SURFACE IRRIGATION POTENTIAL ASSESSMENT OF BONKOKA RIVER CATCHMENT FOR IRRIGATION SCHEME DEVELOPMENT IN DARA WOREDA, SIDAMA ZONE SOUTHERN REGION

MSc THESIS

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HAWASSA, ETHIOPIA

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I hereby certify that I have read this thesis prepared under my supervision and recommend that it could be accepted as fulfilling the thesis requirement.

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DEDICATION

This work is dedicated to my beloved family. It is their love and support that enabled me not only to complete this task but taught me to walk every step of life with confidence and commitment.

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LIST OF ABBREVIATIONS AND ACRONYMS

CU	Consumptive Use
DEM	Digital Elevation Model
DFID	Department for International Development
EST	Exchangeable Sodium percentage
ET	Evapo-transpiration
ETc	Crop Evapo-transpiration
ETo	Reference Evapo-transpiration
FAO	Food and Agriculture organization of the United Nations
GCP	Ground Control Point
GIS	Geographic Information System
GPS	Global Positioning System
IWMI	International Water Management Institute
Kc	Crop Coefficient
L-SiCl	Loam-Silt clay
MAR	Mean Annual Runoff
Mha	Million hectares
MoA	Ministry of Agriculture
Mm	Millimeter
Mmhos/cm	Mill Siemen per centimeter
M^3/s	Meter cube per second

N/A	Not available
NMSA	National Meteorological Service Agency
PAT	Potential Evapo-transpiration
Ra	Extraterrestrial radiation
RS	Remote Sensing
SL	Sandy-Loam
SNNPR	Southern Nation Nationalities Peoples' Region
SRTM	Shuttle Radar Topography Mission
SPOT	Systeme Pour l'Observation de la Terre
SWAT	Soil and Water Assessment Tool
UNESCO	United Nations Scientific and Cultural Organization
UTM	Universal traversal map

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ABSTRACT

Surface irrigation potential assessment is very important for maximizing agricultural production by using surface irrigation method. The objective of this study was to assess surface irrigation potential of Bonkoka river catchment for surface irrigation schemes development in Dara Woreda, Sidama Zone Southern Nation Nationalities Peoples' Regional State. Surface water irrigation potential assessment was undertaken by using ARCGIS10.3 software application, by using soil data, land slope data and land cover or land use data of study area were used in order to identify suitability of river catchment with respect to soil, land slope, land use or land cover and overlay analysis of soil suitability, slope suitability and land use or land cover suitability were undertaken. And also un-gauge Bonkoka River surface water potential discharge were estimated by using runoff coefficient of gauged Kolla river catchment which had similar soil type, land slope and land use or land cover. Water requirement of crops in the study area was estimated by using Cropwat8.0 software application and the Cropwat8.0 software estimates Reference Evapo-transpiration on monthly basis, Crop Evapo-transpiration, Potential Evapo-transpiration, Crop water requirement. Surface irrigation land suitability analysis result with respect to soil show that 100% of soil (covering an area 2,186 ha) are suitable and suitability analysis result with respect to slope 9% of slope in the study area (covering area 198.52 ha) are in the range of highly suitable to marginal suitable for surface irrigation application. Considering suitability analysis result with respect land cover or land use, land covered by agroforestry covering 28% or 606 ha area and 59% cultivated land (covering area 1,300ha) and remaining 13% grass land (covering area 280 ha) are suitable for surface irrigation application. From overlay analysis of suitability of surface irrigation with respect to soil, slope and land cover or land use result show that 31% of Bonkoka catchment (covering area 676ha) is suitable for surface irrigation.

Key words: Irrigation potential, crop water requirement, irrigation requirement, surface water potential and suitable land.

1 INTRODUCTION

1.1 Background

There are two general methods of applying irrigation water. The first method is surface irrigation method. In Surface irrigation method irrigation water is applied above the ground, and surface irrigation is the method generally adopted in all countries in the world. When the water is available at a higher level and water is supplied to lower level (from river diversion area to the command area) by the mere action of gravity. There is a great variety of methods of surface irrigation methods most of which do not merit serious consideration, because they either fail to recognize the natural laws underlying irrigation, or their cost of installation is unaffordable in the current context. The second is sub-surface irrigation methods, the application of irrigation water from below. In sub-surface irrigation methods, water does not wet the soil; the underground water nourishes the plant roots by capillarity. Sub-surface irrigation has the advantage that water so applied is not subject to such direct evaporation from the surface as of necessity accompanies surface irrigation methods (Getaneh, 2011).

According to Widtose (2001), surface irrigation methods are furrow irrigation, flood irrigation, basin irrigation and border irrigation. The choice and adoption of these irrigation methods are depending on the nature of the soil, the contour of the land, the head of the water stream, the quantity of water available and the nature of the crop.

Ethiopia depends on the rain fed agriculture with limited use of irrigation for agricultural production. It is estimated that more than 90% of the food supply in the country comes from low productivity rain fed smallholder agriculture and hence rainfall is the single most important determinant of food supply and the country's economy (Belete, 2006).

The major problem associated with the rainfall-dependent agriculture in the country is the high degree of rainfall variability and unreliability. Due to this variability, crop failures due to dry spells and droughts are frequent. As a consequence, food insecurity often turns into famine with the slightest adverse climatic incident, particularly, affecting the livelihoods of the rural poor (Kebede, 2010).

With declining productivity in rain fed agriculture and with the need to double food production over the next two decades, water has been recognized as the most important factor for the transformation of low productive rain-fed agriculture into most effective and efficient irrigated agriculture (FAO, 1994). It is obvious that the utilization of water resources in irrigated agriculture provide supplementary and full season irrigation to overcome the effects of rainfall variability and unreliability. Hence, the solution for food insecurity could be provided by irrigation development that can lead to security by reducing variation in harvest, as well as intensification of cropping by producing more than one crop per year.

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

Therefore, planning process for surface irrigation has to integrate information about the suitability of the land, water resources availability and water requirements of irrigable areas in time and place (FAO, 1997). Determining the suitability of land for surface irrigation requires thorough evaluation of soil properties and topography (slope) of the land within field (Fasin et al, 2008).

Since this thesis study presents surface irrigation potential assessment of Bonkoka river catchment for irrigation scheme development in Dara Woreda, Sidama Zone, Southern nation nationalities peoples' regional state by assessing irrigation potential of the river, assuring surface water availability and land potentially suitable for irrigation schemes development.

1.2 Statement of the Problem

Despite its importance for the lives of people in the country the surface irrigation potential assessment of Bonkoka river catchment for irrigation development in Dara Woreda, Sidama

Zone, Southern nation nationalities people regional state is poorly understood, like many other Ethiopian river catchment.

According to Irrigation potential studies in Ethiopia that is undertaken by IWMI, 2010 show that it is relatively easy to identify and map large scale irrigation and medium scale irrigation, the information related to small scale irrigation is not readily available because of poor information management and availability of data. There is gap in study to show actual irrigation potential of country. Therefore, there is need to study on Bonkoka River to identify potential irrigable land area for developing surface irrigation in the study area.

1.3. Objectives

1.3.1 Main Objective

- The main objective of this study is to assess surface irrigation potential of Bonkoka river catchment in Dara Woreda, Sidama Zone Southern nation nationalities people regional state.

1.3.2 Specific Objective

- To assess the surface water potential of the river basin in the study area.
- To determine the potential land suitable for surface irrigation.
- To determine the crop water requirement of major irrigable crops in the study area.

1.4 Significance of the Study

The study gives the most important information about the surface water resource potential assessment of Bonkoka river catchment in Dara Woreda, Sidama Zone Southern nation nationalities people regional state for surface irrigation schemes development. So the study enables the utilization of precious water resources to improve communities by planting cash crops, for sustainable food production for local farmers and reduces the effects of famine that is caused by lack of water (drought).

The study address about the identification of surface irrigation potential of Bonkoka river catchment for irrigation schemes development in Dara Woreda, Sidama Zone Southern nation nationalities people regional state. So the study enables to identify available irrigable land in the study area.

It will further serve as bench mark data for any further investigation, as useful material for academic and as an added literature to the existing knowledge.

2. LITERATURE REVIEW

2.1 Irrigation Potential

The explanation of term irrigation potential is not directly defined and expresses a series of assumption about irrigation method, investment capacity, regional or national policies, social and environmental aspects, relationship among countries concerning about sharing of water resources between two or more countries. Even though to search information on land and water resources at the river basin level, knowledge of physical irrigation potential is very important. The area which can be irrigated depends on the physical resources ‘soil and water,’ combined with irrigation water requirements water requirements as determined by the cropping patterns and climate. Therefore, physical irrigation potential represents a combination of information on gross irrigation water requirements, area of soils suitable for irrigation and available water resources by basin (FAO, 1997).

2.2 Irrigation Potential in Ethiopia

The estimates of the irrigation potential of Ethiopia vary from one source of literature to the other that is written by different authors at different time, due to lack of standard or agreed criteria for estimating irrigation potential in the country. The earlier report, for example from the International Water Management Institute which focused on Irrigation Potential in Ethiopia (2010), showed the irrigation potential is 5.3Mha assuming use of existing technologies, including 1.6Mha through rain water harvesting and ground water. There have also been different estimates of the irrigation potential in Ethiopia. According to the Ministry of Agriculture (1986), the total irrigable land in the country measures 2.3 million hectares. A total of 3.7 million ha had been identified as potentially irrigable land by Ministry of Water Resource (2002). Most of these figures are derived by adding up the irrigation potential of the country’s twelve river basins (Silesh et al.., 2007).

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

Table 2.1: Irrigation potential in the river basins of Ethiopia.

			Irrigation potential Respective recent master plan study				Irrigation potential		
Item no	Basin	Catchment area (km2)	Small scale	Medium scale	Large scale	Total	Total drainage area	Irrigable area (ha)	Percent irrigable area of the country
1	Abbay	198,890.7	45,856	130,395	639,330	815,581	201,346	1,001,000	27
2	Tekeze	83,475.94	N/A	N/A	83,368	83,368	90,001	317,000	8.5
3	Baro-Akobo	76,203.12	N/A	N/A	1,019,523	1,019,523	74,102	985,000	26.5
4	Omo-Ghibe	79,000	N/A	10,028	57,900	67,928	78,213	445,000	12
5	Rift valley	52,739	N/A	4,000	45,700	139,300	52,739	139,000	3.7
6	Awash	110,439.3	30,556	24,500	79,065	134,121	112,697	205,000	5.5
7	Genale Dawa	172,133	1,805	28,415	1,044,500	1,074,720	117,042	423,000	11.4
8	Wabishe bele	202,219.5	10,755	55,9501	171,200	237,905	102,697	200,000	5.4
9	Denakil	63,852.97	2,309	45,656	110,811	158,776	74,102		
10	Ogaden	77,121				77,121			
11	Ayisha (Golf of Aden)	2,000				2,000			
	Total	1,118,074.53				3,731,222	982,060	3,715,000	100

Source: IWMI Working paper 123 Water resources and Irrigation development in Ethiopia.

Data compiled from various master plan studies of river basins in Ethiopia. Note that the master plan studies focus mainly on medium and large scale irrigation development, with little on small scale irrigation. Master plan indicate that significant irrigation potential from surface water, the study posits that the methods used to estimate the potential in the master plans underestimate the actual potential (IWMI, 20110).

2.3 Factors Considered for Surface Irrigation Potential Assessment

According to FAO, 1976 in describing surface irrigation potential assessment factors considered Land suitability in its description said that 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 defined uses.

Land evaluation is primarily the analysis of data about the land its soils, climate, vegetation, and etc. In term of realistic alternative for improving the use of that land for irrigation, land suitability analysis, particular attention is given to the physical properties of the soil, to the distance from available water sources and to the terrain conditions in relation to methods of irrigation considered (FAO, 2007). In addition to these factors, land cover/land use types are considered as limiting factors in evaluating suitability of land for irrigation (Hailegebriel, 2007; Meron, 2007).

2.3.1 Soil

The word ‘soil’ has different meanings for different professions. To the agriculturist, soil is the top thin layer of earth within which organic forces are predominant and which is responsible for the support of plant life. To the geologist, soil is the material in the top thin zone within which roots occur. From the point of view of an engineer, soil includes all earth materials organic and inorganic, occurring in the zone overlying the rock crust. It is obvious that during the design, the designer has to make use of the properties of soils, the theories pertaining to the design and his own practical experience to adjust the design to suit field conditions. He has to deal with natural soil deposits which perform the engineering function of supporting the foundation and the superstructure above it (Murthy, 2009). So it is very important identifying the soil type and its suitability for surface irrigation potential assessment of river catchment for irrigation schemes development.

The evaluation of soil qualities to predict the performance for specific crops is an essential part of a land evaluation and land use planning exercise applied to agriculture. According to D.W Thorne, 1949 and H. B. Peterson, 1949 soil suitability for crops should be evaluated by examining soil properties for a given area. Because not all soils can be irrigated due to various physical problems, such as low infiltration rates and poor internal drainage, which may cause salt buildup.

2.3.2 Land Slope

Slope is the incline or gradient of a surface and is commonly expressed as a percent. Slope is important for soil formation and management because of its influence on runoff, drainage, erosion and choice of irrigation types. The slope gradient of the land has great influence on selection of the irrigation methods. According to FAO standard guidelines for the evaluation of slope gradient, slopes which are less than 2%, are very suitable for surface irrigation. But slopes, which are greater than 8%, are not generally recommended (FAO, 1999).

Slope of the land affects the suitability of an area in terms of land preparation for irrigation and irrigation operation.

2.3.3 Surface Water Potential

It is important to make sure that there will be no lack of irrigation water. If water is in short supply during some part of the irrigation season, crop production will suffer, returns will decline and part of the scheme's investment will lay idle (FAO, 2001). Therefore, water supply (water quantity and seasonality) is the important factor to evaluate the land suitability for irrigation according to the volume of water during the period of year which it is available (FAO, 1985). Quantifying the amount of water available for irrigation and determining the exact locations to which water can be economically transported are important in the decision to expand its use. Where possible, the water source preferred to be located above the command area so that the entire field can be irrigated by gravity. It is also desirable that the water source be near the center of the irrigated area to minimize the size of the delivery channels and pipelines. Therefore, distance from water sources to command area, nearness to rivers, is useful to reduce the conveyance system (irrigation canal length) and thereby develop the irrigation system economical (Silesh, 2000).

2.3.4 Land Use or Land Cover

According to Jaruntorn (2004), matching of existing land cover/use with topographic and soil characteristics to evaluate land suitability for irrigation with land suitability classes, present possible lands for new agricultural production. Land cover and land use are often used interchangeably. However, they are actually quite different. Water, ice, bare rock or sand surfaces also count as land cover. However, the definition of land use establishes a direct link between land cover and the actions of people in their environment. Thus, a land use can be defined as a series of activities undertaken to produce one or more goods or services. A given land use may take place on one, or more than one, pieces of land and several land uses may occur on the same piece of land. Definitions of land cover or land use in this way provide a basis for identifying the possible land suitability for irrigation with precise and quantitative economic evaluation (Abraham, 2017).

2.4 Overview of GIS Application

2.4.1 Definition and Concept

A Geographic Information System (GIS) is computer software used for capturing, storing, querying, analyzing, and displaying geographically referenced data (Goodchild, 2000). Geographically referenced data are data that describe both the locations and characteristics of spatial features such as roads, land parcels, and vegetation stands on the Earth's surface. The ability of a GIS to handle and process geographically referenced data distinguishes GIS from other information systems which are the other information system. It also establishes GIS as a technology important to a wide variety of applications. Clearly, the increased availability of large, geographically referenced data sets and improved capabilities for visualization, rapid retrieval, and manipulation inside and outside of GIS will demand new methods of exploratory spatial data analysis that are specifically tailored to this data-rich environment (Wilkinson, 1996; Gahegan, 1999).

Otto Huisman and Rolf (2009) revealed that GIS is a computer based system that provides the following four sets of capabilities to handle geo-referenced data: Those are Data capture and preparation, Data management, including storage and maintenance, Data manipulation and analysis, and Data presentation.

As stated by Johnson (2009), Geographic Information Systems (GIS) have become an increasingly important means for understanding and dealing with the pressing problems of water and related resources management in our world. GIS concepts and technologies help us to collect and organize the data about such problems and understand their spatial relationships. GIS analysis capabilities provide ways for modeling and synthesizing information that contribute to supporting decisions for resource management across a wide range of scales, from local to global. A GIS also provides a means for visualizing resource characteristics, thereby enhancing understanding in support of decision making.

2.4.2 Mapping

The main application in GIS is mapping where things are and editing tasks as well as for map based query and analysis (Campbell, 1984). The map represents geographic information as a collection of layers and other elements in a map view. Common map elements include the data frame containing map layers for a given extent plus a scale bar, north arrow, title, descriptive text, and a symbol legend. GIS mapping can be an effective tool to organize, retrieve, and present spatial data for irrigation districts.

2.4.3 Watershed Delineation

A watershed can be defined as the catchment area or a drainage basin that drains into a common outlet. Simply, watershed of a particular outlet is defined as an area, which collects the rainwater and drains through gullies, to a single outlet. Delineation of a watershed means determining the boundary of the watershed i.e. ridgeline. GIS uses DEMs data as input to delineate watersheds by hydrology tool in Arc GIS spatial analysis (Winchell et al., 2008).

2.4.4 Weighted Overlay Analysis

According to Yang (2003), weighted overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis. Geographic problems often require the analysis of many different factors using GIS. For instance, finding optimal site for irrigation requires weighting of factors such as land cover, slope, soil and surface water availability.

2.4.5 GIS as a Tool for Irrigation Land Potential Assessment

In the past, several studies have been made to assess the irrigation potential and water resources by using GIS tool (FAO, 1987; FAO, 1995; FAO, 1997; Melaku, 2003; Negash, 2004; Hailegebriel, 2007; Meron, 2007; Kebede, 2010and Dagnenet, 2013).

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

In similar way to the FAO (1987) and also FAO (1997) has studied the irrigation potential of Africa taking into consideration the above limitations. It concentrated mainly on quantitative assessment based on physical criteria (land and water), but relied heavily on information collected from the countries. A river basin approach had been used to insure consistency at river and basin level. Geographic Information System (GIS) facilities were extensively used for this purpose. In this study, a physical approach to irrigation potential was understood as setting the global limit for irrigation development.

Melaku (2003) carried out study on assessment of irrigation potential at Raxo dam area (Portugal) for the strategic planning by using Remote Sensing (RS) and Geographic Information System (GIS). This study considered only the amount of available water in dam and topographic factor (slope) in identifying potential irrigable sites in downstream side of the dam.

Negash (2004) conducted a study on irrigation suitability analysis in Ethiopia a case of Abaya-Chamo lake basin. It was a Geographical Information System (GIS) based and had taken into consideration soil, slope, land use and water resource availability in perennial rivers in the basin to identify potential irrigable land.

Hailegebriel (2007) conducted a study on Irrigation potential evaluation and crop suitability analysis using GIS and Remote sensing techniques in Beles sub basin, Beneshangul Gumuz Region. The study considered slope, soil, land cover/use, water resources and climate factors in evaluating surface irrigation suitability.

Meron (2007) carried out similar work on surface irrigation suitability analysis of southern Abay basin by implementing GIS techniques. This study, considered soil, slope and land cover /use factors to find suitable land for irrigation with respect to location of available water resource and to determine the combined influence of these factors for irrigation suitability analysis, weighted overlay analysis was used in Arc GIS.

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

Dagnenet (2013) conducted a study on assessment of irrigation land suitability and development of map for the Fogera catchment using GIS in South Gonder. On the basis of stoniness, soil salinity, soil alkalinity, soil depth and groundwater quality it was concluded that 72 percent of the study area was potentially suitable for irrigation and 28 percent was classified as unsuitable (N) due to drainage limitation, flood hazard, texture and slope factors. Of the potentially suitable land, 1 percent was highly suitable (S1), 28 percent was moderately suitable (S2), and 43 percent is marginally suitable (S3).

2.5 Estimating River Discharge at Un-Gauged Sites from Gauged Sites

An important consideration in water resource assessment is to estimate how much flow is available at the outlet of river catchment. The volume of water reliably available on an annual or seasonal basis can be determined from the available data in case of gauged rivers and for completely un-gauged rivers the runoff coefficient method can be employed (Goldsmith, 2000).

According to DFID (2004), when this is the case, then data from the gauging site should be used to estimate mean annual runoff (MAR) at un-gauged site, provided that the requirements set out below are met.

A, Catchment characteristics should be similar,

B, the distance between the centroids of the catchments should be less than 50 km,

C, at least ten years of mean monthly flows should be available.

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

A, both gauged and un-gauged catchment areas are calculated

B, point rainfall data of stations both in and around gauged and un-gauged catchments are converted to areal or average rainfall over an area of river catchments using Thiessen's polygon method in Arc GIS.

C, both un-gauged and gauged river catchments in terms of their land cover/use, soil type and slope range are compared to determine their similarities.

D, runoff coefficient from the ratio of mean monthly discharge to mean monthly areal rainfall of gauged catchments is determined.

Above steps are followed to estimate monthly average runoff of the un-gauged river catchments from gauged river catchments.

Drainage area weighting is a widely used technique in many cases where limited stream flow monitoring data are available. This method is most valid in situations where watersheds are of similar size, land use, soil types, and experience similar precipitation patterns (Warnick, 1984).

2.6 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 (Michael, 1986).

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 (Bithell and Smith, 2011).

According to Birhanu, 2009 any water resource study and planning without consideration of hydro meteorological data analysis will be futile; as these data are the major sources of information to tell the total amount of water in each of the parts of the hydrologic cycle. The most useful hydro metrological variations are precipitation, evaporation, evapotranspiration, solar radiation (sunshine hours), air temperature, relative humidity, soil moisture, stream discharge and water quality (Raghunth, 1987).

3 MATERIAL AND METHODS

3.1 Description of Study Area

3.1.1 Location

Dara Woreda is located in the southern Nations, Nationalities, and Peoples' Region of Ethiopia, part of Sidama Zone and it bordered on the south by the Gedeo Zone, on either side of it by the West Guji Zone Oromia Region, on the northwest by Aleta Chuko Woreda, on the north by Aleta Wondo Woreda, and on the northeast by Hula Woreda. It has a total area of 250km^2. Geographic coordinate of Bonkoka River catchment is having longitude 714000 to 719000, latitude 436000 to 442000 in UTM (having 38º 03' 47.9'' to 38º 03' 55.45'' Easting, 6º 28' 50.35'' to 6º 29' 8.69'' Northing). It has a total catchment area 2,186 hectare. It is located in Abera Doda Kebele, Shebedesa Kebele, Luya Kebele, Tula Hiricha Kebele and Bemisa Kebele within Dara Woreda.

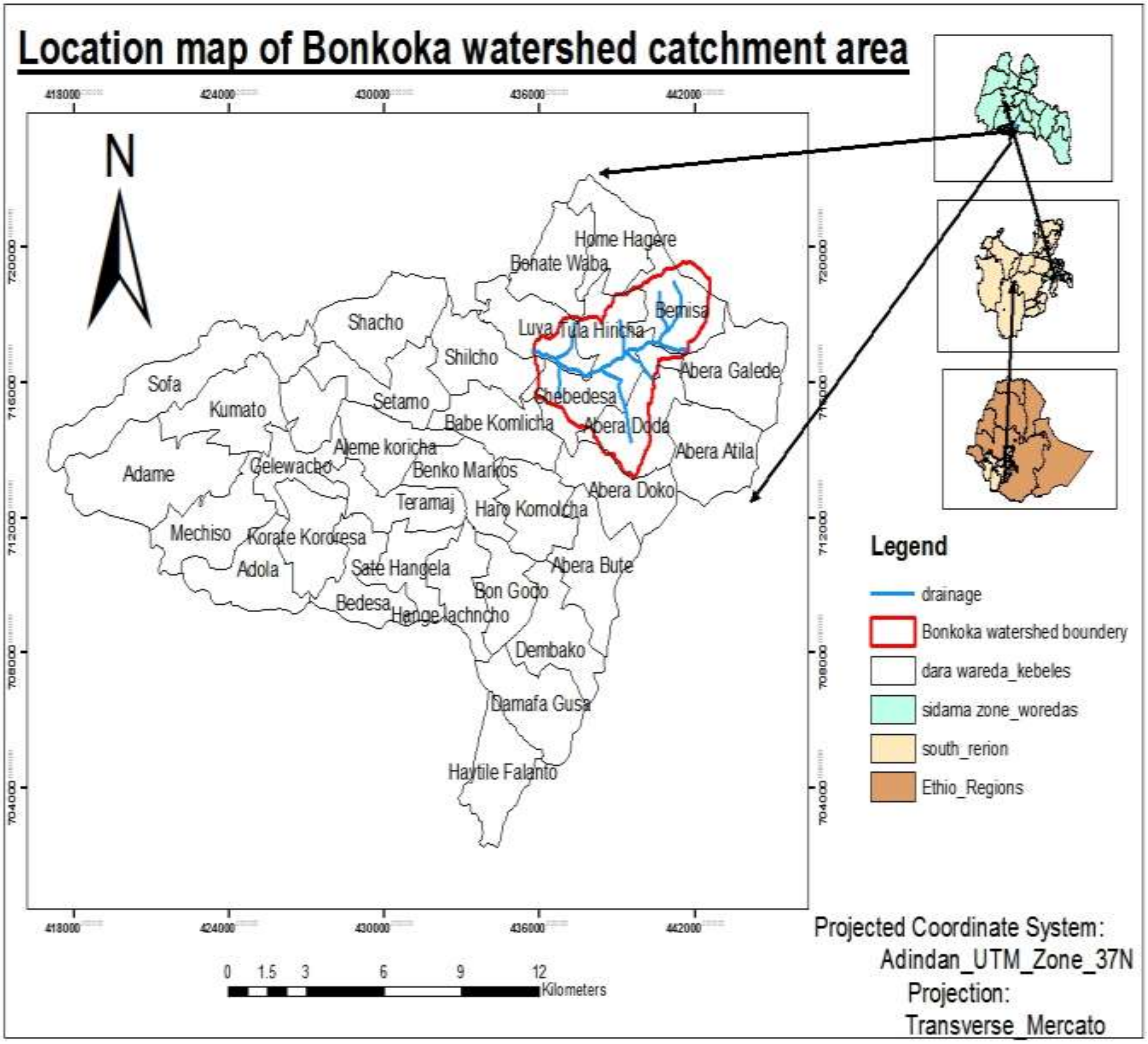

Figure 3.1: Location map of Bonkoka watershed catchment area in Dara Woreda Sidama Zone Southern Nation Nationality peoples Regional State.

3.1.2 Climate

According to Ethiopian National Meteorological Agency Southern Meteorology branch from 2007 to 2017 indicated that meteorological data collected at Bonkoka catchment and near the study area show that Kebado station the annual average maximum and minimum precipitation is 206.3mm and 21.7mm, other climatic data near and around Bonkoka catchment show that annual average maximum and minimum temperature is 31.8 °C and 7.9 °C, annual average maximum and minimum relative humidity is 69.67% and 47.32%, annual average maximum and minimum wind speed is 0.92m/s and 0.33m/s, annual average maximum and minimum Sunshine hour is 8.17 sunshine duration per hour and 3.67 sunshine duration per hour. At Tefer kela meteorological station show that the annual average maximum and minimum precipitation is 259.1mm and 18mm, other climatic data show that annual average maximum and minimum temperature is 26.70 °C and 7.9 °C, annual average maximum and minimum relative humidity is 69.67% and 47.32%, annual average maximum and minimum wind speed is 0.92m/s and 0.33m/s, annual average maximum and minimum Sunshine hour is 8.17 sunshine duration per hour and 3.67 sunshine duration per hour and at Hagereselam meteorological station show that the annual average maximum and minimum precipitation is 265.50mm and 29.5mm, other climatic data show that annual average maximum and minimum temperature is 21.16 °C and 4.29 °C, annual average maximum and minimum relative humidity is 69.67% and 47.32%, annual average maximum and minimum wind speed is 0.92m/s and 0.33m/s, annual average maximum and minimum Sunshine hour is 8.17 sunshine duration per hour and 3.67 sunshine duration per hour.

3.2 Data

The data used to assess the surface irrigation potential of this study area are:

Digital Elevation Model

The digital elevation model was used to show slope map of the Bonkoka river sub catchment and drainage pattern of Bonkoka catchment.

GPS

To collect geographic-coordinate values in (UTM, Latitude-Longitude) was collected at study area. The geographic-coordinate values were used as ground control points to locate river sub catchment for delineation of the Bonkoka River catchment area.

Table 3.1: Summary of table for input data, data source and its use.

Item number	Input data	Source of data	Its Uses
	Meteorological data	National Meteorological Service Agency	To estimate irrigation water requirements of crops like barley, wheat and maize
	Stream flow data	Hydrology department of the inistry of Irrigation, water and Energy	To assess water resources potential of Bonkoka river catchment for surface irrigation potential assessment purposes
	Soil data and land use data	GIS and Remote sensing partment, Ministry of Irrigation, water and Energy	Soil suitability analysis for surface irrigation potential assessment with 30m*30m resolution.
	Digital elevation model (DEM)	GIS and Remote sensing partment, Ministry of Irrigation, water and Energy	To delineate watershed and to derive slope maps of the study area for irrigation suitability analysis with 30m*30m resolution.

River flow data

The gauged river discharge data of Kolla River was collected. The Kolla River discharge data which was recorded at Aleta Wondo gauging station was obtained from Hydrology department of the Ministry of Water, Irrigation and Electric energy Resources. The gauged river discharge data were used to compute discharge of un-gauged Bonkoka River by using run off coefficient method for river catchment having similar catchment characteristics with the Bonkoka river catchment to assess water resources potential for surface irrigation potential assessment.

Meteorological Data

Meteorological data for this study were collected from Hawassa National Meteorological Agency Southern Nation Nationalities Peoples’ Regional State Meteorological service Center.

Meteorological data of rainfall, maximum and minimum temperature, relative humidity, wind speed and sunshine hour from Stations like Hagereselam, Aleta Wondo, Teferi Kella, Kabado and Dilla were collected.

The rainfall, maximum and minimum temperature, relative humidity, wind speed and sunshine hour data were used to estimate monthly reference evapo-transpiration, crop water requirement and irrigation water requirements of crops like maize, barley and wheat which are dominantly cultivated in the study area by using CROPWAT8.0 software application.

Digital Elevation Model (DEM)

Digital Elevation Model data of Ethiopia were used as input data in ArcGIS10.3 to delineate watersheds and to derive slope maps of the Bonkoka river catchment.

3.3 Software

The software used to prepare and analyze data includes ArcGIS10.3 and CROPWAT8.0.

3.3.1 Arcgis10.3 Software

ArcGIS data of soil, digital elevation model and land use or land cover of study area were analyzed to identify soil suitability, slope suitability, land cover or land use suitability and overlay analysis of soil suitability, slope suitability, land cover or land use to determine surface irrigation suitability of study area.

3.3.2 Cropwat8.0 Software

CROPWAT 8.0 is a decision support tool developed by the land and water development division of FAO. 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 scheme water supply for varying crop patterns. All calculation procedures as used in CROPWAT 8.0 are based on the FAO guidelines as laid down in the in the publication No. 56 of the Irrigation and Drainage Series of FAO "Crop Evapo-transpiration Guidelines for computing crop water requirements".

ETo Penman-Monteith can be calculated based on a full set of climatic data ("ETo Penman-Monteith calculated from climatic data"), or based only on temperature data ("ETo Penman-Monteith calculated from temperature data (other data estimated")). In the latter case, CROPWAT 8.0 will estimate the values for the other climatic data (humidity, wind speed, sunshine) based on the temperature data and on altitude/latitude data. In CROPWAT 8.0, air humidity can be expressed as relative humidity or actual vapor pressure. Relative humidity expresses the degree of saturation of the air, as the ratio between the amount of water the ambient air actually holds and the maximum amount it could hold at the same temperature. Relative humidity fluctuates between a maximum near the sunrise and a minimum around early afternoon, in accordance with temperature variations. Relative humidity is expressed as a percentage (%). On the base of climatic data available, CROPWAT estimates the solar radiation reaching soil surface. The extraterrestrial radiation (Ra) represents the radiation received at the top of the earth's atmosphere on a horizontal surface, depending on latitude, date and time of the day. Solar radiation (Rs), computed in CROPWAT calculations, represents the amount of extraterrestrial radiation reaching a horizontal plane on soil surface, that is computing the fraction of extraterrestrial radiation scattered, reflected or absorbed by the atmospheric gases, clouds and dust. Part of the solar radiation is reflected from the soil surface, part is absorbed.

Sunshine represents the duration of the daylight without clouds. Apart from the cloudiness, it depends on the position of the sun and is hence a function of latitude and day of the year. It is expressed as hours of sunshine (hours), as a percentage of daylight (%) or as fraction of daylight (fraction).

In line with agro meteorological standards, CROPWAT 8.0 refers to air temperature measured at 2 meters above the ground. Temperature is given in degree Celsius (°C).

CROPWAT 8.0 can work with minimum and maximum temperatures or with average temperatures if minimum / maximum temperatures are not available. Daily maximum air temperature and daily minimum air temperature are, respectively, the maximum and minimum air temperature observed during the 24-hours period, beginning at midnight. For longer periods, such as decades or months, maximum and minimum temperatures are obtained by dividing the sum of the respective daily values by the number of days in the period. In line with agro meteorological standards, CROPWAT 8.0 refers to wind speed as measured at 2 meters above the ground. Wind speed is slowest at the surface and increases with height.

It is necessary to adjust wind speed data obtained from instruments at elevations other than the standard height of 2 m.

Reference Evapo-transpiration (is calculated using the penman-montheth equation with temperature, wind speed, solar hour and humidity as input) is estimated on the Average monthly values to estimate total irrigation water requirement for Bonkoka catchment surface irrigation potential assessment.

3.4 Filling Missing Rainfall Data

A, Normal Ratio Method

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

$$P_x = \frac{1}{N}\sum\frac{PX}{Pi} * Pg \qquad (3.1)$$

Where:

P_x= missing data,

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

Pi= annual average values of neighboring stations,

Pg= monthly rainfall data in station for the same month of missing station and

N= the total number of gauges under consideration.

In this study missed monthly rainfall data among two or more stations that have annual rainfall more than 10% the above equation 3.3 was used to estimate the missed monthly rainfall data.

B, Station Year Methods

In this method, the records of two or more stations are combined into one long record provided station records are independent and areas in which the stations are located are climatologically the same. The missing record at a station in a particular year may be found by the ratio of averages or by graphical comparison (Raghunath, 2006).

$$Pm = \frac{Pa_1}{Pa_2} * PM \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_}(3.2)$$

Where:

P_m= missing monthly rainfall data at station one,

Pa_1= annual rainfall at station one,

Pa_2= annual rainfall at station two,

PM= monthly average rainfall data at station two.

In this study missed monthly rainfall data among two stations that are climatologically the same the above equation 3.4 was used to estimate the missed monthly rainfall data.

3.4.1 Analysis of Rainfall Correction

Kebado and Tefer Kela stations were climatologically the same. Therefore, missed monthly rainfall at Kebado station in year 2016, February June and July months, in year 2013, October November and December months, in year 2014, October November and December months, in year 2015, December month, in year 2016, December month and with corresponding Tefer Kela station in year 2009, march month, in year 2012, May and September months, in year 2013, March month were corrected by station year method.

3.5 The Mean Rainfall over a Drainage Basin

3.5.1 Arithmetical Mean Method.

This is the simplest method that can be used. It consists of averaging all the amounts that have been recorded at the various stations in the area, as given below:

$$P = \frac{P1 + P2 + P3 + ... + Pn}{n} \qquad (3.3)$$

Where:

P=the mean precipitation on the basin.

P_1, P_2, P_3, P_n are respective precipitation at stations 1, 2, 3 ...n; and n is the total number of stations.

This method yields plausible average arithmetic rainfall values, provided that the rainfall amounts at each station are not different more than 10% relative difference percentage.

3.5.2 Thiessen's Polygon Mean Method

In this method, adjacent stations are joined by straight lines, thus dividing the entire area in to a series of triangles. Perpendicular bisectors are erected on each of these lines, thus forming a series of polygons, each containing one and only one rainfall station. It is assumed that the entire area within any polygon is nearer to the rainfall station that is included in polygon than to any other rainfall station. The rainfall recorded at that station is, therefore, assigned to that polygon. If P is the mean rainfall on the basin, and area of the basin is A. then

$$P = \frac{A_1P_1 + A_2P_2 + A_3P_3 + ... + A_nP_n}{A} \qquad (3.4)$$

Where:

P_1, P_2, P_3,....,P_n represent rainfalls at the respective stations,

Whose surrounding polygons have the areas A_1, A_2, A_3, ...,A_n respectively.

3.6 Mean Areal Rainfall of Bonkoka Watershed Catchment

Mean areal rainfall of Bonkoka watershed catchment, which was used as input data to estimate un-gauged Bonkoka River, was estimated by Thiessen’s polygon mean methods. Figure 3.2 show Thiessen’s polygon maps of Bonkoka watershed catchment.

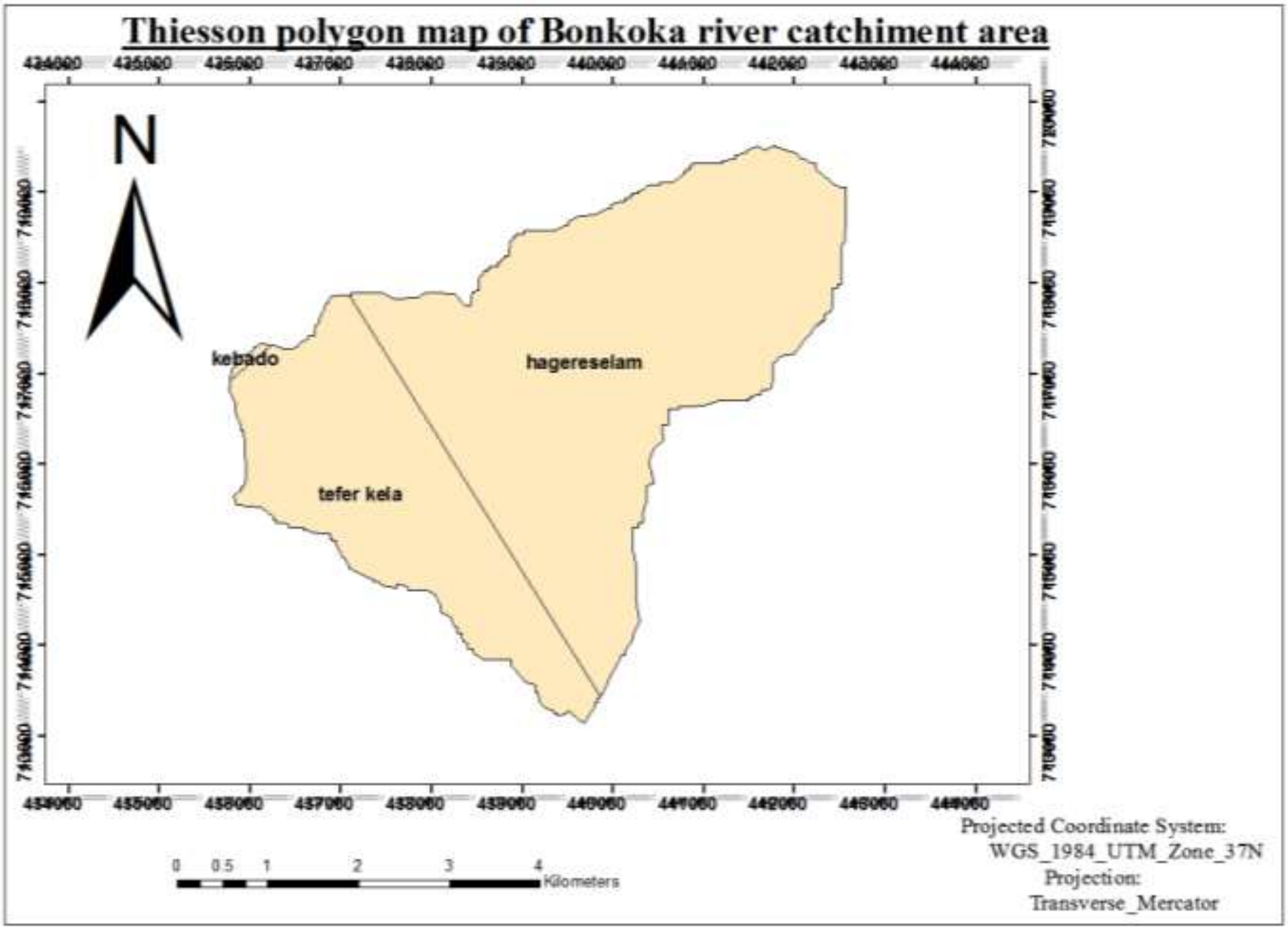

Figure 3.2: Thiessen’s polygon map of Bonkoka river catchment area.

Table 3.2 Shows the rainfall stations, areas within the watershed; rainfall station area fraction and station mean monthly rainfall contribution.

Table 3.2: Thiessen's polygon Average monthly areal rainfall of the Bonkoka catchment.

Station Name	X-Coordinate	y-Coordinate	Station area within catchment (ha)	Station area fraction (%)	Bonkoka Catchment monthly rainfall contribution in (mm)											
					Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hagere selam	447109.4	717195	1458	66.70%	19.8	32.4	51.2	129	179	104	71.07	119.6	105.4	105	58.4	15.5
Teferi Kela	433323.4	708551.98	723	33.07%	5.95	10.4	32.9	74.41	84	45	24.41	33.4	66.24	85.7	40	9.39
Kebado	427139.9	715702	5	0.23%	0.08	0.1	0.24	0.47	0.51	0.25	0.21	0.29	0.42	0.41	0.14	0.09
Total			2,186	100.00%	25.9	42.9	84.4	203.9	263	149	95.69	153.3	172	191	98.5	25

3.7 Watershed Delineation

The watershed delineation process needs a digital elevation model (DEM) with an effective projection. By using digital elevation model (DEM) both ArcGIS10.3 and ARCHYDRO in combination are used to delineate the Bonkoka river catchment by following the drainage boundaries of the sub-basin. By importing Digital Elevation Model data, The Arc Hydro tools were used to derive several data sets that collectively describe the drainage patterns of a catchment. Raster analysis is performed to generate data on flow direction, flow accumulation and watershed delineation.

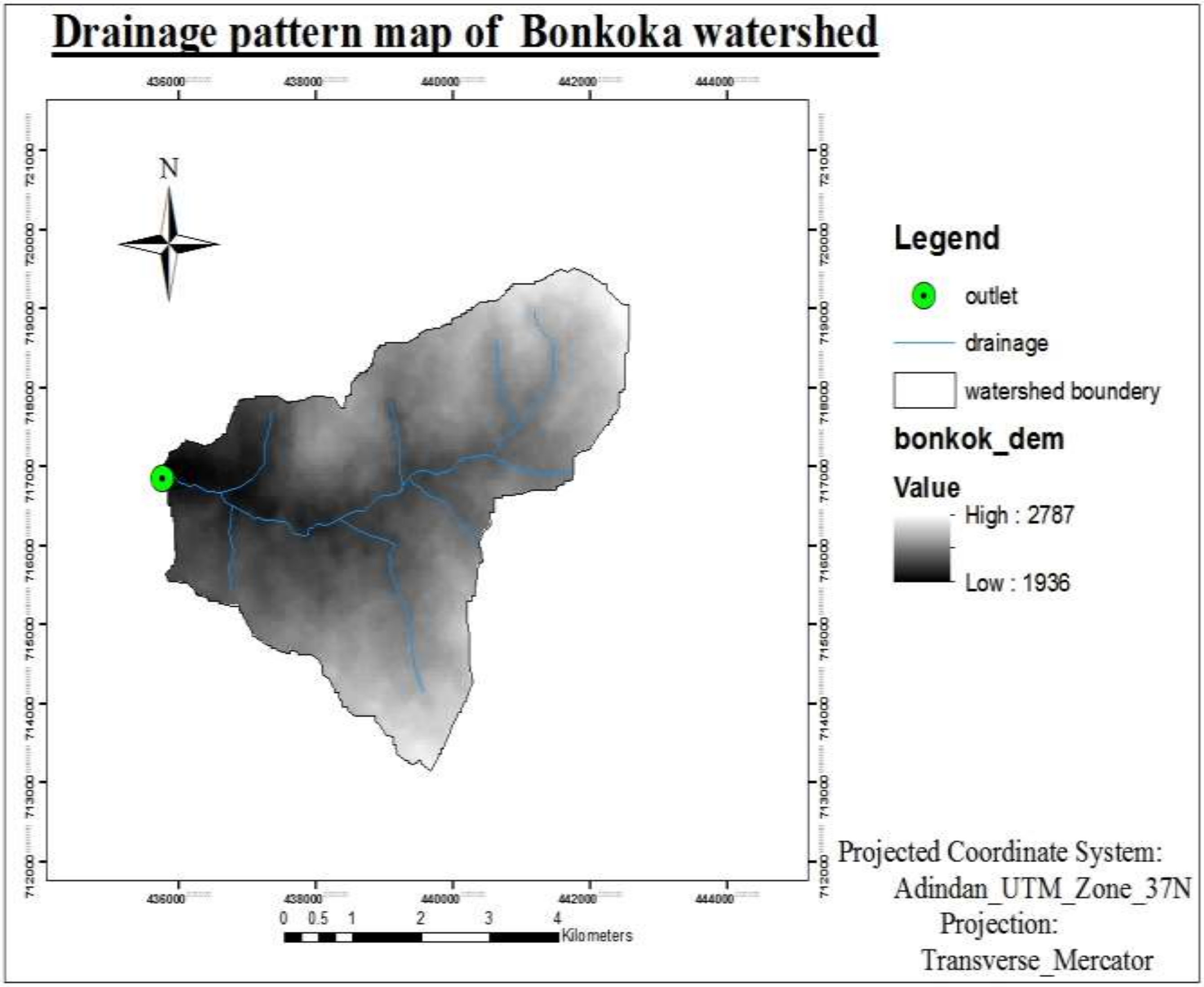

Figure 3.3: Drainage pattern of Bonkoka watershed.

3.8 Identification of Potential Irrigable Area

Suitable sites for irrigation is identified by considering the following factors like slope, soil, land cover/use and the potential command area.

A Slope Suitability

The slope is a major factor affecting irrigation, particularly surface irrigation. The slope map of the study area is derived from SRTM-DEM of 30m special resolution using the spatial analysis-slope tool in ArcGIS10.3. The slope derived from the DEM is classified based on the classification system of FAO (1999) using the reclassification tool in ArcGIS10.3.

The Slope derived from the DEM was classified based on the classification system of FAO (1996) using the “Reclassification” tool, which is an attribute generalization technique in ArcGIS10.3. The four suitability ranges (S1, S2, S3 and N) were classified for surface irrigation as shown in Table 3.3.

Table 3.3: Slope suitability classification for surface irrigation.

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

Source: FAO (1996).

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

B Soil Suitability

To assess soil suitability for irrigation, soil suitability classification of the study area is analyzed through ArcGIS10.3 environment and the result of this soil classification will be used as one input for final irrigable land suitability classification.

The following soil suitability rating was used based on the FAO guidelines for land evaluation (FAO, 1976, 1979, 1990, 1991) and FAO (1997) land and water bulletin.

Table 3.4: Soil suitability factor rating

Factors	Factor rating			
	S1	S2	S3	N
Drainage class	Well	Imperfect	Poor	Very Poor
Soil depth (cm)	>100	80-100	50-80	<50
Soil texture	L-SiCL, C	SL		
Salinity	8mmhos/cm	8-16mmhos/cm		
Alkalinity	<15ESP	15-30ESP		

Source: FAO guideline for land evaluation, (1976, 1979 and 1991).

Further, the soil vector layer will be converted into raster layer using conversion tool “To Raster or Feature to Raster module”. The rasterized soil map of the study area is then reclassified based on their soil type name, texture, and depth and drainage class. Using overlay tool in Arc GIS10.3 Spatial analyst, weighted overlay analysis of these factors are performed to determine their suitability for surface irrigation.

C Land Cover/Use

Land cover/use one of factor that is used to assess the land suitability for surface irrigation. Land use/ cover classifications are analyzed using satellite imagery of the study area for identifying land cover types to estimate potential irrigable land. Geographic positioning system (GPS) is used to collect coordinate values like (UTM, Lat, and Long). For supervised classification of satellite images, geographic coordinate values are used as ground control points (GCP) to locate field photographs. The field photographs are used as signature of land cover class which helps as region of interest in supervised image classification. The supervised image classification is carried out using ArcGIS10.3.

The steps used in supervised image classification are:

Rename each image layer in the table of content and rearrange the table of content listing so that the band 1 image is at the top and the band 8 image is on the bottom.

Turn off image in the table of contents. And save the map document file (File>>save) to the computer.

Activate the image analysis window on the menu bar. Click the window pull-down menu and select image analysis.

To create a true color composite image from band 1, 2, 3 (blue, green, and red respectively), select the three image layers at the top of the image analysis window. Click the composite bands button in the processing section of the window.

Then new composite image layer is appeared in the table of contents. To create the final natural color image, on the property of the layer go to symbology tap and change the band assignments of Red, Green, and Blue to band 3, 2, 1 respectively.

After doing the above process the first step in the image classification is creating training areas. On the image classification tool bar by clicking the draw polygon icon the training areas is created. Though the polygons are dropped with the known land use purposes as well as GPS geographic coordinate values which are collected during the field survey helped by locating the exact place of land uses. For each land use land cover, multiple training areas are created across the study area image. On the training sample manager those multiple training areas for each land use land cover are merged in to the respective classes and the merged training samples is renamed under the class name.

Then by clicking create the signature file icon signature file is created.

There are several types of classification; for the purpose of this study maximum livelihood classification is preferred. On the image classification tool bar by selecting maximum livelihood classification input the signature file on the input signature file field. Then on the output classified raster field the place to save the classified image is selected. By clicking ok the image classification is finished.

D Computing Irrigation Water Requirement

To estimate irrigation water requirements of crops like barley, wheat and maize in the potential irrigable area, climatic data of Hagereselam, Teferikela and Kebado meteorology recording stations were taken to calculate irrigation water requirement of the identified irrigable area.

3.9 Reference Evapo-Transpiration (ETO)

The evapo-transpiration rate from a Reference crop not short of water is called the Reference evapo-transpiration (ETo). The concept of ETo 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-transpiring surface, soil factors do not affect ETo. Relating the evapo-transpiration process to a specific surface provides a reference to which evapo-transpiration from other surfaces can be related. It obviates the need to define a separate evapo-transpiration level for each crop and stage of growth. ETo values measured or calculated at different locations or in different seasons are comparable as they refer to the evapo-transpiration from the same reference surface.

The only factors affecting ETo are climatic parameters. Consequently, ETo is a climatic parameter and can be computed from weather data. ETo expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors. FAO Penman- Monteith method is recommended as the sole method for determining ETo. This method has been selected because it provides values that are very consistent with actual crop water use data worldwide, as it has been demonstrated through many years of evaluations reported in the scientific literature. This method overcomes the shortcoming of previously recommended methods, and explicitly incorporates both physiological and aerodynamic parameters. Moreover, procedures have been developed for using this method even with limited climatic data.

$$ETo = \frac{(0.408(R_n - G\ ) + \gamma \dfrac{900U2}{T + 273} * \left(es - ea\right)}{(\Delta + \gamma(1 + 0.34U2))} \qquad \underline{\qquad\qquad\qquad\qquad\qquad\qquad} (3.5)$$

Where:

ETo = Reference evapotranspiration

Rn = Net radiation at the crop surface

G = Soil heat flux density

T = Mean daily air temperature at 2m height

U2 = Wind speed at 2m height

es = Saturation vapor pressure

ea = actual vapour pressure

es-ea = Saturation vapour pressure deficit

Δ = Slope vapour pressure curve

γ = Psychrometric constant.

The reference evapotranspiration, ETo, provides a standard to which:

Evapotranspiration at different periods of the year or in other regions can be compared;

Evapo-transpiration of other crops can be related.

The equation uses standard climatological records of solar radiation (sunshine), air temperature, humidity and wind speed. To ensure the integrity of computations, the weather measurements should be made at 2 m (or converted to that height) above an extensive surface of green grass, shading the ground and not short of water.

No weather-based evapotranspiration equation can be expected to predict evapotranspiration perfectly under every climatic situation due to simplification in formulation and errors in data measurement. It is probable that precision instruments under excellent environmental and biological management conditions will show the FAO Penman-Monteith equation to deviate at times from true measurements of grass ETo. However, the Expert Consultation agreed to use the hypothetical reference definition of the FAO Penman-Monteith equation as the definition for grass ETo when deriving and expressing crop coefficients.

Crop evapotranspiration estimated by multiplying reference evapotranspiration by crop factor.

$$ET_C = ET_O * K_C \qquad (3.6)$$

Where:

ETo =Reference crop potential evapo-transpiration (mm/day)

ETC= crop evapotranspiration (mm/day)

Kc =crop factor (constant that depends on type of crops)

For agricultural production, effective rainfall refers to that portion of rainfall that can effectively be used by plants. This is to say that not all rain is available to the crops as some is lost through Runoff (RO) and Deep Percolation (DP).

How much water actually infiltrates the soil depends on soil type, slope, crop canopy, storm intensity and the initial soils water content. The most accurate method to determine effective rainfall is through field observation. Rainfall is highly effective when little or no RO takes place. Small rainfall amounts are not very effective as these small quantities of water are quickly lost to evaporation.

As input of monthly rainfall, the average, dependable or actual rainfall data can be given. Care should be taken in selecting appropriate values for the dependable rainfall, based on separately carried out statistical analyses of eleven year rainfall records and Thiessen's polygon mean method is used.

$$IWR = ET_C - P_{ef} \qquad (3.7)$$

Where:

IWR =Irrigation water requirement (mm)

P_{ef} =effect rainfall (mm).

3.10 Crop Water Requirement

The amount of water required to compensate the evapotranspiration loss from the cropped field is defined as crop water requirement. Although the values for Crop evapotranspiration under standard condition (ETc) and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration. Crop evapotranspiration can be calculated from climatic data and by integrating directly the crop resistance, albedo and air resistance factors in the Penman-Monteith approach. As there is still a considerable lack of information for different crops, the Penman-Monteith method is used for the estimation of the Reference evapo-transpiration (ETo). Experimentally determined ratios of ETc/ETo, called Crop coefficient (Kc), are used to relate ETc to ETo.

Differences in leaf anatomy, stomatal characteristics, aerodynamic properties and even albedo cause ETc to differ from ETo 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. Being the calculation of crop water requirements a fundamental element for water management, FAO has paid attention to the standardization and dissemination of the most accurate and accepted methodologies to calculate them. In 1990, FAO organized a consultation of experts and researchers in collaboration with the International Commission for Irrigation and Drainage and with the World Meteorological Organization, to review the published FAO methodologies on crop water requirements and to advice on the revision and update of procedures.

Radiation, air Temperature, Humidity and Wind speed are all incorporated into the ETo estimate. Therefore, ETo represents an index of climatic demand, while Kc varies predominately with the specific crop characteristics and only to a limited extent with climate and soil evaporation. This enables the transfer of standard values for Kc between locations and between climates. This has been a primary reason for the global acceptance and usefulness of the crop coefficient approach and the Kc factors developed in past studies.

Crop rotation cropping pattern is used in study area. In this cropping pattern cultivating barley crop, wheat crop and maize crop alternatively in the catchment area. This method is used for increasing productivity, maintaining fertility and moisture content of the soil.

3.11 Duty of Water

The duty of water is the relationship between the volume of water and the area of the crop it matures. It may be defined as the number of hectares of land irrigated for full growth of a given crop by supply of 1m3/s of water continuously during the entire base period (B) of that crop. Thus, if water is flowing at a rate of one cubic meter per second, runs continuously for base period (B) days, an matures 200 hectares, then the duty of water for that particular crop will be defined as 200 hectares per cumec to the base period (B) of days (Garg, 2005).

Each crop requires a certain amount of water after a certain fixed interval of time, throughout its period of growth. The depth of water required every time, generally varies from 5 to 10cm depending upon the type of the crop, climate and soil. The time interval between two such consecutive watering is called the frequency of irrigation, or rotation period. The rotation period may vary between 6-15 days for different crops. The summation of the total water depth supplied during the base period of a crop, for its full growth, will evidently represent the total quantity of water required by the crop for its full-fledged nourishment. This total quantity of water required by the crop for its full growth (maturity) may be expressed in hectare-meter (Acre-ft) or in million cubic meters (million cubic-ft) or simply as depth to which water would stand on the irrigated area, if the total quantity supplied were to stand above the surface without percolation or evaporation. This total depth of water (in cm) required by a crop to come to maturity is called its delta (Δ) (Garg, 2005).

The duty of water is estimated by using relation.

$$D = \frac{864B}{\Delta} \qquad (3.8)$$

Where:

D is duty in hectare per cumec.

Δ is total water requirement of the crops in cm.

B is crop period in days.

Table 3.5: Input data and output result of Cropwat 8.0 software.

Data	Input	Output
Climatic	Monthly means of minimum and maximum temperature, relative humidity, sunshine duration, wind speed, rainfall data monthly.	Reference evapo-transpiration Crop water requirement irrigation requirement Actual crop evapo-transpiration
Crop	Crop coefficient, Crop description, maximum rooting depth, % area of covered by plant.	Soil moisture deficit

3.12 Computing Un-gauged Bonkoka River Discharge at Sites from Gauged River Site

The stream flow discharge data from gauged stream flow (data which is obtained from Ministry of Irrigation, Water and Electricity) were used to estimate the stream-flow at the un-gauged sites in the study area a long term average of stream-flow at gauged sites. This is estimated by applying runoff coefficient of the gauged sites to un-gauged sites (FAO, 1997; Goldsmith, 2000 and DFID, 2004).

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

A, both gauged and un-gauged catchment areas are calculated

B, Point rainfall data of stations both in and around gauged and un-gauged catchments are converted to areal or average rainfall over an area of river catchments.

C, both un-gauged and gauged river catchments in terms of their land cover/use, soil type and slope range are compared to determine their similarities.

D, Runoff coefficient from the ratio of mean monthly discharge to mean monthly areal rainfall of gauged catchments is determined.

Above steps are followed to estimate monthly average runoff of the un-gauged river catchments from gauged river catchments.

$$Q_{ung} = \frac{A_{ung}}{A_{ga}} * Q_{ga} * \frac{P_{uga}}{P_{ga}} \qquad (3.9)$$

Where:

Qun-gauged = discharge at un-gauged site (m^3 /s).

Aun-gauged = drainage area of un-gauged site (km^2).

Pun gauged = areal rainfall at the un-gauged site (mm).

Q gauged = discharge at gauged site (m^3/s).

A gauged = drainage area at gauged site (km^2).

P gauged = areal rainfall at the gauged site (mm).

The runoff coefficient is the ratio of total stream flow volume to the total precipitation over a certain area and time (Kadioglu and Sen, 2001). The runoff coefficient of the Bonkoka catchment was estimated by using runoff coefficient value of gauged Kolla river catchment in which un-gauged Bonkoka catchment characteristics such as land cover, soil type, and catchment slope ranges were similar with the gauged Kolla river catchment.

The runoff coefficient at the gauged river sub-catchment was estimated by using equation.

$$C = \frac{Q_{ga}}{A_{ga}} * \frac{1}{P_{ga}} \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} (3.10)$$

Where:

Q gauged = discharge at gauged site (m3/s)

A gauged = drainage area at gauged site (km2)

P gauged = areal rainfall at the gauged site (mm).

The discharge at un-gauged river sub-catchment was estimated by using equation.

$$Q_{ung} = C * Au_{ng} * Puga \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} (3.11)$$

Where:

C = Runoff coefficient at gauged river sub-catchment.

Qun-gauged = discharge at un-gauged site (m3 /s).

Aun-gauged = drainage area of un-gauged site (km2).

Pun gauged = areal rainfall at the un-gauged site (mm).

The available surface water of the catchment was estimated by using stream flow discharge (obtained from the ministry of Water, Irrigation and Electric Power) and rainfall data (obtained from National Meteorological Service Agency).

Hydrologically similar river with Bonkoka river catchment was Kolla River that was used as input to determine surface water resources potential of Bonkoka catchment (river discharge at un-gauged site) that was measured at the Aleta Wondo gauging station.

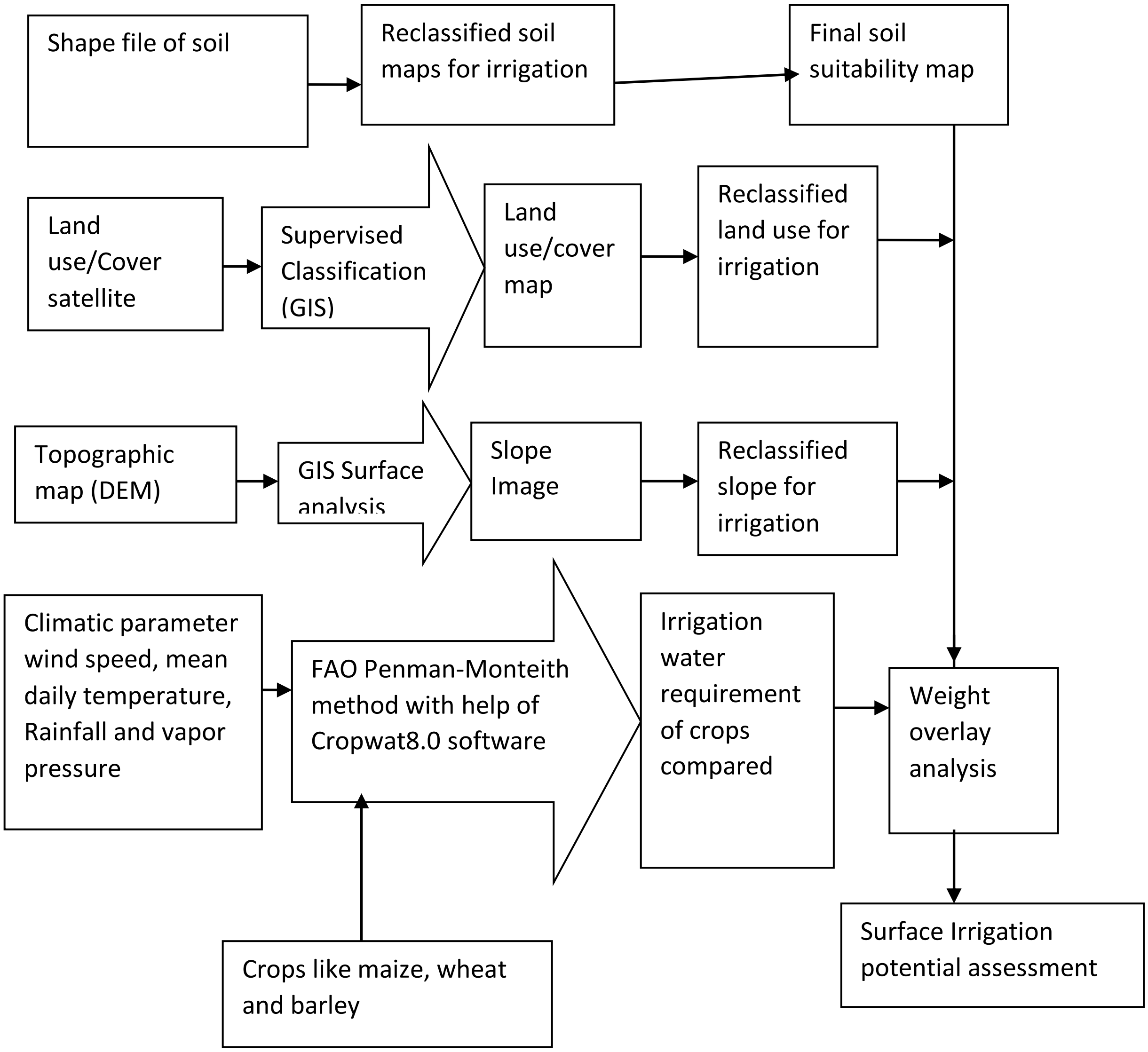

Figure 3.4: Flow chart showing surface irrigation potential assessment.

4 RESULT AND DISCUSSION

4.1 Estimating Bonkoka River Surface Water Discharge from Gauged Kolla River

Bonkoka river flow is estimated by using runoff coefficient method. Kolla River is the gauged river near the Bonkoka river catchment (distance between Bonkoka River and Kolla River is about 30 kilometer far apart) and catchment characteristics like land cover, soil type and land slope is similar with the Bonkoka River catchment.

The monthly Bonkoka river discharge was obtained from gauged Kolla river discharge, Kolla catchment area, monthly rainfall at Aleta Wondo station, Bonkoka catchment area and monthly areal rainfall of Bonkoka catchment area. Thiessen's polygon Average monthly areal rainfall of the Bonkoka catchment as shown above table 3.2, Appendix 1 and Appendix 4.
The runoff coefficient method is used to estimate monthly flow of Bonkoka river flow as shown in equation 3.9 above.

Table 4.1: Monthly river flows of Bonkoka river catchment estimated from gauged Kolla river catchment.

Month	Bonkoka catchment areal monthly rainfall (mm) from 1991 to 2016	Kolla river monthly discharge at Aleta Wondo gauging station (m^3/s) from 1980 to 2010	Kolla river catchment area (m^2)	Aleta Wondo station monthly rainfall (mm) from 1991 to 2016	Bonkoka river catchment area (m2)	Bonkoka river flow in (l/s)
Jan	25.9	1.5	206300000	23.45	21,860,000.00	180
Feb	42.9	1.29	206300000	26.63	21,860,000.00	220
Mar	84.4	1.5	206300000	60.45	21,860,000.00	220
Apr	2203.9	2.53	206300000	181.30	21,860,000.00	3,260
May	263	4.98	206300000	202.30	21,860,000.00	690
Jun	149	5.05	206300000	116.00	21,860,000.00	690
Jul	95.69	5.63	206300000	135.00	21,860,000.00	420
Aug	153.3	9.17	206300000	136.90	21,860,000.00	1,090
Sep	172	8.29	206300000	133.00	21,860,000.00	1,140
Oct	191	10.13	206300000	136.10	21,860,000.00	1,510
Nov	98.5	5.3	206300000	43.00	21,860,000.00	1,290
Dec	25	2.98	206300000	8.77	21,860,000.00	900

As presented in table 4.1, monthly Bonkoka river discharge was shown. Thirty one year (from 1980 to 2010) annual average Bonkoka river discharge was 0.97m^3/s

4.2 Surface Irrigation Suitability Analysis Result Assessment

Surface irrigation suitability evaluation presented by analyzing the result of the land slope, soil type and land cover or land use.

4.2.1 Land Slope

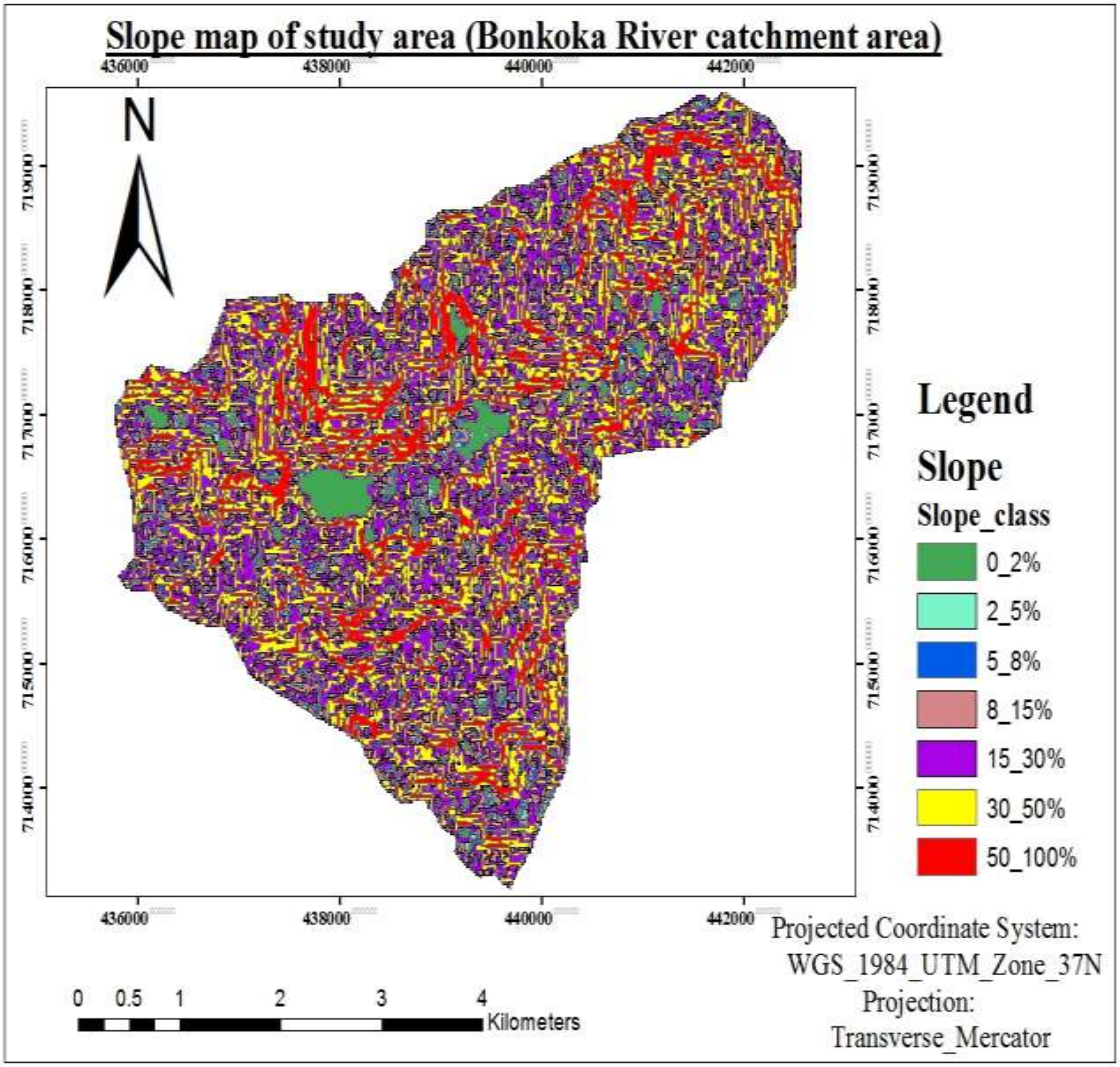

Figure 4.1: Slope suitability map of the Bonkoka catchment area for surface irrigation.

Land slope has been taken as one of the evaluation factors in surface irrigation suitability.

Based on the seven slope groups (0-2, 2-5, 5-8, 8-15, 15-30, 30-50, and 50-100) indicating the land slope of the Bonkoka catchment area for the development of surface irrigation system is shown in the figure 4.1 and the area coverage of the slope suitability groups are presented in the table 4.2.

Table 4.2: Slope suitability group of the study area for surface irrigation.

Slope group	Area coverage (ha)	% of total area
0-2	66.22	3%
2-5	53	2%
5-8	79.3	4%
8-15	253.77	12%
15-30	712.9	33%
30-50	627.2	29%
50-100	393.67	18%

The result table 4.2 and figure 4.1 indicate that 9% of the total area of the Bonkoka catchment area (covering an area of 198.52 ha) is in the range of highly suitable to a marginally suitable for surface system with respect to slope remaining 91% of the area (covering an area of 1,987.48ha) is not suitable. Hence, the majority of the study area is not suitable for surface irrigation in terms of slope suitability factor.

4.2.2 Soil Type

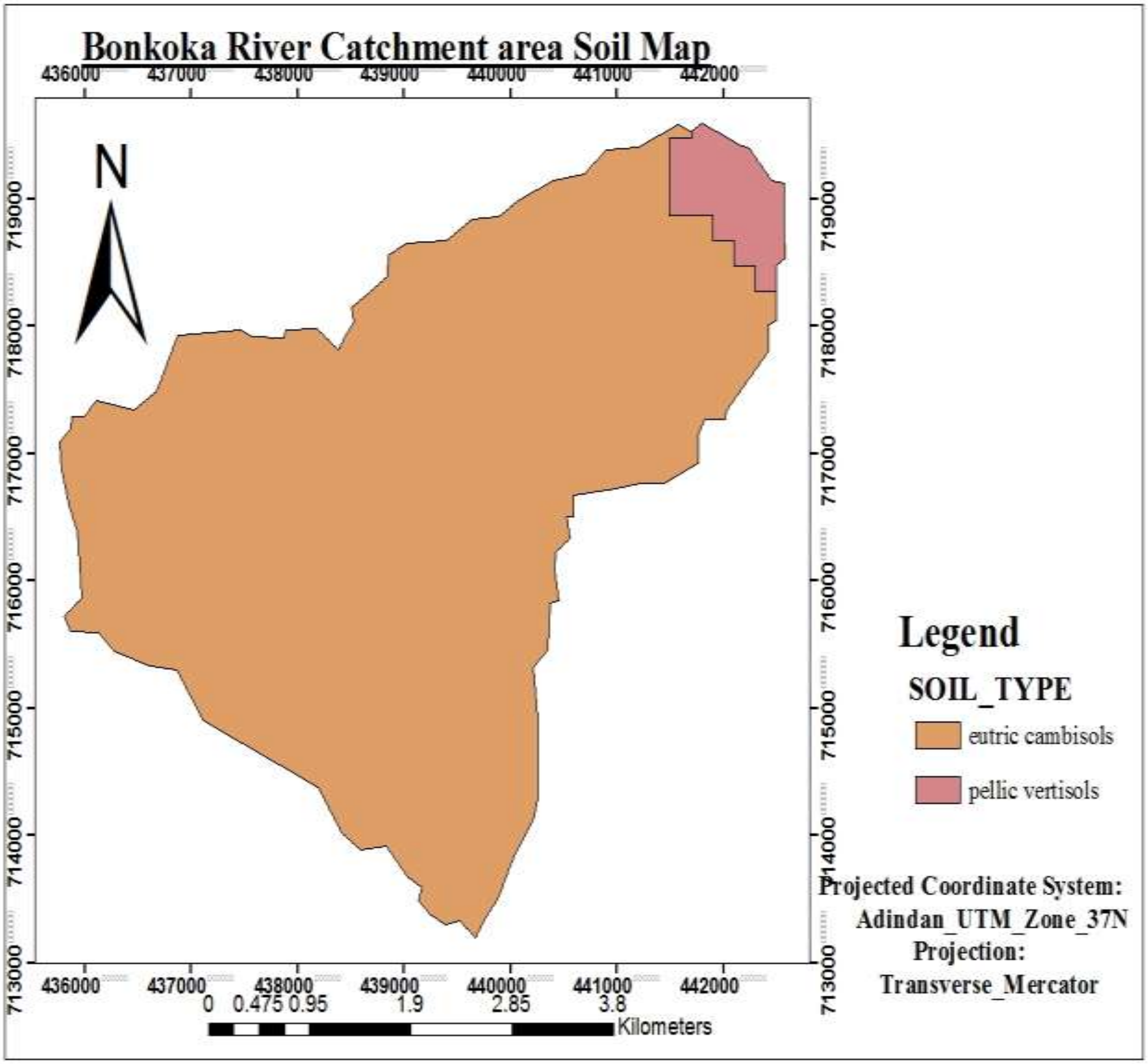

Figure 4.2: Bonkoka catchment area soil type.

The major soil groups identified in the study area are: Eutric Cambisols and Pellic Vertisols as shown in figure 4.2. Summary of soil suitability classification results are given in table 4.3.

Table 4.3: Bonkoka catchment area soil type.

Item number	Soil type	Area (ha)	Percentage (%)
1	Eutric Cambisols	2,101	96.11%
2	Pellic Vertisols	85	3.89%
	Total	2,186	100%

Eutric Cambisols, covering an area of 2,101 ha which accounts 96.11% of the total area, was classified as highly suitable (S1) for surface irrigation.

According to FAO-UNESCO soil map of the World, 1977 Eutric Cambisols is good soils rich in nutrient elements and Preferable for cultivation of food crops.

Pellic Vertisols, covering an area of 85 ha which accounts 3.89% of the total area, was classified as highly suitable (S1) for surface irrigation. According to Holetta Agricultural Research Centre Institute of Agricultural Research, 2003 Vertisols are important agricultural soils in Ethiopia. These soils generally have high clay content and consequently a high moisture storage capacity.

Pellic Vertisols is good soils rich in nutrient elements and Preferable for cultivation of food crops.

4.2.3 Land Cover or Land Use

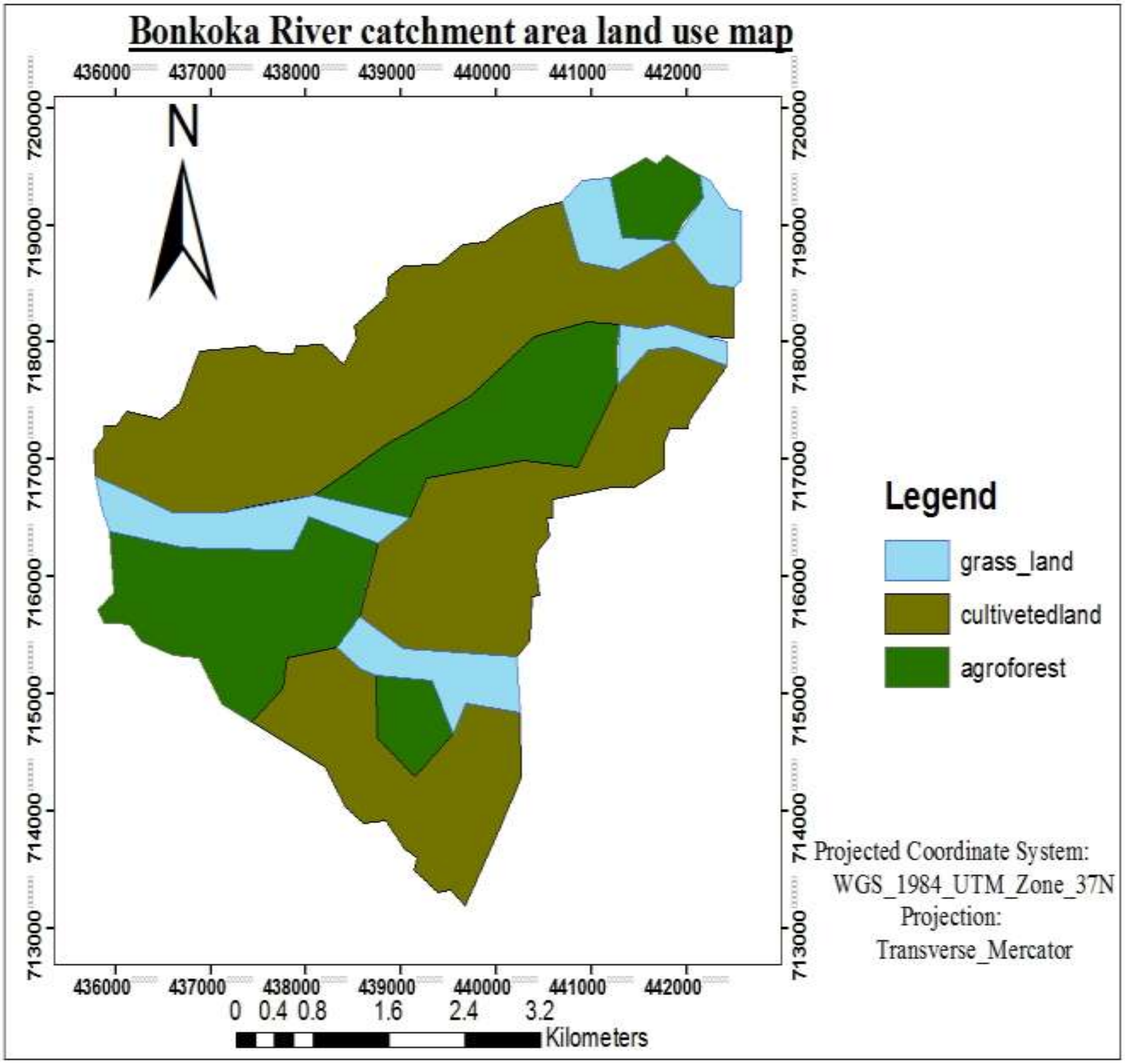

Figure 4.3: land cover or land use of the Bonkoka catchment area.

Table 4.4: Land cover of the Bonkoka catchment area.

Item	Land Cover Type	Area (ha)	Percentage (%)
1	Grass land	280	13%
2	Cultivated land	1300	59%
3	Agroforestry	606	28%
	Total	2,186	100%

Referring to figure 4.3 and table 4.4, discussions of results for the land cover/use are as shown below.

Grass land

This land over is known by having an area covered by open grass land. It is used for grazing purpose. The grass land occupies an area of about 13% of the Bonkoka catchment area.

Cultivated land

This land cover type is large as compared to the other land cover types in the Bonkoka catchment area. It covers 59% of the Bonkoka catchment area.

Agroforestry

This land cover is known by having an area covered by both agriculture and forestry land. It is used for growing cash crop like coffee and avocado. The agroforestry land occupies an area of about 28% of the Bonkoka catchment area.

4.3 Crop Water Requirement

The crop water requirement and irrigation requirement of barley, wheat and maize were estimated by using cropwat8.0 software application.

Table 4.5: Crop water requirement of Barley

ETo Station			Bonkoka		Planting Date		06/02/2019
Rainfall Station			Bonkoka		Harvesting Date		10/06
Month	Decade	Stage	Kc (coeff)	ETc (mm/day)	ETc (mm/dec)	Effective rain	Irrigation requirement
February	1	Initial	0.3	1.14	6.8	6.7	1.3
February	2	Initial	0.3	1.16	11.6	12.5	0
February	3	Development	0.33	1.24	9.90	16.5	0
March	1	Development	0.52	1.89	18.9	19.7	0
March	2	Development	0.74	2.63	26.3	22.9	3.4
March	3	Development	0.98	3.38	37.2	30.5	6.7
April	1	Mid	1.1	3.66	36.6	40.2	0
April	2	Mid	1.1	3.55	35.5	48.1	0
April	3	Mid	1.1	3.43	34.3	48.9	0
May	1	Mid	1.1	3.31	33.1	50.5	0
May	2	Late	0.94	2.73	27.3	52.8	0
May	3	Late	0.65	1.83	20.4	47.8	0
June	1	Late	0.36	1.03	9.3	37.7	0
Total					307.2	434.9	11.4

Figure 4.4 showing irrigation requirement, crop water requirement of Barley crop and effective rainfall at Bonkoka Catchment area.

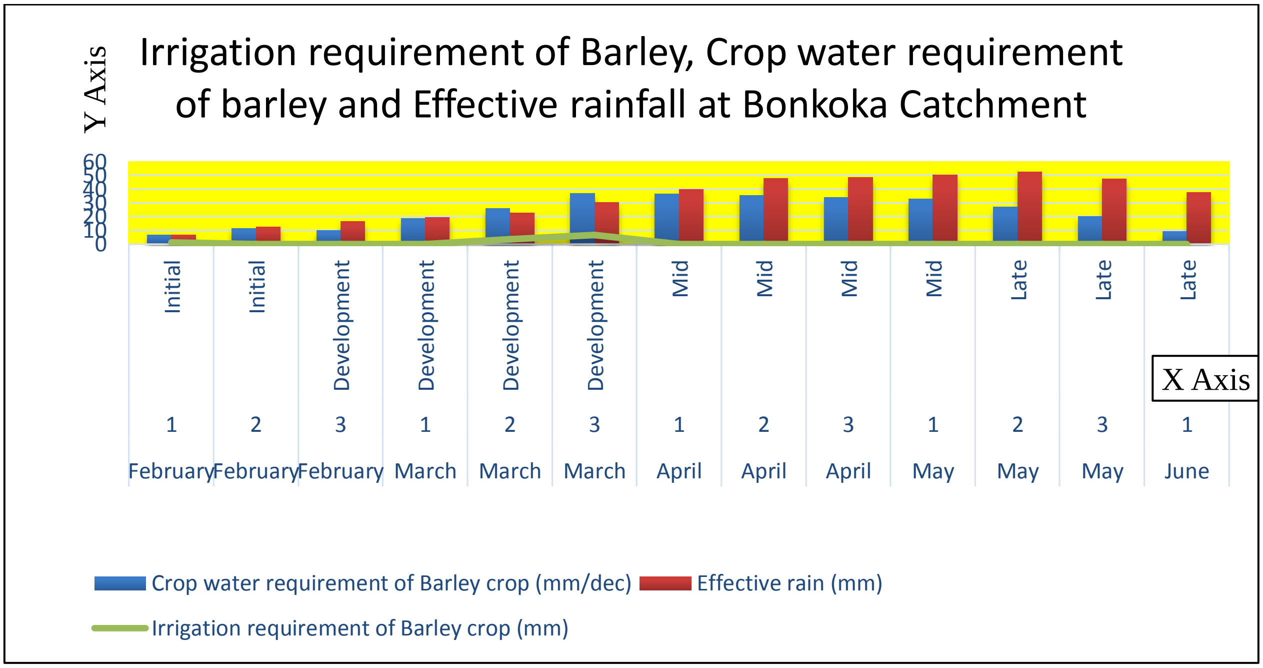

Figure 4.4 Irrigation requirement of barley, Crop water requirement of barley and Effective rainfall at Bonkoka Catchment.

As indicated in table 4.11 above barley crop water requirement was 307.2mm (30.72cm) per decade, 434.9mm effective rain and 11.4mm irrigation requirement. And also figure 4.7 present crop require irrigation at first ten day 1.3mm depth of irrigation, at second and third development stage 3.4mm and 6.7mm depth of irrigation. The remaining growth stage rainfall water is satisfactory for the cultivation of the crop.

Table 4.6: Crop water requirement of wheat.

ETo Station			Bonkoka		Planting	Date	06/02/2019
Rainfall Station			Bonkoka		Harvesting	Date	10/06
Month	Decade	Stage	Kc (coeff)	ETc (mm/day)	ETc (mm/dec)	Effective rain	Irrigation requirement
February	1	Initial	0.3	1.14	5.7	5.6	0.1
February	2	Initial	0.3	1.16	11.6	12.5	0
February	3	Initial	0.3	1.13	9.0	16.5	0
March	1	Development	0.32	1.15	11.50	19.7	0
March	2	Development	0.53	1.87	18.70	22.9	0
March	3	Development	0.81	2.79	30.60	30.5	0.1
April	1	Mid	1.06	3.56	35.6	40.2	0
April	2	Mid	1.11	3.58	35.8	48.1	0
April	3	Mid	1.11	3.46	34.6	48.9	0
May	1	Mid	1.11	3.33	33.30	50.5	0
May	2	Late	1.08	3.13	31.3	52.8	0
May	3	Late	0.84	2.40	26.4	47.8	0
June	1	Late	0.55	1.57	15.70	41.9	0
June	2	Late	0.35	0.99	4.9	18.8	0
Total					304.8	456.7	0.2

Figure 4.5 showing irrigation requirement, crop water requirement of wheat crop and effective rainfall at Bonkoka Catchment area.

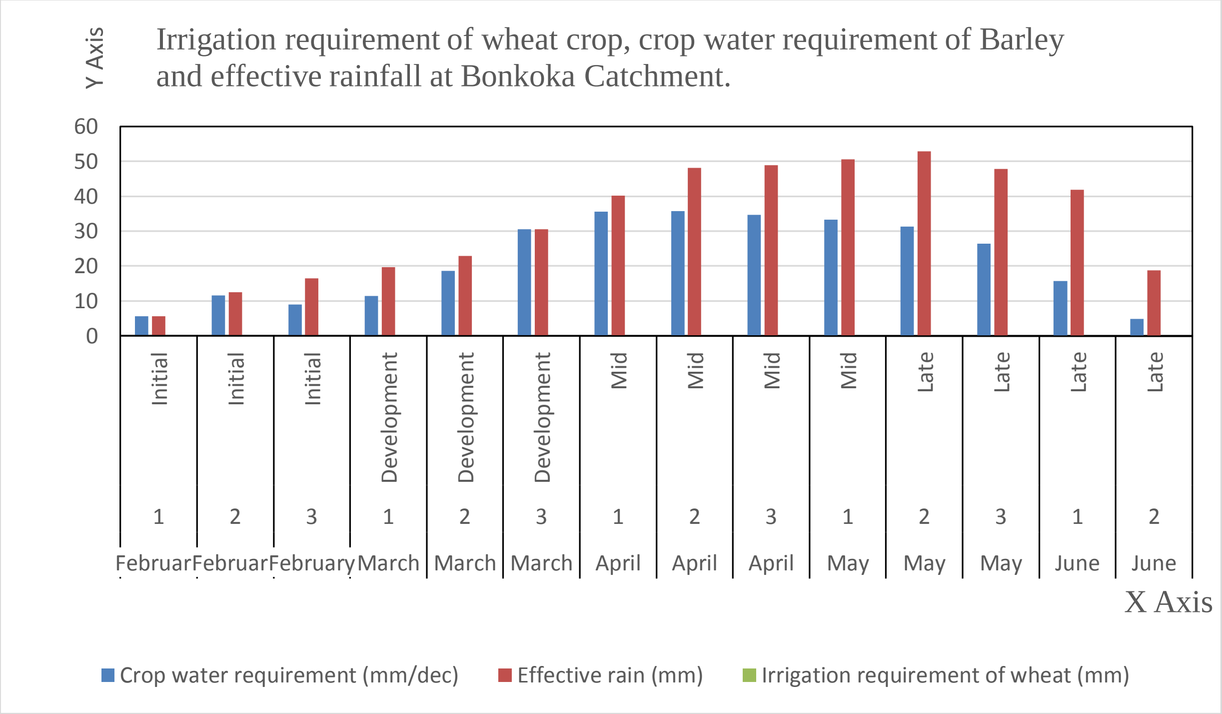

Figure 4.5: Irrigation requirement of wheat, Crop water requirement of wheat and Effective rainfall at Bonkoka Catchment.

As indicated in table 4.6 above wheat crop water requirement was 304.8mm (30.48cm) per decade, 456.7mm effective rain and 0.2mm irrigation requirement. And also figure 4.5 present crop water requirement irrigation at first ten day 0.1mm depth of irrigation, at the end of development stage 0.1mm depth of irrigation. The remaining growth stage rainfall water is satisfactory for the cultivation of the crop.

Table 4.7: Crop water requirement of maize.

ETo Station			Bonkoka		Planting	Date	06/02/2019
Rainfall Station			Bonkoka		Harvesting	Date	10/06
Month	Decade	Stage	Kc (coeff)	ETc (mm/day)	ETc (mm/dec)	Effective rain	Irrigation requirement
February	1	Initial	0.3	1.14	6.8	6.7	1.3
February	2	Initial	0.3	1.16	11.6	12.5	0
February	3	Development	0.33	1.24	9.9	16.5	0
March	1	Development	0.53	1.93	19.3	19.7	0
March	2	Development	0.77	2.73	27.3	22.9	4.4
March	3	Development	1.03	2.53	38.8	30.5	8.3
April	1	Mid	1.15	3.83	38.3	40.2	0
April	2	Mid	1.15	3.72	37.2	48.1	0
April	3	Mid	1.15	3.59	35.9	48.9	0
May	1	Mid	1.15	3.46	34.6	50.5	0
May	2	Late	1.01	2.94	29.4	52.8	0
May	3	Late	0.76	2.17	23.8	47.8	0
June	1	Late	0.51	1.45	13	37.7	0
Total					326.1	434.9	14.0

Figure 4.6 showing irrigation requirement, crop water requirement of maize crop and effective rainfall at Bonkoka Catchment area.

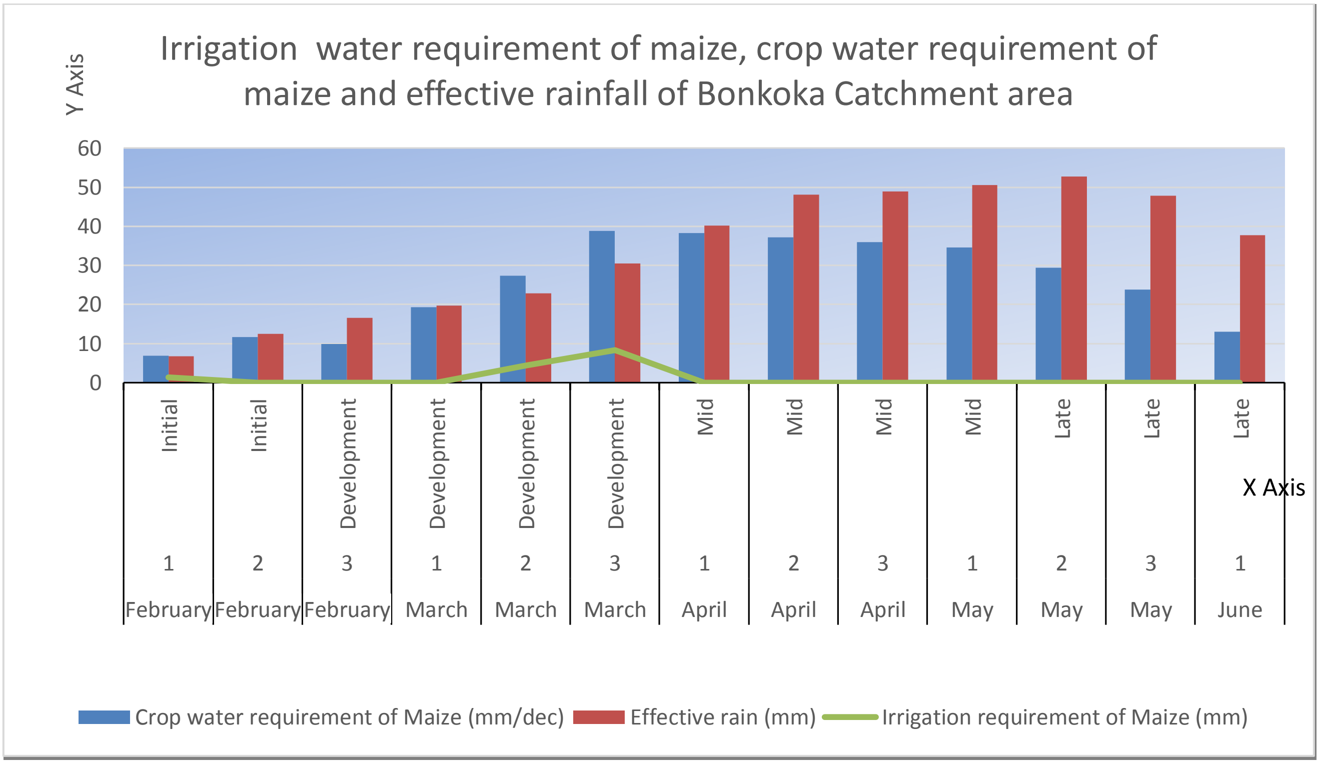

Figure 4.6: Irrigation requirement of maize, Crop water requirement of Maize and Effective rainfall at Bonkoka Catchment.

As indicated in table 4.7 above maize crop water requirement was 326.1mm (32.61cm) per decade, 434.9mm effective rainfall and 14.0mm irrigation requirement. And also figure 4.6 present crop require irrigation at first ten day 1.3mm depth of irrigation, at third and fourth stage of development 4.4mm and 8.3mm depth of irrigation. The remaining growth stage rainfall water is satisfactory for the cultivation of the crop.

When comparing irrigation water requirement of crops barley require 11.4mm, wheat require 0.2mm and maize require 14mm. From this result maize crop require more irrigation water than barley crop and barley crop require more irrigation water than wheat crop.

The cropping pattern used in the study area is crop rotation method. In this cropping pattern it is possible to cultivate two crops at different season of year. Cultivating barley crop from February month to June month and cultivating wheat crop from July month to November month with one year period of time and also cultivating maize crop from December month to April month in the coming next year.

4.4 Duty of Water for Crops

Table 4.8: Crop water requirement, Crop period and Duty of water for barley, wheat and maize crops.

Serial number	Crop type	Crop water requirement (cm)	Crop period (days)	Duty (ha/cumec)	Estimated Potential of Bonkoka river flow (m^3/s)
1	barley	30.72	125	3,515.63	0.97
2	wheat	30.48	130	3,685.04	0.97
3	maize	32.61	125	3,311.87	0.97

Crop water requirement and crop period obtained from above table 4.5, table 4.6 and table 4.7 and also estimated potential of Bonkoka River obtained from above table 4.1.

Based on crop water demand indicated above table 4.8 show that to cultivate barley crop 3,515.63ha of land irrigated for full growth of crop by supply of one meter cube of water during one hundred twenty five crop period (day). To cultivate wheat crop 3,685.04ha of land irrigated for full growth of crop by supply of one meter cube of water during one hundred thirty crop period (day) and to cultivate maize crop 3,311.87ha of land irrigated for full growth of crop by supply of one meter cube of water during one hundred twenty five crop period (day). The estimated thirty one year (from 1980 to 2010) annual average Bonkoka river discharge was $0.97m^3/s$.

4.5 Suitable Land for Surface Irrigation

As shown above surface irrigation suitability factors are indicated below.

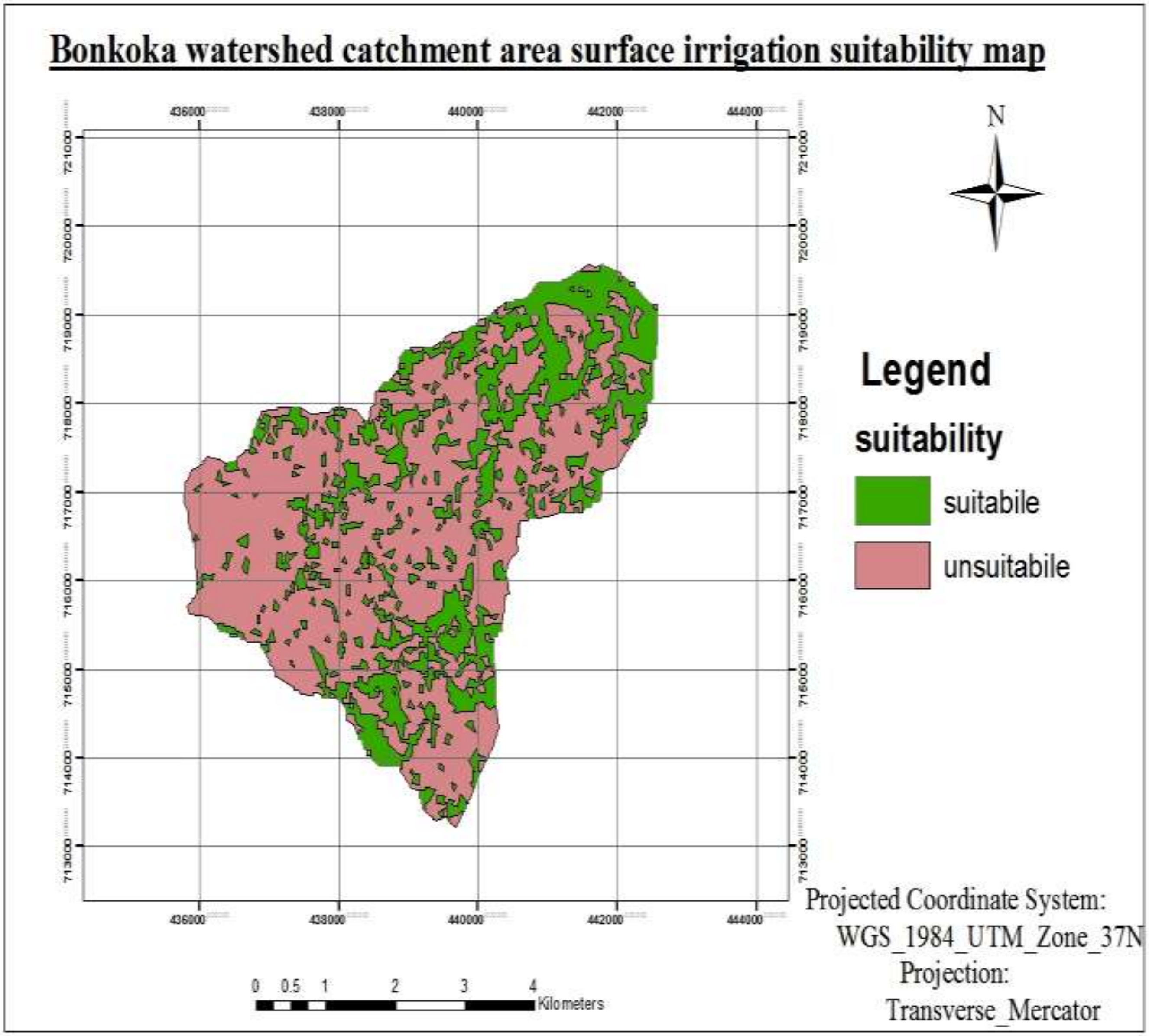

Figure 4.7: Bonkoka watershed catchment area surface irrigation suitability map.

Table 4.9: Bonkoka watershed catchment area surface irrigation suitability.

Item number	Suitability	Area (ha)	Percentage (%)
1	Suitable	676	31%
2	Unsuitable	1,492	69%
	Total	2,168	100%

Based on Bonkoka watershed catchment area surface irrigation suitability analysis by overlaying slope suitability, soil suitability and land cover or land use result present that 31% of the total Bonkoka catchment area (covering an area of 676 ha) is suitable for surface irrigation from total of 2,186ha of land area.

5 CONCLUSION AND RECOMMENDATION

5.1. Conclusions

The main objective of this study was to assess surface water irrigation potential from Bonkoka river catchment in Dara Woreda, Sidama Zone Southern nation nationalities people regional state. The catchment areas obtained through watershed delineation of the Bonkoka River catchment was 2,186 ha. Mean monthly discharge of Bonkoka River was estimated by using runoff coefficient of gauged Kolla River discharge that had similar catchment characteristics such as land cover, soil type and catchment slope. As presented in table 4.8 above, estimated monthly Bonkoka river discharge was shown. Thirty one year annual average Bonkoka river discharge was 0.97m^3/sec. The estimated Bonkoka River discharge was minimum flow 0.18 m^3/s at January and maximum flow 3.26m^3/s at April.

Surface irrigation land suitability analysis result show that 100% of soil (covering an area 2,186 ha) and 9% of slope in the study area (covering area 198.52 ha) are in the range of highly suitable to marginal suitable for surface irrigation application. Considering land cover or land use, land covered by agroforestry covering 28% or 606 ha area and remaining 59% cultivated land (covering area 1,300ha) and 13% grass land (covering area 280 ha) are suitable for surface irrigation application. Land suitable for suitable for surface irrigation by overlay analysis of land slope suitability, soil type suitability and land use or land cover result show that 31% of the total Bonkoka catchment area (covering an area of 676 ha) is suitable for surface irrigation from total of 2,186ha of land area.

As shown in table 4.10, table 4.11 and table 4.12 above to cultivate barley crop water requirement shall be met by rainfall except at initial stage, third and fourth development stage. To cultivate wheat crop water requirement shall be met by rainfall except at initial stage and third development stage and to cultivate maize crop water requirement shall be met by rainfall except at initial stage, at second and third development stage.

5.2 Recommendations

Surface irrigation potential assessment work help to inform the policy maker to know the potential Bonkoka River for the development irrigation scheme. As the result of development of irrigation scheme in rural area inside the catchment area local communities became beneficiaries by planting crops in Dara Woreda, Sidama Zone Southern nation nationalities people regional state.

In Bonkoka River catchment there is 2,186 ha total area but only 676 ha area is suitable for surface irrigation application.

The study focused on surface irrigation potential assessment from existing meteorological data, estimating un-gauged River from gauged River discharge, estimating crop water requirement and surface irrigation suitability analysis with respect soil type, land slope and land cover or land use. The future study should consider suitable surface irrigation methods on this river catchment area.

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Appendices

Appendix 1: Kolla River monthly flow at Aleta Wondo (m^3/s).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annu
1990	0.43	0.60	0.87	4.62	0.62	0.53	0.8	9.40	0.69	0.60	0.40	0.40	19.99
1991	0.39	0.43	0.53	0.59	0.56	0.53	0.59	0.60	0.70	0.80	0.40	0.40	6.46
1992	0.43	0.49	0.45	0.52	0.62	0.57	0.58	1.00	1.33	1.30	1.00	0.70	8.98
1993	0.70	0.83	0.75	0.97	1.16	0.99	0.81	0.80	0.97	1.10	0.60	0.50	10.13
1994	0.58	0.60	0.57	0.69	0.75	0.78	0.97	1.30	1.10	0.80	0.60	0.50	9.20
1995	0.88	0.91	0.96	1.02	1.00	1.00	1.02	1.00	1.12	1.00	0.90	1.00	11.81
1996	1.01	1.00	1.74	3.47	5.46	0.67	0.55	0.60	0.58	0.60	0.40	0.40	16.52
1997	0.43	0.44	0.42	0.50	0.49	0.53	0.54	0.60	0.57	0.60	0.60	0.50	6.15
1998	0.45	0.46	0.51	0.48	0.58	0.51	0.49	0.50	0.59	0.70	0.50	0.50	6.29
1999	0.47	0.47	0.48	0.47	0.47	0.49	0.50	0.50	0.52	0.60	0.50	0.40	5.88
2000	0.44	0.42	0.45	0.48	0.52	0.51	0.50	0.50	0.64	0.80	0.70	0.60	6.60
2001	0.66	0.65	0.66	0.71	0.70	0.75	0.72	0.70	0.86	0.80	0.70	0.60	8.51
2002	0.63	0.60	0.66	0.68	0.73	0.69	0.68	0.70	0.74	0.70	0.60	0.60	8.01
2003	0.63	0.61	0.64	0.68	0.68	0.71	0.72	0.70	3.27	0.80	0.70	0.60	10.80
2004	0.88	0.91	0.96	1.02	2.79	0.63	0.64	0.60	0.75	0.80	0.60	0.60	11.15
2005	0.59	0.60	0.61	0.61	0.71	0.65	0.64	0.70	0.84	0.70	0.70	0.60	7.88
2006	0.50	0.52	0.60	0.67	0.65	0.64	0.76	0.80	0.79	0.80	0.70	0.60	8.05
Mean	0.59	0.62	0.70	1.07	1.09	0.66	0.68	1.20	0.94	0.80	0.60	0.60	9.55

Appendix 2: Monthly rainfall Data at Teferi Kela Station (mm).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Annual mean
2006	12.4	72.9	101.9	265.7	267	167.8	15.5	159.5	70	321.6	97.8	75.7	1627.8	135.65
2007	40.7	21.1	75.4	275.9	365.2	213.1	118.8	111.4	195.4	204.7	105	6.8	1733.5	144.458333
2008	3.5	2.1	76.7	203.1	143.6	79	110.4	133.4	190.1	324.6	122	4.7	1393.2	116.1
2009	53.1	32.6	30.2	433	266.6	99.2	14	62	170.7	128.6	55.4	116.1	1461.5	121.791667
2010	23	104.5	343.4	233.4	282.7	85.3	84	82.2	226.7	220.4	27.1	0.3	1713	142.75
2011	0.5	23.8	47.6	91.5	324	118.9	147	194.8	256.7	227.8	277.6	23.3	1733.5	144.458333
2012	11.6	5.3	29.1	239.9	233.9	98.6	110	151.3	158.9	216.7	169.7	22.4	1447.4	120.616667
2013	24.8	11.6	163.2	226.21	272	127.2	81.9	48.4	287.2	251.5	127.2	1.2	1622.41	135.200833
2014	19.7	47.7	95.8	125.08	250	238.8	69.2	84.3	386.14	430.1	135	15	1896.82	158.068333
2015	0	15.7	95.1	150	188.9	204.4	20.2	19.4	199.9	274.7	211.3	42.8	1422.4	118.533333
2016	22.1	25	61.4	227.6	215.1	159	30.5	0.3	75	255.5	64.6	27.2	1163.3	96.9416667
2017	4.5	14.3	73.7	230	240.9	35.1	83.7	162.2	186.6	253	60.6	5.6	1350.2	112.516667
Mean	18	31.4	99.5	225	254	136	73.8	101	200.3	259.1	121.1	28.43	1547.09	128.923819

Appendix 3: Monthly rainfall Data at Kebado Station (mm).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	48.00	72.80	106.30	99.20	131.00	97.30	96.40	39.80	184.74	100.20	19.10	7.00
1992	46.00	56.00	71.00	175.00	253.00	119.80	64.50	97.60	163.90	314.70	12.50	59.30
1993	38.00	152.00	140.50	217.60	284.60	165.00	56.10	52.20	126.20	184.10	19.20	16.90
1994	0.00	20.90	118.40	374.70	333.20	157.60	170.40	159.90	177.40	72.40	67.90	9.80
1995	0.00	80.30	99.10	419.71	244.87	52.49	77.00	104.50	176.20	151.20	23.40	76.10
1996	77.70	78.80	245.10	298.10	255.70	169.40	105.20	147.70	180.50	118.00	40.50	50.50
1997	61.90	0.00	25.30	318.10	273.80	127.60	152.40	102.70	162.80	236.60	156.90	68.90
1998	73.40	94.70	98.50	171.43	137.00	120.80	124.20	99.40	185.30	192.60	90.00	15.90
1999	18.80	25.90	187.00	88.00	312.50	99.30	76.20	99.80	141.40	211.90	28.20	26.10
2000	4.40	0.00	20.80	139.10	175.70	39.30	116.70	151.30	189.80	211.10	82.00	30.40
2001	18.70	32.80	105.10	183.00	169.50	193.00	81.40	172.70	215.20	292.50	70.60	40.10
2002	35.90	6.60	188.80	55.30	182.60	139.50	30.80	91.60	175.80	135.10	14.60	185.30
2003	43.90	3.80	54.80	226.80	163.80	144.80	56.10	134.70	120.20	122.00	59.30	32.80
2004	111.10	63.10	58.90	171.40	153.00	34.00	58.10	106.60	147.10	73.30	89.80	85.40
2005	17.70	7.20	120.10	287.10	209.50	145.90	76.60	59.20	177.50	156.30	17.90	0.00
2006	21.00	55.60	127.50	195.50	207.50	114.90	121.80	160.10	150.20	358.70	77.10	13.60
2007	62.8	76.2	90.3	158.5	270.7	96.9	73.2	252.7	303.0	184.1	36.7	0.0
2008	2.6	10.4	42.1	168.0	285.1	83.3	85.1	62.0	282.5	197.6	66.7	7.9
2009	84.8	27.0	102.0	176.1	197.7	45.0	26.4	54.4	211.6	168.1	6.0	96.9
2010	47.3	130.7	162.9	289.6	282.0	165.6	147.5	181.7	95.4	119.1	26.7	5.6

2011	12.2	15.4	27.9	116.5	272.0	71.2	39.8	252.8	262.1	135.3	199.4	9.7
2012	4.6	0.0	48.1	166.0	118.3	128.1	184.6	92.9	275.1	121.0	41.9	31.9
2013	28.7	7.3	107.3	209.7	119.7	101.2	54.0	139.7	150.4	93.7	6.1	16.3
2014	7.2	27.5	159.6	168.8	313.7	0	157.4	182.0	123.0	175.70	101.818	12.6118
2015	0.0	0.0	89.6	156.7	123.5	74.8	47.6	51.1	102.2	145.8	68.2	39.6575
2016	0.0	13.8	34.4	66.1	80.4	64.9507	39.4	131.5	113.9	135.0	64.3	13.6072
Mean	33.33	40.72	101.21	196.00	213.48	105.84	89.19	122.33	176.67	169.46	57.18	36.63

Appendix 4: Monthly rainfall Data at Aleta Wondo Station (mm).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Mean
2007	66.9	13	111.9	172.6	164.7	164	116	210.7	219	175.5	67.3	0	1482	123.5
2008	36	32.7	15.6	161.1	195.9	113	164	109.8	104	181.3	105	6.6	1224	102
2009	55.8	46.2	86.5	192.3	98.7	172	28	66.1	130	145.8	25.1	44.3	1091	90.88
2010	24.6	94.8	106	209.2	253.8	138	86	178.6	89.2	0.3	18.4	28.2	1227	102.3
2011	0.8	19.4	0	160	277.1	17.3	160	38	17.3	112.5	51.6	0	853.5	71.13
2012	0	0	19.4	114	96.5	69.2	149	245.4	259	167	17.6	8.6	1146	95.47
2013	0	0	132.5	137.4	114	51	269	139	130	224.3	39.8	0	1237	103.1
2014	18.8	28	132.6	185.5	350.6	118	230	239	265	0	0	0	1567	130.6
2015	0	0	0	269.8	244.5	214	75.2	16.2	42.6	50.6	85.4	0	998.3	83.19
2016	31.6	32.2	0	211	227	101	71.4	126.4	75.1	303.8	20.1	0	1200	100
Mean	23.45	26.63	60.45	181.3	202.3	116	135	136.9	133	136.1	43	8.77	1203	100.2

Appendix 5: Monthly rainfall Data at Hagere Selam Station (mm).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
2007	84.20	51.70	53.30	211.50	196.20	245.40	117.20	278.40		84.70	1.81	2.00	120.58
2008	0.00	24.00	47.40	109.40	159.70	170.20	90.00	158.00	212.30	143.50	103.80	5.00	101.94
2009	91.90	36.30	72.90	126.60	220.60	78.90	46.60	249.80	72.90	142.80	29.60	77.30	103.85
2010	25.90	181.60	200.70	263.10	329.90	111.10	96.30	130.60	193.20	214.50	3.60	6.10	146.38
2011	18.10	35.70	51.30	48.40	368.40	150.20	143.30	154.50	150.20	199.40	259.70	13.50	132.72
2012	2.40	2.10	24.50	264.70	137.20	112.20	89.10	78.80	158.90	145.10	39.20	34.50	90.73
2013	5.90	96.60	93.00	322.40	328.40	116.90	144.80	171.70	96.00	138.20	119.20	0.00	136.09
2014	7.58	20.45	108.03	128.78	386.37	262.30	137.70	239.30	245.20	205.40	110.60	18.20	155.83
2015	30.00	22.60	35.70	244.10	244.90	113.80	58.50	135.80	122.10	116.40	152.40	74.20	112.54
2016	29.50	10.50	75.30	199.80	283.00	179.60	133.50	182.20	159.60	176.80	47.80	0.00	123.13
Mean	29.50	48.20	76.20	191.90	265.50	154.10	105.70	177.90	156.70	156.70	86.80	23.10	122.68

Appendix 6: Monthly average Maximum and Minimum Temperature at Hagereselam Station(°C).

Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
2007	Tmax	18.7	20.11	20.3	19.2	19.28	17.77	18.89	18.7	18.24	18	18.24	20.72	18.99
	Tmin	6.48	7.42	6.37	7.08	7.58	6.24	7.43	7.09	6.02	7.5	6.02	4.28	6.63
2008	Tmax	20.53	20.32	20.4	20.2	20.02	18.67	17.18	16.3	17.33	19	18.14	18.8	18.87
	Tmin	3.82	5.12	5.22	5.64	6.98	6.56	6.17	5.84	6.49	5.6	4.18	3.49	5.42
2009	Tmax	20.98	21.21	22.7	18.6	18.59	19.45	17.5	17.3	17.24	17	18.2	18.45	18.89
	Tmin	4.09	4.21	5.38	6.46	5.66	4.97	4.09	5.06	4.9	3.6	5.82	6.05	5.02
2010	Tmax	19.24	19.36	19.6	20.5	20.74	20.54	15.77	16	18.24	20	19.56	20.23	19.12
	Tmin	5.97	6.7	7.24	8.17	9.14	8.02	7.24	7.4	7.27	7	5.91	5.09	7.09
2011	Tmax	20	19.98	19.7	19.7	18.94	18.64	18.45	17.1	18.64	21	20.71	18.45	19.25
	Tmin	6.05	6.45	6.73	7.12	7.65	7.34	6.16	6.45	7.34	6.1	6.07	3.49	6.41
2012	Tmax	24.52	24.59	24.3	18.4	18.04	18.24	18.89	17.1	17.83	19	19.98	24.07	20.40
	Tmin	5.21	5.56	6.92	5.36	5.63	5.45	3.77	6.07	6.02	5.6	5.7	4.64	5.49
2013	Tmax	26.04	25.84	20.4	19.3	19.1	18.77	17.5	17.3	17.24	17	23.9	27.23	20.75
	Tmin	5.16	5.07	5.22	5.62	5.6	5.5	3.77	3.77	3.77	3.8	5.79	3.45	4.71
2014	Tmax	20.98	21.21	22.7	18.6	18.59	22.53	21.84	19.2	19.64	20	21.64	23.42	20.84
	Tmin	4.09	4.21	5.38	6.46	5.66	6.06	5.1	3.79	4.94	6	6.41	4.55	5.22

2015	Tmax	27.29	25.43	24	19.7	18.9	19.13	18.65	18.7	19.7	20	20.07	20.65	21.00
	Tmin	6.5	6.5	5.29	4.63	4.67	5.02	3.77	4.15	4.12	4.4	4.67	4.72	4.87
2016	Tmax	21.58	20.45	22.6	19.8	18.61	17.97	18.56	19	19.4	20	22.5	25.58	20.49
	Tmin	5.04	5.53	5.63	5.32	4.72	3.74	3.46	3.44	4.22	4.1	3.25	3.08	4.29
2017	Tmax	27.32	26.07	26.3	23.6	19.28	17.77	17.75	17.7	18.63	20	19.56	20.23	21.16
	Tmin	2.67	4.16	4.17	3.91	7.65	7.34	3.02	2.81	3.23	3.6	5.82	6.05	4.53

Appendix 7: Monthly average Maximum and Minimum Temperature at Dilla Station (°C).

Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
2007	Tmax	29.46	31.01	30.36	28.31	28.26	27.10	26.15	25.84	25.52	27.11	28.18	29.08	51.75
	Tmin	12.27	12.32	12.06	13.98	14.34	15.15	14.85	14.44	14.69	12.15	11.75	8.10	24.02
2008	Tmax	30.68	30.93	31.72	28.46	26.09	25.88	24.64	25.20	26.30	26.31	27.29	29.18	51.18
	Tmin	9.30	9.89	11.07	13.73	14.06	13.92	15.15	14.43	14.37	13.80	11.48	9.21	23.14
2009	Tmax	29.64	30.94	32.34	28.13	28.30	27.27	26.88	27.59	27.10	27.38	29.46	28.95	52.92
	Tmin	10.20	11.24	12.44	14.34	14.30	13.19	13.57	13.78	14.20	14.06	11.35	17.47	24.64
2010	Tmax	29.21	29.45	28.46	27.95	26.84	26.44	25.06	25.59	25.91	27.49	29.45	29.93	51.04
	Tmin	11.32	14.81	14.45	15.03	15.70	14.74	15.07	15.39	14.72	13.94	11.09	9.60	25.52
2011	Tmax	31.03	31.94	32.03	31.74	27.02	25.96	25.94	25.49	25.52	27.29	26.48	28.06	52.08
	Tmin	10.03	9.73	12.94	13.76	15.43	15.24	14.73	14.76	14.66	12.95	13.82	9.85	24.29

2012	Tmax	30.70	31.88	32.38	28.28	27.50	26.57	26.00	26.01	25.43	27.30	29.50	29.15	52.42
	Tmin	8.16	8.28	10.80	14.17	13.87	14.55	14.50	14.73	14.35	13.25	12.60	11.10	23.13
2013	Tmax	30.59	32.37	30.25	27.56	28.30	25.60	24.66	24.99	26.23	26.13	27.21	27.70	51.01
	Tmin	10.43	10.61	15.36	14.85	15.70	14.94	15.11	14.56	14.10	14.03	12.91	17.50	26.17
2014	Tmax	30.17	30.28	30.66	28.57	27.01	26.69	25.96	25.84	26.18	26.31	27.65	28.56	51.37
	Tmin	10.55	12.92	12.98	13.13	14.30	13.57	14.45	13.90	13.56	14.19	12.61	9.93	24.01
2015	Tmax	30.38	31.92	32.01	28.75	27.52	26.58	26.70	28.02	27.53	27.65	28.20	29.10	52.98
	Tmin	8.05	9.93	12.26	13.50	14.36	14.49	13.96	13.06	13.05	13.69	11.30	17.50	23.87
2016	Tmax	30.55	31.93	31.76	28.40	27.20	26.23	25.48	25.20	26.51	26.99	28.24	29.12	51.94
	Tmin	13.32	11.61	13.55	16.13	15.02	13.97	15.73	15.40	13.76	14.09	12.12	9.32	25.23
2017	Tmax	30.79	31.19	32.18	30.05	27.11	27.27	25.31	25.42	25.91	27.49	29.45	29.93	52.63
	Tmin	5.76	11.05	12.96	13.70	14.94	14.05	15.37	14.77	14.20	14.06	11.35	17.47	24.57

Appendix 8: Monthly average Maximum and Minimum Temperature at Teferikella Station (°C).

Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
2006	Tmax	27.9	27.9	26.8	24.6	24.5	23.9	22.8	23.5	23.7	24.2	24.1	25.1	24.92
	Tmin	13.1	13.5	11.6	11.7	12.1	10.8	9.7	10.0	10.8	10.4	10.8	11.4	11.32
2007	Tmax	26.7	27.7	28.7	26.2	25.0	24.5	24.1	22.9	24.1	24.1	25.0	26.6	25.47
	Tmin	10.9	10.6	9.3	7.3	12.9	11.5	11.7	12.3	12.6	10.8	9.8	7.9	10.63
2008	Tmax	28.3	28.4	29.0	26.1	24.9	24.0	22.4	23.3	24.1	24.2	25.2	27.0	25.59
	Tmin	7.9	7.2	10.7	12.6	12.2	11.7	12.4	12.8	13.2	13.5	12.4	6.8	11.11
2009	Tmax	26.8	28.0	29.2	25.3	24.4	24.4	23.9	24.8	24.5	24.9	26.4	25.4	25.65
	Tmin	8.3	9.1	11.1	12.1	12.4	11.3	11.4	11.9	12.2	12.1	9.3	11.4	11.05
2010	Tmax	26.3	26.6	25.8	25.4	24.7	25.1	24.2	24.8	23.9	24.5	27.1	27.1	25.47
	Tmin	9.1	11.4	12.3	12.3	13.3	12.8	12.3	12.1	11.6	11.3	10.6	11.1	11.69
2011	Tmax	28.2	28.3	28.5	27.3	24.5	24.6	24.7	24.6	24.7	25.3	25.2	26.5	26.04
	Tmin	8.6	7.6	11.0	12.2	12.5	12.4	12.3	12.0	12.3	11.5	11.5	9.8	11.14
2012	Tmax	28.1	28.5	28.6	25.6	25.0	24.3	25.0	24.5	23.0	23.3	25.2	26.6	25.64
	Tmin	9.2	9.9	11.3	11.9	12.0	11.2	10.5	11.3	11.1	10.6	10.6	9.4	10.75
2013	Tmax	28.0	29.0	27.2	24.6	24.8	24.6	25.1	25.4	24.7	23.9	25.2	20.0	25.22
	Tmin	9.8	9.7	12.2	11.7	11.5	12.4	11.7	11.4	11.6	11.8	11.2	10.2	11.28
2014	Tmax	27.5	27.4	27.2	26.3	25.3	25.4	24.7	26.1	24.5	24.0	25.0	21.0	25.36
	Tmin	10.9	11.3	11.8	12.1	13.0	12.2	12.1	11.7	12.1	12.7	11.9	6.8	11.55
2015	Tmax	28.1	28.9	28.4	27.1	25.0	24.1	26.3	27.0	26.6	25.0	24.8	25.8	26.43
	Tmin	8.7	11.2	11.9	11.2	12.1	13.0	11.6	11.5	12.7	12.7	12.5	10.9	11.66

2016	Tmax	27.3	29.0	29.7	26.0	25.0	24.6	26.5	28.4	26.5	24.9	25.4	27.2	26.70
	Tmin	11.6	10.1	12.2	13.9	12.9	12.2	12.4	11.7	11.0	12.1	10.2	9.6	11.65
2017	Tmax	28.2	28.0	29.8	28.0	25.2	25.4	24.9	25.7	23.9	23.7	26.8	27.6	26.43
	Tmin	3.7	4.2	4.5	4.2	13.4	13.8	12.7	12.6	13.7	13.8	13.0	6.0	9.64

Appendix 9: Monthly relative humidity at Dilla Station (%).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
2002	59.87	49.68	64.77	67.10	73.29	73.50	72.19	73.93	82.20	74.00	77.20	76.61	70.36
2003	67.74	64.75	61.23	80.50	77.38	74.87	74.74	75.77	72.47	86.00	67.16	70.47	72.76
2004	65.45	66.03	52.39	72.43	70.00	72.93	71.06	69.52	71.73	68.32	67.30	64.38	67.63
2005	54.58	44.89	56.97	63.47	79.84	76.23	76.58	74.16	75.50	78.87	68.10	59.06	67.35
2006	57.97	56.18	65.19	72.60	75.42	76.33	77.29	77.45	73.87	78.00	71.97	69.55	70.99
2007	60.45	56.96	67.48	69.20	75.29	74.17	76.17	79.35	81.13	77.48	86.00	63.19	72.24
2008	52.65	49.14	25.90	51.83	63.48	63.33	68.03	65.90	63.53	61.32	53.03	40.23	54.86
2009	36.55	33.54	31.26	52.30	60.00	56.00	52.32	49.71	54.00	57.26	41.90	72.81	49.80
2010	41.55	48.18	53.06	58.73	75.00	62.70	62.74	69.52	71.73	68.32	67.30	64.38	61.93
2011	37.00	31.68	32.39	36.50	60.06	64.77	65.23	66.16	64.10	57.03	60.17	46.74	51.82
2012	28.71	26.14	24.94	47.90	59.61	58.17	56.00	61.85	61.03	56.26	60.17	44.97	48.81
2013	37.26	32.25	41.61	52.93	60.00	71.57	74.29	72.48	71.27	71.45	60.00	57.03	58.51
2014	37.00	56.29	70.03	59.77	67.52	66.07	68.94	69.26	69.50	73.32	65.43	62.35	63.79
2015	47.26	40.89	61.42	69.20	75.29	68.33	62.70	62.74	69.52	56.26	60.17	44.97	59.90
2016		53.14	68.62	69.32	70.80	71.71	71.71	65.90	63.53	61.32	53.03	40.23	62.66
Mean	48.86	47.32	51.82	61.59	69.53	68.71	68.67	68.91	69.67	68.35	63.93	58.46	62.23

Appendix 10: Monthly Wind Speed at Dilla Station (m/s).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
2006	0.65	0.8	0.59	0.6	0.58	0.36	0.3	0.4	0.4	0.37	0.36	0.35	0.48
2007	0.50	0.59	0.57	0.46	0.47	0.45	0.41	0.33	0.41	0.49	0.51	0.50	0.47
2008	0.59	0.78	0.86	0.61	0.46	0.44	0.33	0.36	0.37	0.34	0.37	0.46	0.50
2009	0.53	0.63	0.78	0.52	0.47	0.39	0.39	0.50	0.43	0.40	0.48	0.17	0.47
2010	0.49	0.49	0.49	0.42	0.33	0.32	0.28	0.28	0.31	0.42	0.42	0.46	0.39
2011	0.57	0.66	0.67	0.65	0.41	0.34	0.30	0.29	0.30	0.33	0.27	0.33	0.43
2012	0.44	0.53	0.65	0.48	0.36	0.30	0.47	0.29	0.30	0.35	0.36	0.38	0.41
2013	0.43	0.70	0.60	0.41	0.47	0.28	0.25	0.31	0.31	0.29	0.42	0.35	0.40
2014	0.96	0.52	0.60	0.43	0.34	0.28	0.27	0.28	0.29	0.25	0.31	0.35	0.41
2015	0.65	0.80	0.59	0.60	0.58	0.26	0.25	0.36	0.33	0.31	0.42	0.46	0.47
2016	0.96	3.66	0.65	0.39	0.33	1.21	0.31	0.36	0.37	0.34	0.37	0.46	0.78
Mean	0.62	0.92	0.64	0.51	0.44	0.42	0.33	0.34	0.34	0.35	0.39	0.39	0.47

Appendix 11: Monthly Sunshine Duration per Hour at Dilla Station.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
2006	8.73	7.96	6.92	5.9	3.8	3.7	3.3	4.1	6.2	7.12	8.16	8.03	6.16
2007	7.41	4.68	5.89	4.88	4.54	3.49	3.43	6.12	8	9.32	9.17	8.41	6.28
2008	8.54	6.46	5.06	4.46	3.35	3.66	3.41	4.78	7.99	8.82	7.41	8.56	6.04
2009	8.26	5.71	6.6	5.89	4.42	4.61	4.19	5.7	7.82	5.98	7.62	5.12	5.99
2010	4.92	5.3	3.56	4.3	2.12	2.77	4.15	5.85	8.4	8.15	8.8	9.38	5.64
2011	8.15	7.12	0.41	4.4	3.82	3.71	3.25	5.87	5.56	8.97	8.4	8.63	5.69
2012	6.66	5.66	5.19	0	3.95	3.23	6.09	5.59	8.83	6.09	7.82	5.59	5.39
2013	8.8	6.7	3.45	3.3	3.38	4.44	5.35	3.38	4.44	5.35	8	9.3	5.49
Mean	7.68	6.2	4.64	4.1	3.67	3.7	4.15	5.18	7.15	7.48	8.17	7.88	5.84

Appendix 12: ETO and climatic data for Kebado meteorological station.

	COUNTRY	ETHIOPIA			Station	KAEBADO	
	Altitude	1807m	Latitude	6.3°	Longitude	38.4°	
Month	Min Temp (°C)	Max Temp (°C)	Humidity %	Wind (m/s)	Sun (hours)	Rad (MJ/m²/day)	ETo (mm/day)
January	9.9	30.5	49	0.6	6.7	18	3.59
February	11.1	31.9	47	0.9	6.2	18.3	4.08
March	12.8	31.7	52	0.6	4.6	16.5	3.68
April	14.2	28.9	62	0.5	4.1	15.7	3.38
May	14.7	27.3	69	0.4	3.7	14.7	3.08
June	14.3	26.4	69	0.4	3.7	14.3	2.93
July	14.8	25.7	69	0.3	4.2	15.1	2.99
August	14.5	26	69	0.3	9.9	24.2	4.36
September	14.2	26.3	70	0.3	11.1	26.4	4.7
October	13.7	27	68	0.3	12.8	28.4	4.92
November	12	28.2	64	0.4	14.2	29	4.86
December	12.5	28.9	58	0.4	14.7	28.9	4.77
Average	13.2	28.2	62	0.5	8	20.8	3.94

Appendix 13: ETO and climatic data for Teferi Kela meteorological station.

	COUNTRY	ETHIOPIA			Station	Teferi Kela	
	Altitude	1870m	Latitude	6.3°	Longitude	38°	
Month	Min Temp (°C)	Max Temp (°C)	Humidity %	Wind (m/s)	Sun (hours)	Rad (MJ/m²/day)	ETo (mm/day)
January	10.6	27.5	49	0.6	7.7	19.5	3.64
February	11.9	28	47	0.9	6.2	18.3	3.89
March	12.6	28.5	52	0.6	4.6	16.6	3.58
April	12.7	26	62	0.5	4.1	15.8	3.25
May	12.6	24.5	69	0.4	3.7	14.6	2.91
June	12.7	24.1	69	0.4	3.7	14.3	2.8
July	12.5	23.9	69	0.3	4.2	15	2.87
August	12.4	23.7	69	0.3	5.2	17.1	3.16
September	12.2	24.7	70	0.3	7.2	20.3	3.67
October	12.3	24.3	68	0.3	7.5	20.4	3.62
November	11.1	25.2	64	0.4	8.2	20.4	3.54
December	10.8	26.4	58	0.4	7.9	19.4	3.38
Average	12	25.6	62	0.5	5.8	17.6	3.36

Appendix 14: ETO and climatic data for Dilla meteorological station.

COUNTRY	ETHIOPIA			Station	Dilla		
Altitude	1515m	Latitude	6.3°	Longitude	38.5°		
Month	Min Temp (°C)	Max Temp (°C)	Humidity %	Wind (m/s)	Sun (hours)	Rad (MJ/m^2/day)	ETo (mm/day)
January	9.9	30.5	49	0.6	7.7	19.5	3.77
February	11.1	31.2	47	0.9	6.2	18.3	4.04
March	12.8	31.7	52	0.6	4.6	16.6	3.69
April	14.2	28.9	62	0.5	4.1	15.8	3.37
May	14.7	27.3	70	0.4	3.7	14.6	3.04
June	14.3	26.4	69	0.4	3.7	14.3	2.91
July	14.8	25.7	69	0.3	4.2	15.1	2.95
August	14.5	26	69	0.3	5.2	17.1	3.28
September	14.2	26.3	70	0.3	7.2	20.3	3.76
October	13.7	27	68	0.3	7.5	20.3	3.73
November	12	28.2	64	0.4	8.2	20.3	3.65
December	12.5	28.9	58	0.4	7.9	19.3	3.5
Average	13.2	28.2	62	0.5	5.8	17.6	3.47

Appendix 15: ETO and climatic data for Hagereselam meteorological station.

	COUNTRY	ETHIOPIA			Station	Hagereselam	
	Altitude	2809m	Latitude	6.5°	Longitude	38.5°	
Month	Min Temp (°C)	Max Temp (°C)	Humidity %	Wind (m/s)	Sun (hours)	Rad (MJ/m²/day)	ETo (mm/day)
January	9.9	30.5	49	0.6	7.7	19.4	3.88
February	11.1	31.5	47	0.9	6.2	18.3	4.12
March	12.8	31.7	52	0.6	4.6	16.6	3.79
April	14.2	28.9	62	0.5	4.1	15.8	3.49
May	14.7	27.3	69	0.4	3.7	14.6	3.17
June	14.3	26.4	69	0.4	3.7	14.3	3.04
July	14.8	25.7	69	0.3	4.2	15.1	3.1
August	14.5	26	70	0.3	5.2	17.1	3.43
September	14.2	26.3	70	0.3	7.2	20.3	3.94
October	13.7	27	68	0.3	7.5	20.3	3.9
November	12	28.2	64	0.4	8.2	20.3	3.82
December	12.5	28.9	58	0.4	7.9	19.3	3.64
Average	13.2	28.2	62	0.5	5.8	17.6	3.61