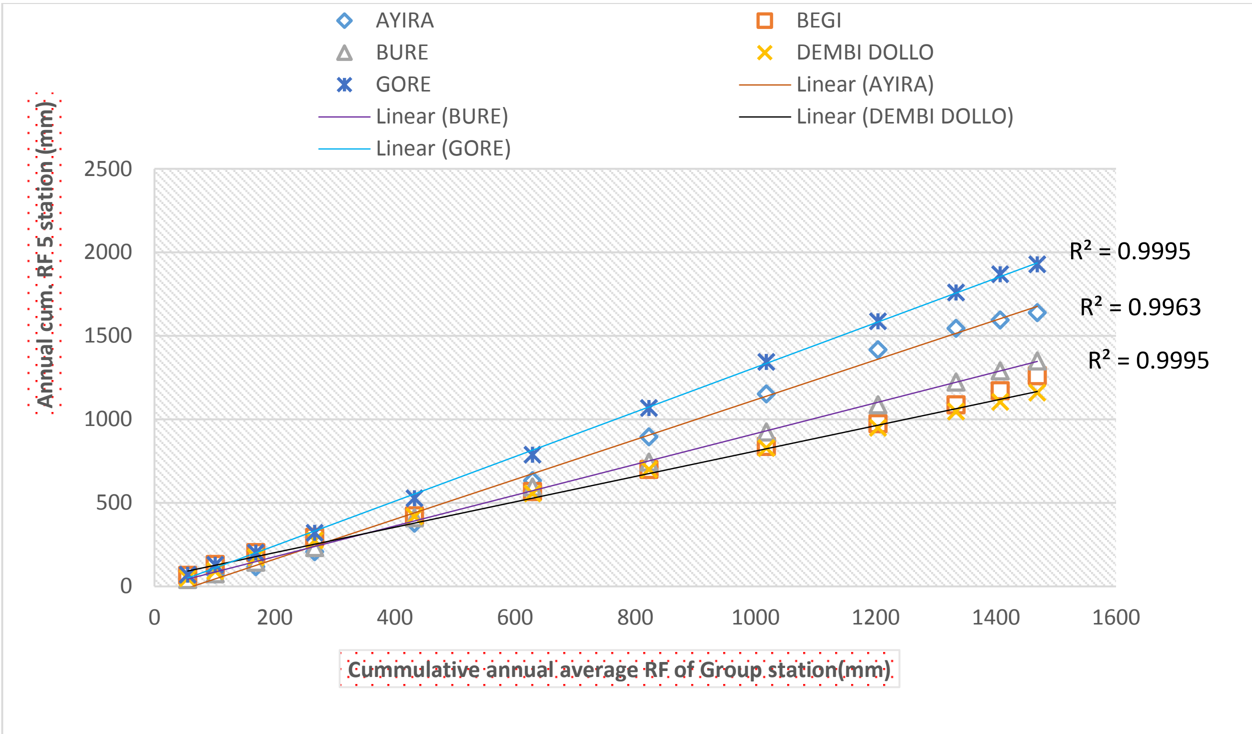


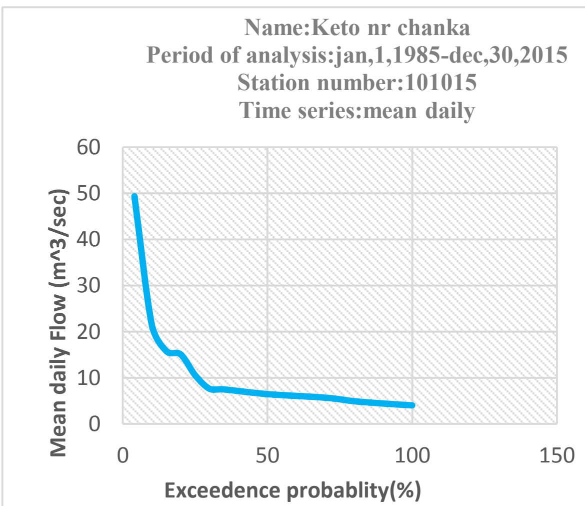
Figure 4. 4: Group Double mass curve of Rainfall at study area

4.2. Flow duration curve

A flow duration curve of the stream is a plot of discharge against the percentage of time the flow was equaled or exceeded. It is also known as discharge frequency curve. The curve characterizes the stream variability and nature of streams (Michael, 1986).According to analysis of Keto river flow, lower portion of the curve reveals the presence of considerable base flow and where as FDC of other rivers is found in Appendix 3.By using program calculates statistical parameters of average daily precipitation data analysis through Excel analysis is Missing rainfall data is estimated.

Table 4.1: Summary of missing rainfall data for the stations

Rainfall station	Year and months with missing records
Dembi Dollo	1987(*Jan, Feb, Mar, May, Aug, Sep, Oct, Nov, Dec), 1994 (May, Jun, Jul); 1995(Jan, Feb, May, Jun, Jul, Aug);1997(Feb, Jun, Jul, Aug, Sep, Oct, Nov, Dec), 2014(Feb, Mar, Apr, Jun);2015(Apr, Jun)*
Ayira	*1987(Jan, Feb, Mar), 1992 (Jan, Feb, May, Sep, Oct, Nov, Dec),1991(Jan, Feb, May, Sep, Oct, Nov, Dec) 1992(Jan, Feb, May, Sep, Oct, Nov, Dec) 1993(Nov, Dec), 1994 (Jun, Jul, Oct, Nov, Dec)*
Begi	*1987(Jan, Feb, Mar), 1992 (Jan, Feb, May, Sep, Oct, Nov, Dec),1991(Jan, Feb, May, Sep, Oct, Nov, Dec)*
Bure	1985*(Jan, Feb, Mar) 1991(Jan, Feb, May, Sep, Oct, Nov, Dec)*



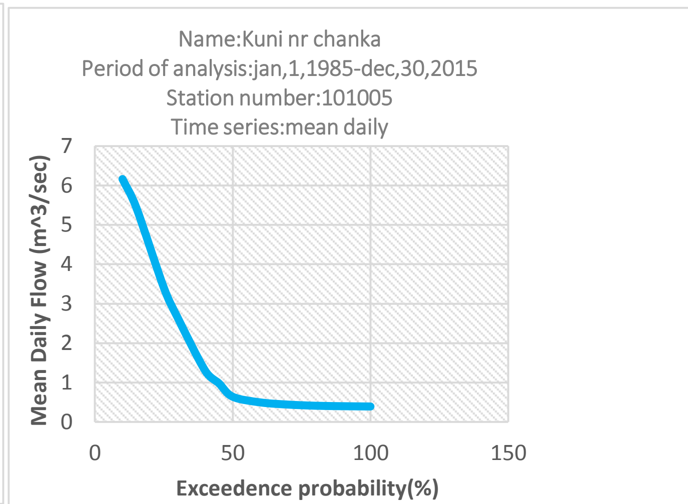


Figure 4. 5: FDC low flows of Keto River at station Keto near Chanka
Figure 4. 6: FDC low flows of Kuni River at station Kuni near Chanka

Percentage exceedence flow means, the flow in a stream that based on statistical probability will be exceeded given percentage of time on an annual basis. As percentile used as a low flow index depending on the type of river being studied, for perennial rivers, Q_{90} or Q_{95} are typically applied. Nevertheless, 95% is one of the most common low flow indices used operationally (Guta. Fasil.T, 2011).

The percentage exceedence probability of rivers with average and monthly minimum flow is given in table 4.2 and 4.5 respectively.

Table 4.2: Exceedence probability Values of Rivers in the study area

River	Average Run off volume(m^3/s)	Average minimum flow(m^3/s)	Percentage exceedence flow (m^3/s)				
			80%	85%	90%	95%	100%
Kuni	5.9	2.2	2.07	2.2	1.9	2.25	2.53
Keto	54.9	20.53	11.04	21.4	13.35	19.95	36.9

Table 4.3: Analysis of 100%, 95%, 90%, 85%, 80% low flow of Kuni

%Exceedence	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
100	0	0.1	0	0.1	0.3	0.7	1.6	16.4	8	1.8	0.9	0.5
95	0.1	0	0	0	0.4	0	3.7	21.2	0	1.4	0	0.3
90	0.2	0.1	0.1	0.7	0.6	2.1	5.7	7.8	3.4	2	0.8	0.4
85	0.2	0.1	1.1	0.1	0.4	5.2	7	5.2	4.1	2.1	0.8	0.4
80	0.2	0	0.1	0.1	0.5	6.5	3.8	6.5	4.3	1.8	0.7	0.4

Table 4.4: Analysis of 100%, 95%, 90%, 85%, 80% low flow of Keto River

%Exceedence	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
100	0.5	0	0.1	0.9	1.1	5.5	105	111	111	85	16.3	5.5
95	0.7	0	0.2	0.5	1.6	28	53	80.2	39	25	7.1	3.7
90	0.8	0.2	0.3	0	2.1	11.5	46	33.9	34	22	6.3	2.9
85	1	0.5	0.3	0.9	2.9	24.3	47	83.7	56	23	12.6	3.1
80	1.1	0.5	0.4	0	2.7	0	21	85.8	0	18	0	2.9

4.3. Flood frequency analysis

The annual series of hydrological data was used and predicted the possible flood magnitude of future flooding of 25 and 100 years as in table 4.5.

Table 4.5: Flood frequency analysis of the study area Rivers for25 and 100 year RP (Return Period)

Rivers	Expected Discharge	
	RP 25 Year	RP 100 Year
Keto	20253.4	4384.25
Kuni	621.35	1018.4

4.4. Watershed delineation

2.20.1. Identification of flow direction

Direction of flow of individual DEM cell was carried out by using arc swat and Arc tool box spatial analysis tool module, Hydrology tool (Flow direction and accumulation). The pour point of main and sub watershed was identified after so many nodes are distinguished into drainage outlets along the stream arcs and coordinate point specify them was prepared and converted to UTM (Universal Transverse Mercator) by using Arc Catalog and addressed individually.

The result of delineation demonstrated that the study area constitutes two cognized donating watersheds namely, Keto and Kuni. Keto is the largest watershed having area of **1058.592**km^{2}including Kuni (146.6 km^2) and other remaining.

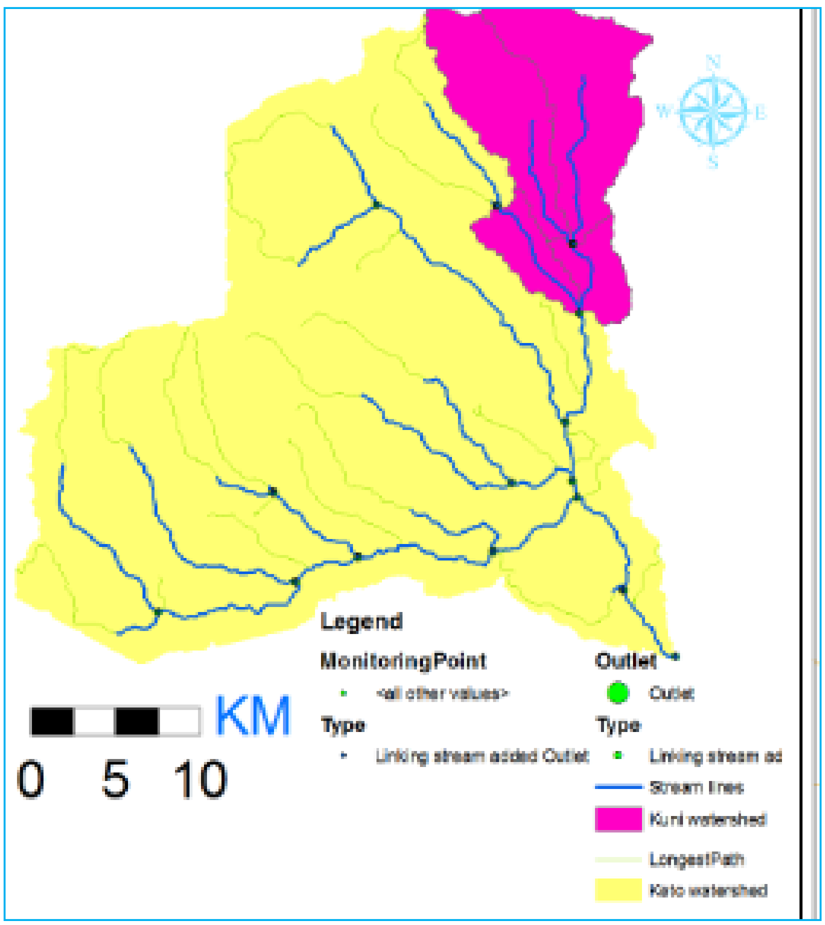


Figure 4. 7Main /Sub watershed pours points.

4.5. Irrigable land suitability evaluation

Surface irrigation suitability was evaluated by examining the following factors as:

4.5.1. *Soil Suitability*

The distinguished study area soil groups are Dystric nitosols, Dystric gleysol, Orthic acrisols, Orthic solonchaks, calcic xerosols and Leptosols. Whereas, gist of soil suitability classification result is described in the table below and suitability to do with proposed crops, land units and soil are found in Appendix 1.

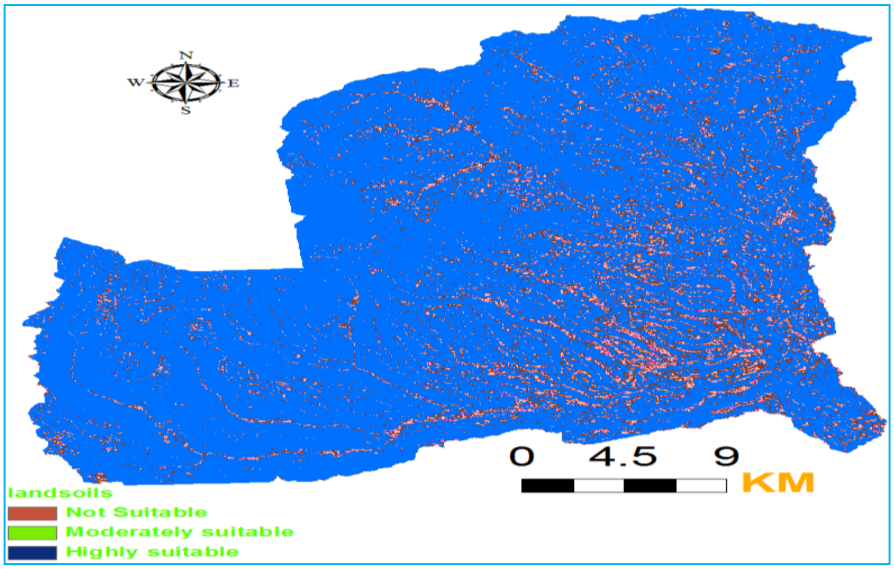


Figure 4. 8: Soil suitability map of the study area

The analysis revealed that the study area could be assorted into three irrigation suitability classes as:

- Highly suitable (S1)
- Moderately suitable (S2) and
- Not suitable (N)

In case of surface irrigation practices considering soil and crops proposed to be grown in the study area, both soil groups have well drained condition and the land unit soil have characterized soil textural nature, soil depth, drainage, and rock outcrops. Fine texture soils having the properties of clay, silt and sand (Sandy clay loam and clay loam) and are classified as highly suitable (S1) for surface irrigation and medium one has to do with the nature of medium sand and sandy loam so that marginally suitable for surface irrigation. Also few mapping units are characterized by the rock outcrop (stoniness) such an area has medium textured and well drained except that it is limited for stoniness they are marginally suitable (S2) for surface irrigation. However, area inclined towards non suitability is very stony areas, medium texture having shallow depth. Generally, more than half of the study area's land unit soil are considered as highly suitability class apart from those areas limited by stoniness. The soil suitability analysis result for selected study area crops with suitability criterion is given in Appendix 1.

Table 4.6: Soil suitability analysis Result

Mapping Unit	Soil type	Texture	Depth(cm)	Drainage	Salinity	Alkalinity	Irrigation suitability	Area(ha)	%
Rfv⁶	Dystric Nitosol	SCL	150	W	0.15	0.1	S1	180	65.2
Rwg²	Dystric gleysol	F	120	W	-	0.1	S1	180	33.2
V²h	Orthnic acrisols	F	120	W	0.4	0.6	S1	170	0.4
Ak	Orthic solonchaks	SL	50	W	15	0.3	N	170	0.5
Rd1c	Calcic xerosols	SCL	50	W	0.1	0.1	S2	175	0.4
Rm1g	Leptosols	S	>60	W	-	-	N	175	0.3

M=Medium, F=Fine, W=Well, N=Not suitable, S1=highly suitable, S2=Marginal

4.5.2. Land use and land cover analysis

The study area was classified into seven land use/cover classes using arc GIS spatial analyst, reclassify tool. The discovered LULC are: Montane forest, sub-montane forest, mosaic forest/Savanna, Deciduous woodland, Decorous shrub land with sparse trees and crop land, which are highly dominant coverage of the study area.

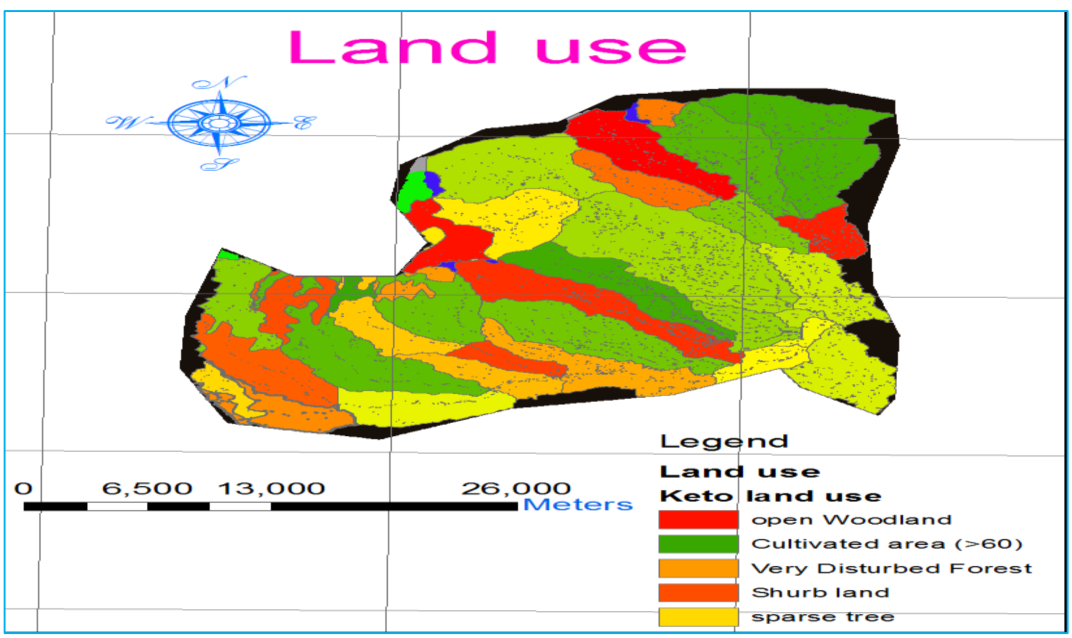


Figure 4. 9: Land use/cover Suitability map

Montane forest is found sparsely around Illuababor Keto river catchment including few parts of round about Dembi dollo area and flows down to Mettu. So such type of cover is Non suitability family (N) for irrigation.

According to both local and authorized policies, forested is not deserved for irrigation purpose. Therefore, it is not suitable (N) for surface irrigation.

Savanna/Mosaic forest is characterized by short stem trees with grass cover and mixed cultivated land. It includes some part of, Dale sadi woreda and downstream of the Keto catchment. Since some part of the land is characterized by cultivation, it is set under marginally suitable class (S3). Because, grass cover areas are reserved for other local activities beyond irrigation. As a result, practicing irrigation on such an area is condemned both locally and institutionally.

Deciduous woodland is characterized by drought resistant small to moderate sized deciduous trees and shrubs with small evergreen leaves most probably, occurring between 900-1900m. This land cover densely constitutes south western part of the catchment including Meti river catchment and the route downward course of upper Keto. This type of land is restricted for irrigation. Therefore, it is categorized as not suitable (N).

Deciduous shrub land is sparsely situated in the study area and few parts of it is found in and around Dale sedi woreda, Kuni sub river catchments periphery and area about the upper Keto exit. This is highly suitable (S1) for irrigation.

Cropland is the most dominant land cover of the study area surfacing more than 50% of the catchment land. This land is highly suitable (S1) for irrigation practices.

Table 3.7: Analyzed LULC areal and percentage coverage

S/No	ID	Class name	Area (ha)	Percentage (%)
1	1	Open Woodland	*248.1721*	*0.5*
2	5	Cultivated area (>60%)	*60.9996*	*79.0*
3	9	Very Disturbed Forest	*0.0971*	*12.1*
4	12	Disturbed Forest	*5.8884*	*10.4*

4.5.3. Slope suitability

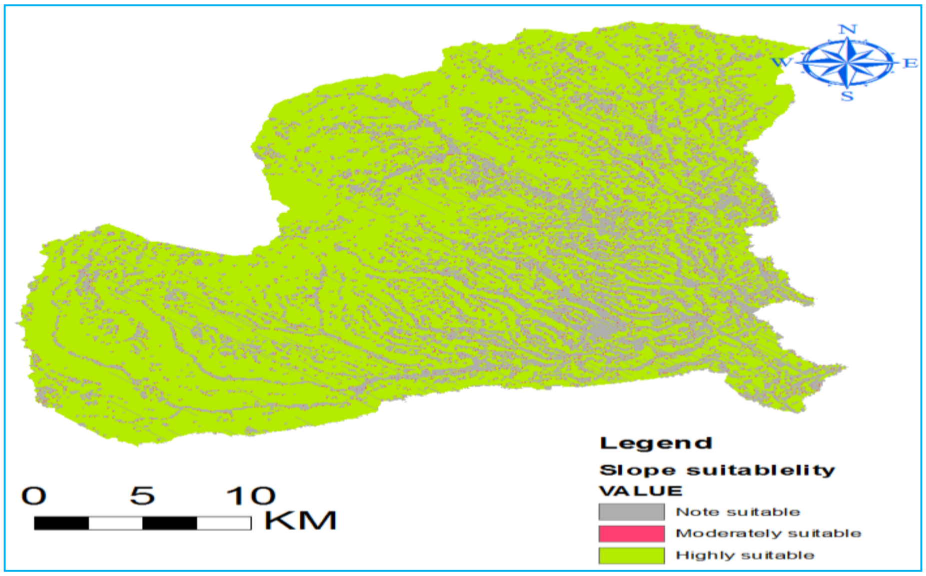


Figure 4. 9: Slope suitability map

Table 4. 1 The Study area slope suitability array

S/No	slope class	Area(Hectare)	Percentage (%)	Suitability
1	0-2	9654	38.3	S1
2	2-5	50973	35.2	S2
3	5-8	83745	13.3	S3
4	>8	896199	13.2	N

Weighted suitability of Map

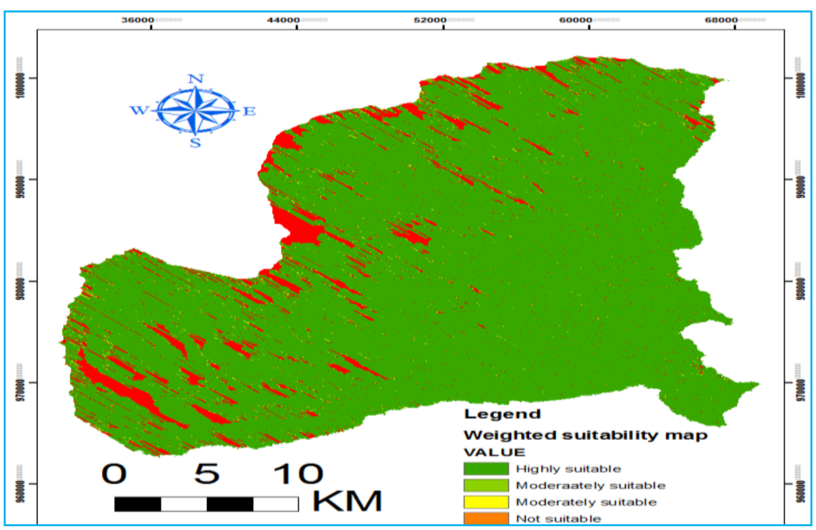


Figure 4. 10: Weighted suitability Map

Tabulated results indicated that the total slope wise area of the catchment in the scope of highly suitable for marginally suitable for surface irrigation practices is 550,876.3ha (86.8% of the total area) and 84,013.7ha (13.2% of the total area) is left over in surface irrigation. Accordingly, most of the study area, slope nature is suitable for practicing surface irrigation.

Table 4.2: Main and sub catchments percentage coverage as per slope classes estimated area partakes slope class out of total

Catchment	Total area(ha)	0-2(%)	2-5(%)	5-8(%)	>8(%)
Keto	1043932	8477.3	49862	85252.6	898180.1
Kuni	14660	5614.7	5158.0	1947.4	1939.9
Total percentages (%)		38.3	35.2	13.3	13.2

4.6. Irrigation potential of the Catchment

By comparing irrigation requirements of identifying land suitable for surface irrigation and the available mean monthly flows of the river catchments, FAO (1997). Imply as the possibility that irrigation potential of particular field could be attained. Accordingly, this study substantiates the two commonly growing crops in and around the study area, namely, Maize and Potato compute their gross irrigation requirement and available mean monthly flows of representative river catchments as tabulated below.

The outcome of these analyses exposes that monthly Gross irrigation requirements of both Potato and Maize are less than the available mean monthly flows, Keto (at Dembi dollo), Kuni (at Ayira). According to MoWE (2002), since the monthly flows are far more-greater than the irrigation demand of both crops, the identified potential irrigable land was admitted as their irrigation potential without considering low flow. Consequently, the irrigation potential of the study area considering rivers watershed are as in table 4.2.

Hence, the total irrigation potential of Keto basin (the study area) is ascertained to be **99123.26ha** which constitutes 60% of the total catchment area. However, the total surface irrigation potential considering water resource potential (95% low flows) is 0.014 ha which represents 2% and 1.25% of total irrigable land and total catchment area respectively.

Table 4.3. Study area potential irrigable land and name of the river irrigabe land (Hectere)

Name of the River	Irrigable land(ha)
Keto	92842.86
Kuni	6280.4
Total	99123.26

As projected by FAO (1997), to get potential irrigable area for the study area, comparison of the gross irrigation requirement and available 95% low flow of the identified surface irrigation potential area was gone through for most widely growing crops of the study area (Maize and potato). The outcome of the analysis indicated that monthly gross irrigation requirement of both

Table 4.4: Comparition of availiable low flow with gross irrigation requirement of Maize crop

River	**Potential area (ha)**	**Area with 95%**	**95% exceedence low flow and growth irrigation requirements(M3/sec) in case of Maize crop**												
			Low flow and Gross irrigation	J	F	M	A	M	J	J	A	S	O	N	D
Keto	77599.1	0.014	Available 95% low flow(M3/s)	0.7	0	0.2	0.5	1.6	28	53	80	39	25	7.1	3.7
			Gross irrigation requirement(M3/s)	39	35	14	0.0	0.	0.0	0	0	0	0.8	1.6	19
Kuni	6280.4	0.03	Available 95% low	0.1	0.0	0.0	0.0	0.40	0.0	3.7	21	0.0	1.4	0.0	0.3
			flow(M3/s)Gross irrigation requirement(M3/s)	3.1	2.8	1.1	0.0	0.00	0.0	0.0	0.0	0.0	0.1	0.13	1.6

Table 4. 5: comparison of available low flow with gross irrigation requireiment of potato

River	**Potential area(ha)**	**Area with 95% exceedence**	**95% exceedence low flow and growth irrigation requirement(M3/sec) in case of Potato crop**												
			Low flow and Gross irrigation	J	F	M	A	M	J	J	A	S	O	N	D
Keto	77599.1	0.014	Available 95% low flow(M3/s)	0.7	0	0.2	0.5	1.6	28	53	80	39	25	7.1	3.7
			Gross irrigation requirement(M3/sec)	36	37	14	0.8	0.0	0.0	0.0	0.0	0.0	0.0	3.1	22
Kuni	6280.4	0.03	Available 95% low	0.1	0.0	0.0	0.0	0.4	0.0	3.7	21	0.0	1.4	0.0	0.3
			Gross irrigation requirement(M3/se)	2.9	3.0	1.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.8

4.7. Storage requirement

Depending on the requirements of the crops and potential command area, the storage requirement in Mm^3 (Million-meter cube) was computed considering **20%** of the flow for downstream ecological equilibriums. The continuous rise of the mass curve shows there exists continuous flow, and the slope of the curve at any point indicates the rate of low at that particular time. Also the straight line demand curve indicates a constant rate of demand for both rivers. Analysis of accumulated flow against time MC and accumulated demand against time DC

(Demand curve) were conducted for the study area's rivers as found in table 4.6. Therefore, it was concluded from the figure 4.12 that both Keto river and Kuni has flow throughout the period of time having constant demand.

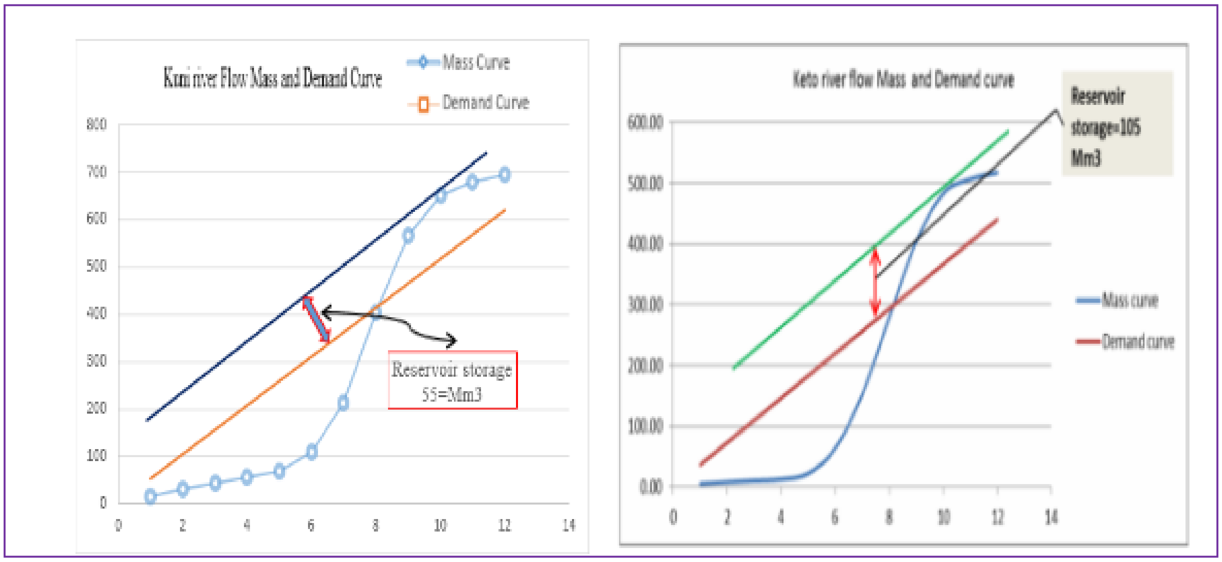


Figure 4. 11: Both Demand and mass curve of Keto and Kuni rivers

Table 4. 6. Storage requirement with 95% exceedance low flow

River	Potential area(ha)	95% exceedance	Area by 95%	Storage requirement (Mm3)
Keto	92842.86	20.0	0.014	105
Kuni	6280.4	2.3	0.032	55

4.7.1. Annual Sensitvity Analysis

Sensitivity analysis for stream flow at the gauging point for the period of 31 years which contains both calibration and set up periods has been shown that 27 parameters are considered in the analysis. These parameters with 10 intervals of sampling (totally 270 iterations) were used for sensitivity analysis and only 6 of them showed meaningful effect on the monthly flow simulation of the study area. As shown in Table 4.22, the first Six parameters indicate a relative sensitivity, being the Initial SCS CN2 value, Soil evaporation compensation factor (Esco) and Threshold Water Depth in the shallow aquifer for flow(Gwqmn) are high sensitive. Hence, the most sensitive parameters controlling stream flow in the basin are Initial SCS CN2 value), Soil evaporation compensation factor(Esco) and Threshold Water Depth in the shallow aquifer for flow (Gwqmn).

Observations Standard Deviation Ratio (RSR). RSR is calculated as the ratio of the root mean square error and standard deviation of measured data, as shown in the following equation.

$$RSR = \frac{RMSE}{STDEVobs} = \left[\frac{\sqrt{\sum_{t=1}^{n}(Y_t^{obs} - Y_t^{simu})^2}}{\sqrt{\sum_{t=1}^{n}(Y_t^{obs} - Y^{mean})^2}} \right] \ldots\ldots (20)$$

Where

$\boldsymbol{STDEVobs}$ is standard deviation of observed data of the constituent being evaluated,

$\boldsymbol{Y_t^{sim}}$ is the $\boldsymbol{i^{th}}$ simulated value for the constituent being evaluated,

$\boldsymbol{Y_t^{obs}}$ is the $\boldsymbol{i^{th}}$ observation for the constituent being evaluated

$\boldsymbol{Y^{mean}}$ is the mean of observed data for the constituent being evaluated,

$\boldsymbol{n}$ is the total number of observation,

RSR varies from the optimal value of 0, which indicates zero RMSE or residual variation and therefore perfect model simulation, to a large positive value

Nash-Sutcliffe Efficiency (NSE): The Nash-Sutcliffe Efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information"). NSE Indicates how well the plot of observed versus simulated data fits the 1:1 line. NSE is computed as shown in the following

$$NSE = 1 - RSM = 1 - \left[\frac{\sqrt{\sum_{t=1}^{n}(Y_t^{obs} - Y_t^{simu})^2}}{\sqrt{\sum_{t=1}^{n}(Y_t^{obs} - Y^{mean})^2}} \right] \ldots\ldots (21)$$

NSE Ranges between $-\infty$ and 1.0 (1 inclusive), with NSE =1being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance. Percent bias ($PBIAS$): Percent bias ($PBIAS$) measures the average tendency of the simulated data to be larger or smaller than their observed counterparts. The optimal value of $PBIAS$ is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias. $PBIAS$ is calculated with the following equation,

$$PBIAS = \left[\frac{\sqrt{\sum_{t=1}^{n}(Y_t^{obs} - Y_t^{simu}) * (100)}}{\sqrt{\sum_{t=1}^{n}(Y_t^{obs})}} \right] \ldots\ldots (22)$$

Where,

PBIAS is the deviation of data being evaluated, expressed as proportionCoefficient of Determination (R^2) . R^2 Is the index of correlation of measured and simulated R^2values, has been used to evaluate the accuracy of the overall model calibration and validation.

$$R^2 = \left[\frac{\sum_{t=1}^{n}(Y^{obs} - Y^{obs\,mean})(Y^{simu} - Y^{simu\,mean})}{(\sum_{t=1}^{n}(Y^{obs} - Y^{obs\,mean})^2 * (\sum_{t=1}^{n}(Y^{simu} - Y^{simu})^2}\right]^2 \ldots\ldots\ldots\ldots\ldots (23)$$

The value of R^2 ranges between 0 and 1. The more the value of approaches 1, the better is the performance of the model and the values of less than 0.5 indicates poor performance of the model *(Lenahart et al., 2002)*.

Table 4.3: adjusted parameter values of the flow calibiration and adjusted parameter values of the flow calibration

Rank	Parameter	Discription	Lower bound	Upper bound	Fitted value	Category of sensitivity
1	Cn2	Initial SCS CN2 value	35	98	40.229	High
2	Gwqmn	Threshold water Depth in the shallow aquifer for flow	0	5000	2565	High
3	Esco	Soilevaporation compensation factor	0	1	0.461	High
4	Soil_Awc	Soil available water capacity(mm WATER/mmsoil	0	1	0.661	Medium
5	Sol_Z	The total soil Depth(mm)	0	3000	2715	Low
6	Gw_Revap	Groundwater revap coefficient	30	450	160.62	Low

4.8. Flow Calibration

SWAT simulation by the default value of parameters at the gauging stations has shown a weak hydrograph in matching the simulated and observed stream flows of SWAT2009 model. In computing the efficiency, both the first and the second years of simulated model result was excluded, because it is a warm period, which means the influence of the initial conditions such as soil water content will be minimized. Afterwards manual Swat-cup (sufi-2) calibration for average annual and monthly water balance and stream flow was done. Once the model is calibrated for average annual conditions it can be repeated for monthly basis. As shown in Figure 4.13 the calibration results have been indicated that there is a good agreement between the observed and simulated monthly flow relationships. In this study the validation was carried out four years from January 1st 1994 to December 31st 1998. This is demonstrated by objective functions; the correlation coefficient ($R^2 = 0.89$) and the Nash_Sutclife (1970) efficiency

(NSE= 0.82)

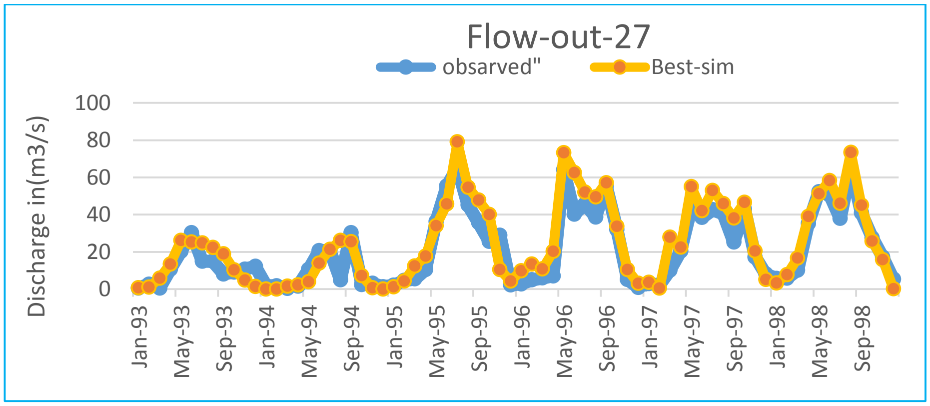


Figure 4. 12: Calibration results of average Monthly Simulated and gauged flows at the outlet of Upper Keto River Catchment.

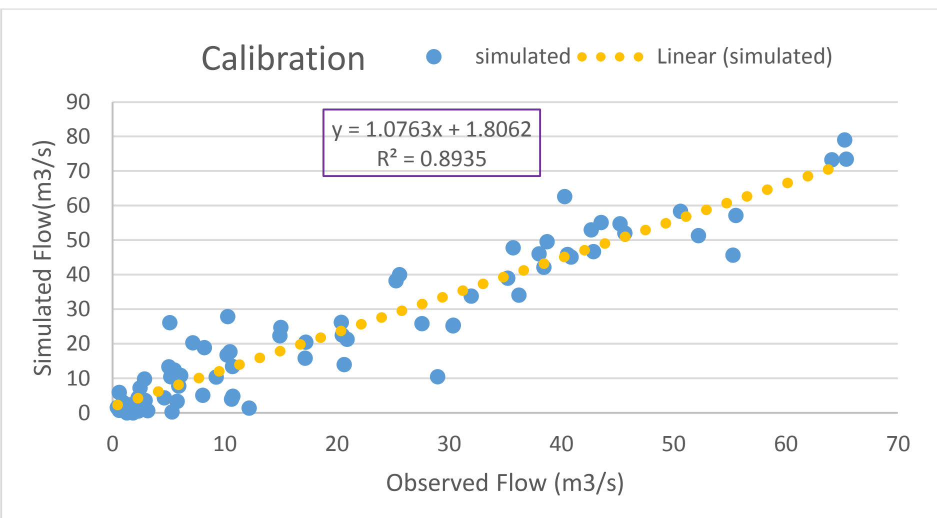


Figure 4. 13: Scatter Plots of monthly simulated and gauged flows at the outlet gauged area

4.9. Flow Validation

The purpose of model validation is to cheek weather the model can predict flow for another range of time period or conditions than those for which the model calibrated for. Model validation involves re-running the model using input data independent of data used in calibration, differing time period, but keeping the calibrated parameters unchanged. In this study the validation was carried out four years from January 1st 1999 to December 31st 2003. The correlation coefficient during validation period was (R^2=0.89) and the Nash-Sutclife (1970) simulation coefficient (NSE=0.82). Therefore, the validation period shows a good agreement between the simulated and gauged flow of the outlet of the gauged area.

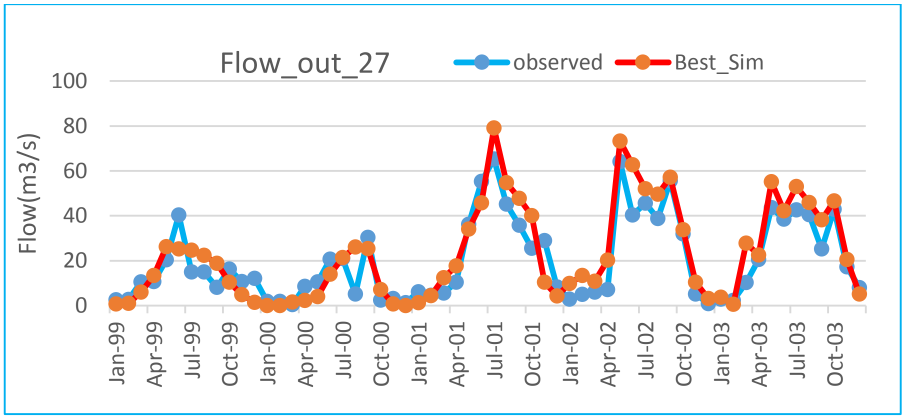


Figure 4. 14: Validation results of average Monthly Simulated and gauged flows at the outlet of Upper keto

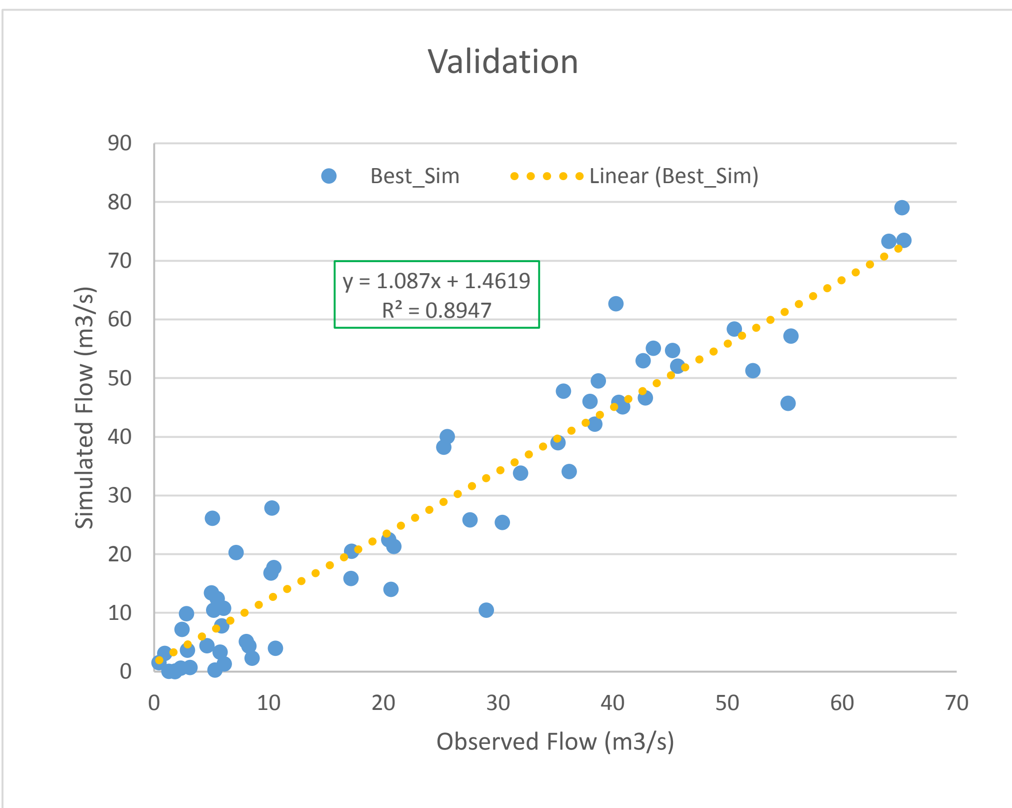


Figure 4. 15: Scatter Plots of monthly Validation and gauged flows at the outlet gauged

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

In general speaking, the assortment of the study lies in the surface irrigation suitability analysis, considering available land resources which service (slope, soil and LULC), available water resource and estimation of crop water demand for most dominantly growing crops of the studyarea. The potential irrigable land of the Keto basin was analyzed considering three topographic parameters viz. Slope, Land use/Cover, and Soil. These three potential suitability parameters of the watershed were examined within the Arc GIS and Arc swat interface being raster map and their cognitive contents have reclassified as per surface irrigation requirement. Consequently, 73.5% of the total area have got slope 0-8%, 97.8% of soil, which comprises Dystric Nitosol, Dystric gleysol and Orthic acrisols and 79% of Land use/cover was calculated for all identified rivers irrigable land and weighted overlay analysis of three factors resulted the total potential irrigable land to be *99123.26ha (*60%)of the total catchment area. Though, the total surface irrigation potential of the river catchment considering rivers low flow (95% flow exceedence) was 0.014 ha, which accounts 2% of the irrigable land.

Stream flow hydrological analysis was carried out for each rivers flow. The flow duration curve was conducted on excel spread sheet in order to estimate 80%, 85%, 90%, 95% and 100% percentage low flow exceedence. Also flood frequency analysis was dealt and predicted expected flood once in 25 and 100 years. Product of analysis proves that there are sufficiently water resources in the Keto basin. Mean monthly flows of rivers took part in the study was compared with gross irrigation requirement of identified irrigable area of the catchments and yields 92842.86, 6280.4ha for Keto and Kuni, rivers respectively However, results of low flow compared with gross irrigation requirement indicated that there exist 0.014ha. Therefore, analysis of low flow revealed that there should existed storage requirement to satisfy selected crops and potential irrigable land. A SWAT hydrological model simulation has shown that the model is able to simulate the observed stream flow in the basin reasonably. This was proved during Calibration and Validation period of the model performance criterion such as coefficient of determination and validation period of the model performance criterion such as R^2 and NSE used to evaluate the model are in the range of 0.8935 to 0.8947 in both calibration and validation period. Stream flow model efficiency by coefficient of determination and Nash-Sutcliffe was 0.82 and 0.821 for calibration respectively. This shows that the SWAT model simulates well or good agreement for stream flow in Keto River catchment.

5.2. Recommendations

1) The surface irrigation potential was carried out in this research by considering Soil, Slope and Land cover/use factors. On the other hand, the effect of other factors such as environmental, economical and social terms should be assessed to get reliable result.
2) As far as the study is limited to analysis of surface irrigation potential analysis depending only on, further detail factors of suitability indicators would better be represented to validate available irrigable land.
3) The available water resource potential was computed from hydrological data. However, it does not typify the real site. Therefore, it is encouraged to analyze with data relating to the productive result.
4) Also, it is recommended to generate up-to-date hydrological model specifically for the study area so that relevant information on the site to do with both hydrology and meteorological data series maintained.
5) For most precise result, application of remote sensing and others most recent technologies is necessary to interpret the spatial data.
6) Soil suitability evaluation of the study area was carried out by using secondary data, previous FAO laboratory results. Since ecology of our country was becoming a dynamic due to environmental changes, the result may not exactly constitute the site.
7) Hence, it is recommended to analyze soil both physical and chemical properties so that possible suitability for particular crop development could occur.

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APPENDICES

*Appendix 1*Soil suitability evaluation for study areas most dominantly growing crops

M/U Rfv6
Soil Dystric gleysols
Crop Maize

S/No	**Land quality**	**Land characteristics**	**Unit**		**Range of Suitability**	
				S1	S2	N
				Highly suitable	Moderate to marginal	Not suitable
1	Temperature	Altitude	m	S1		
		Mean Temperature for growing period	oC	S1		
		Possible occurrence of frost hazard	Month	S1		
2	Growing period	Length of growing period	Day	S1		
3	Moisture availability	Rainfall during growing period	Mm		S2	
4	Drainage	Soil drainage	Class	S1		
5	Degradation hazard	Length of growing period	Day	S1		
		Soil unit	FAO unit	S1		
		Soil texture	Class	S1		
		Stones and rock outcrops	%			N
		Slope angle	%			N
6	Nutrient status and retention	Soil texture	Class	S1		
		Soil reaction	PH		S2	
		Organic matter	%	NA	NA	NA
		Effective soil depth	Cm	S1		
7	Rooting condition and workability	Stones and rock outcrops	%	S1		
		Soil texture	Class	S1	S2	
		Soil structure	Class	NA	NA	NA
8	Toxicities	Electrical conductivities	mmhos/cm	NA	NA	NA
		Other limiting	ESP%	NA	NA	NA
		toxicities	Caco3%	NA	NA	NA
9	Management land preparation and mechanization potential	Slope angle	%	S1		
		Stones and rock outcrops	%	S1		
		Soil texture	Class	S1		

M/U AK
Soil Orthic solonchaks
Crop Maize

S/No	Land quality	Land characteristics	Unit		Range of Suitability	
				S1	S2	N
				Highly suitable	Moderate to marginal	Not suitable
1	Temperature	Altitude	m	S1		
		Mean Temperature for growing period	ºC	S1		
		Possible occurrence of frost hazard	Month	S1		
2	Growing period	Length of growing period	Day	S1		
3	Moisture availability	Rainfall during growing period	Mm		S2	
4	Drainage	Soil drainage	Class	S1		
5	Degradation hazard	Length of growing period	Day	S1		
		Soil unit	FAO unit		S2	
		Soil texture	Class		S2	
		Stones and rock outcrops	%	S1		
		Slope angle	%	S1		
6	Nutrient status and retention	Soil texture	Class		S2	
		Soil reaction	PH		S2	
		Organic matter	%	NA	NA	NA
7	Rooting condition and workability	Effective soil depth	Cm	S2		
		Stones and rock outcrops	%	S1		
		Soil texture	Class	S1		
		Soil structure	Class	NA	NA	NA
8	Toxicities	Electrical conductivities	mmhos/cm	NA	NA	NA
		Other limiting	ESP%	NA	NA	NA
		toxicities	Caco3%	NA	NA	NA
9	Management land preparation and mechanization potential	Slope angle	%	S1		
		Stones and rock outcrops	%	S1		
		Soil texture	Class		S2	

M/U Rf6v

Soil Dystric nitosols
Crop Potato

S/No	Land quality	Land characteristics	Unit		Range of Suitability	
				S1	S2	N
				Highly suitable	Moderate to marginal	Not suitable
1	Temperature	Altitude	m		S2	
		Mean Temperature for growing period	oC		S2	
		Possible occurrence of frost hazard	Month	NA	NA	NA
2	Growing period	Length of growing period	Day	S1		
3	Moisture availability	Rainfall during growing period	Mm			N
4	Drainage	Soil drainage	Class	S1		
5	Degradation hazard	Length of growing period	Day		S2	
		Soil unit	FAO unit	S1		
		Soil texture	Class	S1		
		Stones and rock outcrops	%	S1		
		Slope angle	%	S1		
6	Nutrient status and retention	Soil texture	Class	S1		
		Soil reaction	PH			N
		Organic matter	%		NA	NA
7	Rooting condition and workability	Effective soil depth	Cm	S1		
		Stones and rock outcrops	%	S1		
		Soil texture	Class	S1		
		Soil structure	Class	NA		
8	Toxicities	Electrical conductivities	mmhos/cm	NA	NA	NA
		Other limiting	ESP%			
		toxicities	Caco3%	NA	NA	NA
9	Management land preparation and mechanization potential	Slope angle	%			N
		Stones and rock outcrops	%	S1		
		Soil texture	Class	S1		

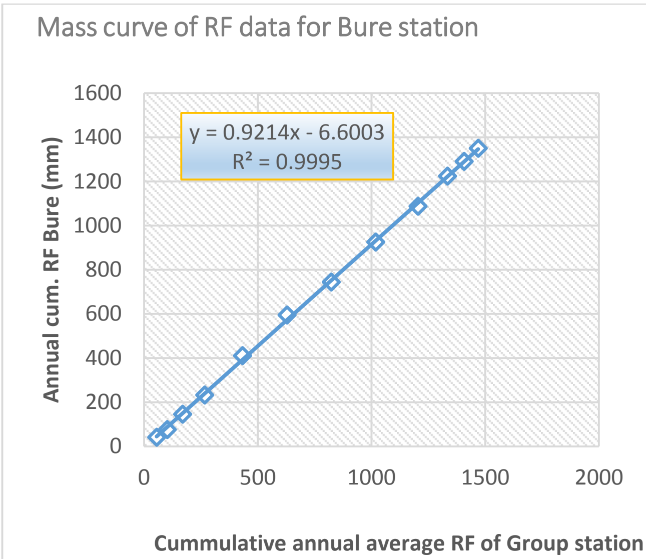
M/U Rfv6

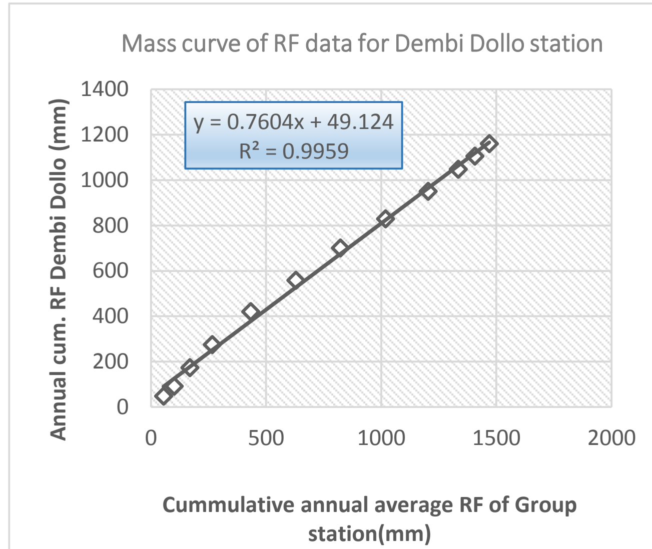
Soil Dystric gleysols
Crop Potato

S/No	**Land quality**	**Land characteristics**	**Unit**	**Range of Suitability**		
				S1 Highly suitable	S2 Moderate to marginal	N Not suitable
1	Temperature	Altitude	m		S2	
		Mean Temperature for growing period	ºC		S2	
		Possible occurrence of frost hazard	Month	NA	NA	NA
2	Growing period	Length of growing period	Day	S1		
3	Moisture availability	Rainfall during growing period	Mm			N
4	Drainage	Soil drainage	Class	S1		
5	Degradation hazard	Length of growing period	Day		S2	
		Soil unit	FAO unit	S1		
		Soil texture	Class	S1		
		Stones and rock outcrops	%	S1		
		Slope angle	%	S1		
6	Nutrient status and retention	Soil texture	Class	S1		
		Soil reaction	PH			N
		Organic matter	%		NA	NA
7	Rooting condition and workability	Effective soil depth	Cm	S1		
		Stones and rock outcrops	%	S1		
		Soil texture	Class	S1		
		Soil structure	Class	NA		
8	Toxicities	Electrical conductivities	mmhos/cm	NA		
		Other limiting	ESP%	NA	NA	NA
		toxicities	Caco3%	NA	NA	NA

Appendix 2 Double mass curve Analysis

Double mass curve analysis of Rainfall data





Appendix 3 Climatic data and estimated ETo values for study area's Climatic stations.

Climatic data and estimated ETo values for study area's Climatic stations and crop irrigation requirements.

Monthly ETo Penman-Monteith - untitled

Country ETHIOPIA Station BURE

Altitude 1750 m. Latitude 8.23 °N Longitude 35.10 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	15.7	26.0	67	89	6.7	17.6	3.51
February	16.0	26.4	65	90	6.6	18.7	3.80
March	16.1	26.5	66	81	6.6	19.6	3.98
April	16.1	26.0	69	71	6.6	19.7	3.94
May	15.7	25.3	71	70	6.6	19.1	3.77
June	15.3	24.4	72	70	6.5	18.6	3.59
July	15.3	24.2	74	70	6.4	18.6	3.57
August	15.3	24.2	74	67	6.6	19.3	3.67
September	15.3	24.7	73	69	6.7	19.5	3.74
October	15.1	24.6	72	73	6.6	18.7	3.57
November	15.1	25.4	71	78	6.7	17.8	3.41
December	15.3	26.1	69	83	6.6	17.1	3.35
Average	**15.5**	**25.3**	**70**	**76**	**6.6**	**18.7**	**3.66**

Monthly ETo Penman-Monteith - untitled

Country: ETHIOPIA | Station: AYIRA

Altitude: 1555 m. | Latitude: 9.10 °N | Longitude: 35.55 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	14.3	28.2	65	113	20.0	36.2	6.02
February	15.2	29.7	60	115	21.6	40.7	7.05
March	15.6	29.8	64	117	20.7	41.3	7.41
April	15.5	28.8	69	117	19.7	40.0	7.18
May	15.2	27.1	75	116	19.2	38.2	6.64
June	15.0	25.4	80	110	16.8	33.8	5.74
July	14.9	24.4	81	108	15.9	32.7	5.46
August	14.8	24.5	81	109	18.5	37.4	6.13
September	14.8	24.8	79	111	20.1	40.1	6.51
October	14.5	25.7	75	110	20.0	38.6	6.28
November	14.1	26.7	72	107	18.3	34.1	5.59
December	13.8	28.7	68	108	18.8	33.7	5.65
Average	**14.8**	**27.0**	**72**	**112**	**19.1**	**37.2**	**6.31**

Appendix 4*Irrigation requirements of selective crops, crop scheduling and scheme supply*

CROP WATER REQUIREMENTS

ETo station: BURE — Crop: MAIZE (Grain)

Rain station: BURE — Planting date: 05/07

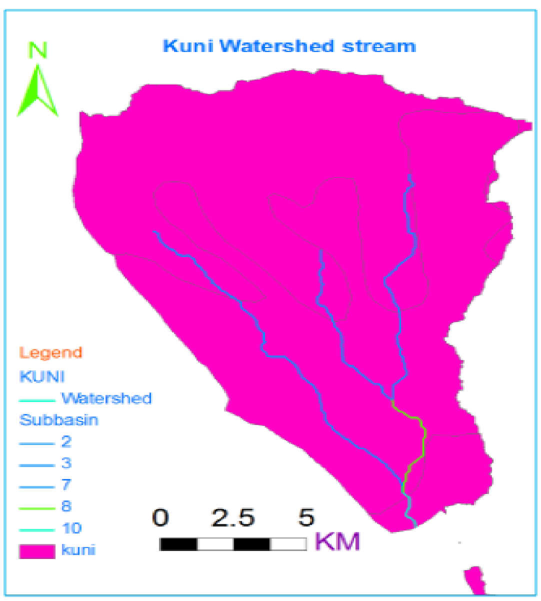
Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jul	1	Init	0.30	1.07	6.4	1.0	5.6
Jul	2	Init	0.30	1.07	10.7	1.6	9.1
Jul	3	Deve	0.36	1.29	14.2	1.7	12.5
Aug	1	Deve	0.59	2.16	21.6	1.8	19.7
Aug	2	Deve	0.83	3.04	30.4	1.9	28.4
Aug	3	Mid	1.06	3.92	43.1	1.9	41.2
Sep	1	Mid	1.12	4.16	41.6	1.9	39.7
Sep	2	Mid	1.12	4.19	41.9	1.8	40.0
Sep	3	Mid	1.12	4.12	41.2	1.7	39.5
Oct	1	Late	1.10	4.00	40.0	1.6	38.4
Oct	2	Late	0.90	3.21	32.1	1.5	30.7
Oct	3	Late	0.63	2.22	24.4	1.2	23.2
Nov	1	Late	0.41	1.43	8.6	0.6	8.1
					356.2	20.3	336.2

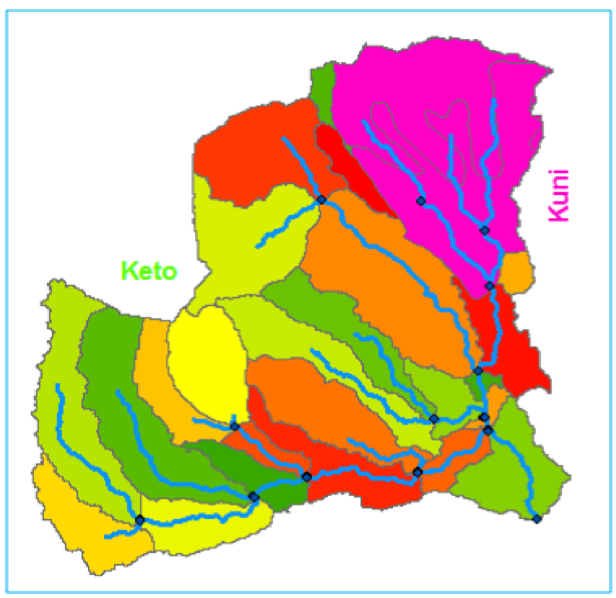
MONTHLY ETO PENMAN-MONTEITH DATA
(File: untitled)

Country: Ethiopia Station: Gore
Altitude: 2033 m. Latitude: 8.15 °N Longitude: 35.53 °E

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m²/day	ETo mm/day
January	14.1	25.4	50	130	7.9	19.4	4.10
February	14.7	26.5	41	138	7.5	20.0	4.59
March	14.9	26.5	49	156	6.7	19.7	4.67
April	14.9	25.7	58	147	7.0	20.3	4.50
May	13.9	23.7	69	147	5.0	16.8	3.65
June	13.1	21.8	78	121	4.5	15.7	3.09
July	13.1	20.9	81	121	4.0	15.0	2.88
August	13.2	21.1	79	112	2.9	13.7	2.75
September	13.1	22.1	76	130	5.0	17.0	3.30
October	13.5	22.9	68	130	6.6	18.8	3.67
November	13.9	23.8	65	121	7.0	18.3	3.61
December	13.9	24.6	61	112	7.8	18.8	3.68
Average	13.9	23.8	65	130	6.0	17.8	3.71

Appendix 5Study Area of Rivers Watershed Map





Kuni and Keto Watershed

*Appendix 6*Summary of Hydrological data Keto River Monthly flow (M^3/s)

Keto River Monthly flow (M^3/s)

YEAR	JAN.	FEB.	MAR.	APR.	MAY.	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	ANNUAL
1985	35.54	35.52	25.74	43.51	55.82	369.58	687.09	907.52	1160.3	324.74	117.33	78.89	7647.62
1986	80.64	114.05	81.22	48.95	13.88	111.49	462.17	927.99	808.09	447.05	74.69	31.16	6322.12
1987	19.72	14.89	18.27	17.31	74.38	217.35	646.29	796.08	847.17	628.47	190.1	70.35	7061.04
1988	44.59	38.57	33.18	40.19	73	497.2	395.22	668.51	725.95	955.44	264.85	86.46	7601.73
1989	43.27	19.63	16.56	14.77	41.34	155.54	572.59	1368.76	772.46	603.14	180.67	81.11	7696.41
1990	41.69	20.97	13.25	11.04	22.4	109.47	339.46	1219.96	1075.41	458.34	156.51	84.46	7064.23
1991	35.16	15.09	12.38	19.38	159.32	291.28	1059.18	1416.49	848.52	333.29	207.85	55.96	8872.64
1992	24.62	14.1	12.84	14.09	51.03	273.86	668.83	2061.57	2101.78	781.83	189.27	69.49	12502
1993	34.44	16.39	13.17	4.59	54.41	489.92	422.72	740.53	759.51	964.3	279.91	90.81	7706.96
1994	45.63	20.03	12.02	12.48	120.72	343.09	551.19	889.75	955.82	230.07	110.73	51.11	6639.65
1995	24.22	11.89	10.87	9.4	26.65	151.12	540.55	869.19	1662.75	476.09	148.15	71.77	7981.08
1996	40.22	20.2	23.82	24.1	110.24	389.01	1150.68	865.21	1059.88	682.09	135	45.55	9051.78
1997	21.39	6.99	6.03	10.81	35.88	403.18	815.3	959.09	649.01	757.21	405.45	173.9	8467.09
1998	101.9	55.89	45.76	24.77	47.95	286.82	642.84	863	1619.17	1423.58	520.71	246.67	11656.22
1999	164.94	105.32	85.98	78.42	391.01	1167.3	1110.23	1226.82	1223.88	1752.93	230.67	14.97	14940
2000	46.48	23.19	14.8	27.75	146.07	549.02	765.68	861.4	790.41	775.8	245.64	105.33	8656.66
2001	55.8	31.24	24.58	23.71	92.23	289.08	646.48	1215.72	1017.76	412.52	162.3	84.87	8056.78
2002	51.75	25.85	21.65	17.79	33.84	161.44	465.59	943.4	750.91	265.82	86.75	7.13	5612.09
2003	24.11	85.22	410.27	600.02	888.04	455.72	136.83	63.8	36.02	21.09	12.64	18.33	5480.07
2004	28.4	136.57	577.87	637.15	916.44	568.29	159.17	81.99	42.03	21.99	25.67	13.97	6390.68
2005	34.69	248.55	450.64	704.03	946.01	401.2	172.63	63.79	35.46	20.92	10.49	6.94	6156.01
2006	63.66	300.8	638.49	950.8	740.39	508.46	308.91	197.27	149.6	123.19	118.37	142.15	8420.52
2007	221.14	462.44	791.05	841.47	594.19	307.82	217.38	182.49	140.51	117.74	121.81	360.98	8496.9
2008	619.36	701.59	857.68	748.04	441.43	268.73	198.56	156.02	124.49	112.42	119.21	122.74	8321.18
2009	285.73	433.35	581.35	592.66	422.03	240.63	176.41	137.3	207.21	477.79	642.32	662.87	9433.57
2010	432.8	243.9	197.7	152.03	119.91	104.34	110.67	182.12	345.19	609.34	738.55	564.57	7169.44
2011	340.66	190	164.65	118.82	94.93	84	91.19	188.19	390.55	683.05	706.03	647.63	7058.74
2012	407.8	255.29	193.14	141.92	114.54	95.26	97.93	269.78	385.17	646.15	829.95	724.51	7915.08
2013	521.3	251.9	147.28	25.17	84.58	163.91	157.17	112.83	39.9	14.19	7.96	1.64	2534.36
2014	1.02	1.06	2.7	36.58	146.46	187	360.08	118.16	71.68	38.43	15.58	1.64	1959.76
2015	1.02	1.06	2.7	36.58	146.46	187	360.08	118.16	71.68	38.43	35.79	30.08	2057.06
MEAN MONTHLY	125.6029032	125.8561	177.0206	194.4623	232.4381	317.0358	467.3903	666.8674	673.17	490.24	228.7403	153.1626	

Kunni River Monthly flow (M^3/s)

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1985	36.44	86.96	55.43	97.73	14.45	2.94	11.27	5.37	2.69	2.81	4.59	22.67	343.35
1986	145.93	301.96	207.66	116.85	30.25	12.08	34.09	80.58	57.68	96.94	22.07	1.06	1107.15
1987	12.54	5.46	3.41	2.32	3.33	18.23	122.46	285.84	205.91	161.61	29.71	15.05	865.87
1988	32.57	65.92	63.75	85.17	43.6	6.8	35.46	95.91	53.47	94.11	7.15	6.78	590.69
1989	8.81	4.3	3.06	2.31	6.21	33.62	174.76	288.87	224.17	79.62	25.8	9.32	860.85
1990	2.08	2.29	1.35	1.53	4.81	18.41	69.78	303.27	225.02	88.62	29.54	13.97	760.67
1991	2.08	2.26	1.33	1.54	5.16	19.03	72.12	321.49	208.96	84.46	28.74	13.47	760.64
1992	2.08	2.29	1.31	1.66	5.47	21	82.09	334.12	193.14	77.88	27.21	12.47	760.72
1993	2.12	2.16	1.31	1.77	5.64	22.16	88.17	336.97	186.93	74.89	26.52	13.65	762.29
1994	22.49	13.89	8.69	5.25	15.17	29.46	47.77	183.83	205.86	42.42	24.19	11.12	610.14
1995	4.68	1.48	0.81	0.61	4.55	75.36	180.45	175.57	445.44	76.49	25.24	12.5	1003.2
1996	6.45	3.22	5.46	2.08	14.52	69.84	249.24	131.64	146.63	188.07	33.2	16.06	866.41
1997	7.97	2.76	0.89	4.24	11.43	102.52	173.51	239.45	131.83	111.03	62.15	22.29	870.07
1998	11.11	4.49	1.67	1.12	6.84	42.88	129.72	270.4	365.11	143.53	52.11	38.43	1067.4
1999	9.82	4.57	2.14	1.27	22.02	96.29	89.09	131.06	132.44	78.4	48.82	23.4	639.32
2000	7.7	3.61	1.78	3.06	22.78	97.86	121.69	124.79	85.01	102.22	45.97	20.72	637.19
2001	12.53	10.04	8.65	5.77	3.7	5.53	77.38	184.19	169.98	61.23	31.91	15.28	586.19
2002	8.79	3.83	2.1	1.14	2.24	19.96	43.11	161.79	115.43	53.57	21.28	11.9	445.14
2003	5.93	2.64	1.82	0.57	2.95	19.7	85.08	114.6	115.15	65.44	22.02	12.35	448.25
2004	6.45	3.01	1.13	1.38	2.57	20.56	99.47	159.79	108.84	74.43	26.22	12.56	516.41
2005	6.32	2.61	2.68	0.49	3.38	45.74	96.62	133.73	120.83	48.48	18.77	9.58	489.23
2006	5.4	2.83	0.73	0.01	16.99	38.45	138.41	252.41	86.54	110.03	28.5	14.24	694.54
2007	6.94	3.97	3.03	2.98	8.23	31.9	60.67	93.87	213.16	66.1	27.56	14.82	533.23
2008	8.99	4.9	3.34	6.15	48.17	72.69	184.31	114.25	166.09	43.56	24.24	14.19	690.88
2009	9.22	5.66	3.73	3.67	4.92	27.82	68.88	89.55	76.68	59.73	22.48	12.76	385.1
2010	7.27	3.19	0.75	0.32	14.26	33.5	89.92	223.22	177.55	70.57	36.79	21.85	679.19
2011	13.75	7.81	6.62	5.65	9.28	36.66	91.11	146.62	108.1	50.02	22.44	12.99	511.05
2012	6.25	1.5	0	8.77	6.06	32	135.24	152.38	110.73	20.47	14.64	6.83	494.87
2013	1.92	0.1	0	0	13.16	38.98	123.06	194.28	95.53	106.97	20.56	9.74	604.3
2014	5.95	0.49	1.5	0.6	16.82	60.06	150.3	295.53	262.4	106.21	51.48	29.06	980.4
2015	5.95	0.49	1.5	0.6	16.82	60.06	150.3	295.53	262.4	106.21	51.48	28.87	980.21
mean monthly	13.75	18.08	12.82	11.82	12.44	39.09	105.66	190.99	163.21	82.13	29.46	15.48	

Corrected Monthly Rainfall at Dembi Dollo (mm)

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1985	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	0	0	0	0	107.2
1986	0	0	0	0	0	0	0	0	0	0	0	0	0
1987	13.4	28.1	78.4	96	186.5	123.7	279.5	167.1	118.8	160.	30	10.5	1292.8
1988	18.9	17.7	44	122.6	318.8	231.2	142.9	169.9	211.7	152.	21.5	7.7	1459.3
1989	0	0	134	72.8	203.9	150.7	147.4	166.3	114.3	136.	39.6	22	1187.6
1990	11.6	16.9	29.7	150.8	242.9	209.3	146.7	269.5	156.7	68.2	52.4	6.2	1360.9
1991	16.9	35.1	35.5	125.3	161.6	190.3	154.3	156.9	153.8	42.9	34.9	22.4	1130.1
1992	27.3	0	99	95.3	250.4	164.0	193.7	143.4	212.9	97.1	38	25.1	1346.2
1993	2.3	46.91	24.4	170.1	195.1	217.2	73.79	182.2	116.1	76.4	57.4	20	1181.9
1994	3.8	12.18	56.6	104.5	126.9	123.8	170.3	168.6	57.18	2.3	9.1	12.2	847.7
1995	12.28	3.9	48.4	84.2	121.8	160.7	125	119.2	154.2	71.6	7.9	0	909.24
1996	9.53	2.2	218.	281.2	213.8	143.5	133.8	209.4	62.2	5.4	11.1	24.9	1316.0
1997	3.1	120.7	98.4	95.3	98.47	95.3	161.2	221.9	194.1	176	21.2	30	1316.1
1998	9.9	11.3	33.8	159.1	187.1	266.4	148.2	112.1	157.4	176.	36.7	22.4	1320.9
1999	0	21.8	47.5	91.2	154.1	159.8	172	205.5	159	106.	40.3	43.9	1201.5
2000	6.3	6.18	53	36.4	39.58	123.1	202.8	144.6	98.1	86.5	29.4	98.4	924.5
2001	98.47	88.94	98.4	95.3	98.47	95.3	98.47	98.47	95.3	98.4	95.3	98.4	1159.4
2002	98.47	88.94	98.4	95.3	98.47	95.3	98.47	98.47	95.3	98.4	95.3	98.4	1159.4
2003	0	29.9	42.6	107.2	165.8	159.8	252.4	197.3	208.5	53.5	34.2	28.1	1279.3
2004	25.8	3.1	27.6	171.8	220.3	158	205.1	208.5	206	27.3	143.	23.7	1421.1
2005	155	167.4	180.	95.3	155	167.4	192	116	117.2	108.	14.2	1.6	1470
2006	24.33	14.8	92	44.7	191.3	188.2	98.47	98.47	95.3	98.4	95.3	98.4	1139.8
2007	23.2	9.8	9.8	0	4.5	9.8	9.8	9.8	9.8	9.8	7.3	4.5	108.1
2008	9.8	9.8	9.8	9.8	9.8	7.3	9.3	9.8	0	4.5	9.8	9.8	99.5
2009	9.8	9.8	9.8	7.3	182.2	113.6	194.4	73.9	72.3	31.8	87.3	207	999.2
2010	268	60.2	8.4	77.6	126.6	294.8	211.6	215.2	136.6	165.	86.4	72.3	1723.6
2011	17.8	125.9	190	316	71.9	7.5	78.5	103.3	330.8	186.	233	116.	1778.8
2012	196.8	59.6	88.6	31.8	85.3	184.4	339.1	95.8	3.2	82.8	57.7	345.	1571
2013	181.8	200.3	175	152.1	103	72.3	60.9	58.6	189.1	320.	136	3.2	1653.4
2014	62.4	35.9	324	185.9	242.9	191.1	116.4	128.3	76.1	308	196	215	2085.1
2015	183.1	115.9	160	66.9	204.5	164.6	201.2	0	164.6	67.6	75.7	9.8	1414.4
mean monthy	48.50	43.76	81.6	101.7	144.3	138.1	142.9	127.8	121.5	97	58.0	54.1	

Appendix 7**Summary of other Climatic data**

Dembi dollo Maximum Temperature

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	mean Annual
1985	24.59	24.59	24.59	24.59	24.59	24.59	24.59	24.6	24.59	24.59	24.59	24.59	24.6
1986	24.59	24.59	24.59	24.59	24.59	24.59	24.59	24.6	24.59	24.59	24.59	24.59	24.6
1987	28	28.81	27.85	26.92	24.7	22.79	22.95	22.9	24.23	24.17	24.6	26.35	25.1
1988	26.87	27.54	28.48	26.97	24	22.46	20.8	20.8	22.17	23.46	23.78	25.37	24.2
1989	26.44	26.93	26.26	25.4	23.23	22.04	21.05	21.4	22.49	23.72	24.12	24.55	23.8
1990	26.11	26.59	27.9	26.98	24.42	22.55	21.37	21.7	22.46	24.03	24.72	25.87	24.4
1991	26.4	28.33	27.34	25.4	24.5	22.37	22	23.5	24.28	24.37	24.32	25.82	24.8
1992	25.24	25.54	26.78	25.82	24.31	22.6	20.83	20.7	22.33	22.43	23.64	24	23.6
1993	24.94	25.05	26.75	24.3	23.94	22.92	21.54	22.2	22.67	23.86	24.82	25.57	24.0
1994	26.36	27.74	28.43	26.76	23.91	22.29	20.81	20.9	22.27	24.59	24.04	25.14	24.3
1995	27	26.69	26.19	24.73	24.6	23.64	21.33	22.3	22.68	24.02	24.91	24.68	24.2
1996	24.99	26.03	25.61	25.63	23.14	22.2	21.55	21.3	22.1	23.97	25.39	24.53	23.8
1997	24.29	25.71	25.67	24.14	22.5	21.93	20.62	21.3	22.97	23	22.82	23.97	23.2
1998	25.26	26.96	26.18	27.55	24.32	22.72	20.97	20.5	22.16	22.35	24.13	25.6	24.0
1999	25.59	27.86	28.35	26.88	22.87	22.23	20.36	20.8	22.04	21.67	24.45	24.82	23.9
2000	25.82	27.27	28.43	25.18	24.02	22.16	21.23	20.8	22.33	22.21	23.85	24.69	23.8
2001	25.33	27.31	26.25	26.76	24.39	21.65	21.4	21.4	22.66	23.31	23.86	24.78	24.0
2002	24.5	26.99	26.23	26.41	24.72	21.89	22.17	21.6	22.47	23.4	24.04	23.93	24.0
2003	25.85	25.11	24.59	24.59	24.59	24.59	24.59	24.6	24.59	24.59	24.59	24.59	24.6
2004	24.98	27	27.62	26.28	24.99	21.94	21.24	22.1	22.25	23.85	23.99	24.68	24.2
2005	25.56	28.83	27.66	26.85	24.95	22.38	20.92	22	22.25	22.98	23.92	25.61	24.4
2006	27.1	28.19	27.88	27.69	24.27	24.61	21.81	21.4	21.91	22.96	23.71	23.94	24.4
2007	24.72	25.8	27.63	26.08	24.46	22.81	21.34	21.4	22.53	24.49	24.7	25.54	24.3
2008	25.69	26.64	27.76	24.93	23.61	22.35	20.89	21	22.44	23.72	23.72	24.14	23.8
2009	25.22	25.92	26.52	25.8	25	23.54	21.58	21.5	22.45	23.39	24.48	24.05	24.0
2010	25.82	26.71	27.21	28.32	24.07	22.78	21.03	21.8	21.85	23.68	23.71	23.58	24.1
2011	24.6	27.37	27.05	27.07	24.4	22.36	22.23	21.5	22.54	24.79	24.17	24.65	24.4
2012	26.23	28.52	28.19	27.59	24.92	22.79	25.18	24.6	24.59	24.59	24.59	24.59	25.5
2013	24.59	24.59	13.44	24.59	24.59	13.43	13.04	23	13.02	22.95	24.59	24.59	20.2
2014	25.68	27.65	26.81	25.37	23.69	23.41	21.84	24.5	24.59	33.71	34.37	35.21	27.4
2015	27.02	39.56	39.79	36.17	34.16	33.5	32.48	32.3	33.62	35.21	34.97	29	34.6
mean monthly	25.7	27.2	26.9	26.3	24.5	22.8	21.9	22.4	22.9	24.3	24.9	25.3	

Dembi Dollo Minimum Temperature

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Mean monthly
1985	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.2
1986	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.2
1987	13.07	15.24	14.98	15.22	14.82	14.14	13.82	14.22	13.99	13.52	11.79	11.52	13.9
1988	11.37	13.18	13.51	15.03	14.66	14.13	13.55	13.39	13.86	13.09	11.16	10.36	13.3
1989	9.47	10.31	13.48	13.41	13.85	13.35	13.51	12.99	13.06	12.33	11.77	11.78	12.7
1990	11.17	12.09	12.31	14.03	14.8	13.83	13.27	13.45	13.55	12.22	11.62	10.88	12.9
1991	11.44	12.11	14.45	15.06	14.33	13.46	13.57	13.61	13.48	11.95	11.04	10.56	13.0
1992	11.5	11.54	14.12	14.55	13.53	13.42	13.19	13.65	13.29	13.18	11.35	11.06	13.0
1993	11.32	12.77	14.11	14.6	14.68	14.12	13.47	13.54	13.5	13.56	13.3	12.25	13.6
1994	11.29	11.88	13.03	13.96	14.82	13.84	13.62	13.42	12.63	10.4	11.26	11.18	12.7
1995	11.29	12.11	12.97	14.62	14.85	14.43	13.8	13.53	13.5	12.68	13.16	11.96	13.4
1996	13.15	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.2
1997	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.2
1998	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.2
1999	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.2
2000	12.62	12.75	14.47	14.62	13.24	13.32	12.77	12.55	12.8	12.87	11.77	10.73	12.9
2001	9.24	9.36	13.29	14.33	14.6	13.66	13.18	13.87	13.48	12.92	11.07	10.92	12.8
2002	11.16	12.73	14.2	14.76	14.8	13.82	13.95	13.19	13.79	12.59	12.02	10.85	13.3
2003	10.72	13.05	14.44	14.25	15.32	14.05	13.71	13.79	13.85	12.18	12.18	10.42	13.4
2004	11.69	12.1	14.43	14.97	14.84	13.65	13.13	13.32	13.35	12.53	11.9	11.13	13.2
2005	15.56	14.46	13.81	15.77	14.4	13.87	13.87	13.65	14.23	12.66	10.83	10.55	13.5
2006	14.14	14.79	11.77	12.96	13.59	13.58	14.48	14.31	13.86	13.17	13.16	13.16	13.5
2007	10.35	11.24	13.03	13.82	13.69	13.76	10.84	12.68	14.14	15	14.02	13.42	13.2
2008	13.31	14.17	12.96	14.49	14.56	14.07	14.24	13.55	13.68	12.77	13.25	14.15	13.8
2009	12.92	14.54	14.55	14.08	14.24	13.63	13.61	12.89	13	13.16	13.16	13.16	13.6
2010	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.2
2011	13.31	14.16	13.01	14.44	14.55	14.08	14.24	13.6	13.65	12.89	13.1	14.16	13.8
2012	12.96	14.49	14.55	14.08	14.24	13.63	13.61	12.89	12.73	12.66	12.72	13	13.5
2013	12.73	13.08	13.98	14.05	12.96	14.49	14.08	14.2	13.57	13.66	12.85	12.25	13.6
2014	12.34	9.79	12.77	13.01	13.17	13.16	13.16	11.31	10.07	13.89	14.5	14.02	12.6
2015	13.75	12.7	13.92	14.32	14	13.84	12.51	13.02	12.1	11.81	11.31	8.5	12.6
mean monthly	12.3	12.8	13.6	14.1	14.0	13.7	13.4	13.3	13.3	12.9	12.5	12.1	

Table:-*Summary of other Climatic data*

	Begi station Monthly other climatic data			
Month	Relative Humidity	Wind speed	Sunshine	solar radiation
	(%)	km/day	(hr)	(rad)
Jan	64.6	113.3	20.0	36.2
Feb	59.8	114.8	21.6	40.7
Mar	64.0	116.5	20.7	41.1
Apr	69.3	117.3	19.7	40.0
May	74.9	115.9	19.2	38.2
Jun	79.6	110.2	16.8	33.8
Jul	81.4	108.0	15.9	32.7
Aug	80.9	109.0	18.5	37.4
Sep	78.8	110.7	20.1	40.1
Oct	74.7	110.0	20.0	38.6
Nov	72.3	107.3	18.3	34.1
Dec	68.0	107.5	18.8	33.7

Bure station Monthly other climatic data				
Month	Relative Humidity	Wind speed	Sunshine	solar radiation
	(%)	km/day	(hr)	(rad)
Jan	67	88.8	6.7	17.6
Feb	65	90.3	6.6	18.7
Mar	66	81.0	6.6	19.6
Apr	69	71.0	6.6	19.7
May	71	69.7	6.6	19.1
Jun	72	69.8	6.5	18.6
Jul	74	69.9	6.4	18.6
Aug	74	67.3	6.6	19.3
Sep	73	68.6	6.7	19.5
Oct	72	73.4	6.6	18.7
Nov	71	78.4	6.7	17.5
Dec	69	82.9	6.6	17.1

Table Bure station monthly other climatic data

Gore station Monthly other climatic data				
Month	Relative Humidity	Wind speed	Sunshine	solar radiation
	(%)	km/day	(hr)	(rad)
Jan	50	130	7.9	19.4
Feb	41	138	7.5	20.0
Mar	49	156	6.7	19.7
Apr	58	147	7.0	20.3
May	69	147	5.0	16.8
Jun	78	121	4.5	15.7
Jul	81	121	4.0	15.0
Aug	79	112	2.9	13.7
Sep	76	130	5.0	17.0
Oct	68	130	6.6	18.8
Nov	65	121	7.0	18.3
Dec	61	112	7.8	18.8

	Dembi dollo station Monthly other climatic data			
Month	Relative Humidity	Wind speed	Sunshine	solar radiation
	(%)	(km/day)	(hr)	(rad)
Jan	58	130	8.0	19.5
Feb	57	138	7.7	20.2
Mar	60	156	6.1	18.7
Apr	66	147	7.0	20.3
May	78	121	5.2	17.1
Jun	82	121	4.8	16.1
Jul	83	112	4.2	15.4
Aug	84	130	2.5	13.1
Sep	78	130	5.3	17.4
Oct	75	121	6.6	18.7
Nov	69	112	7.1	18.4
Dec	63	112	8.0	19.0

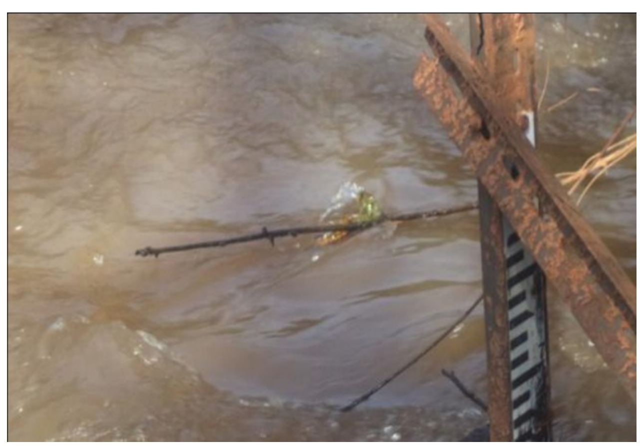
Appendix 8 Soil laboratory result obtained from OARC, Dale Sadi research center

Analytical data sheet for soil physical properties (use as representative of study area soil

Zone	**District**	**Sampled area**	**Soil moisture content**		**Bulk Density (g/cm^3)**	**Particle Size Distribution (soil texture)Bouyouns hydrometrer method**			
			%	Mef		Sand%	Clay%	Silt%	class
Kellem Wollega	Sayo	Tabor	19.589	1.196	0.000	55	22	23	Sandy Clay Loam
Kellem Wollega	Sayo	Meti	14.705	1.197	1.072	49	26	25	Sandy Clay Loam
Kellem Wollega	Hawagelan	Geba Kidame	19.674	1.197	0.000	55	30	15	Sandy Clay Loam
Kellem Wollega	Dale Wabara	Kombo	4.167	1.042	0.000	61	16	23	Sand Loam
Kellem Wollega	Dale Sadi	Research Station	13.766	1.138	0.000	55	16	9	Sand Loam
West Wollega	Guliso	Wera Sayo	9.146	1.091	0.000	53	20	27	Sand Loam

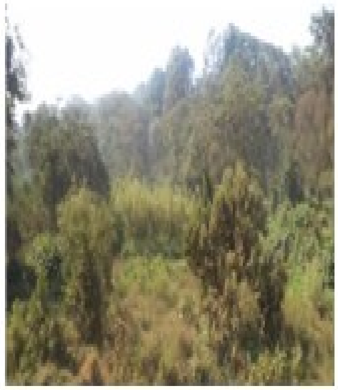
Appendix 9 **Photos Compiled from field visit**

Kuni river gauging staff placement



Kuni river gauging staff

Forest covers around(Kuni)



Forest around Keto (trial)

Irrigated area around Keto (trial)

Irrigated farm around Keto (Trial)

Landscape around Keto (Trial)