Addis Ababa University

Addis Ababa institute of Technology

School of Civil and Environmental Engineering

SURFACE IRRIGATION POTENTIAL MAPPING USING GIS AND REMOTE SENSING BASED MULTI CRITERIA ANALYSIS IN THE ABBAY BASIN, UPPER BLUE NILE, ETHIOPIA

A Thesis in Geodesy and Geomatics

By:

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A Thesis

Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Geodesy and Geomatics.

Addis Ababa University

Addis Ababa Institute of Technology (aait)

School of Civil and Environmental Engineering

The undersigned have examined the thesis entitled 'Surface irrigation Potential Mapping using GIS and Remote Sensing based Multi criteria Analysis in Abbay Basin, Upper Blue Nile, Ethiopia' presented by Kitessa Gidisa, a candidate for the degree of Master of Science in Geodesy and Geomatics and hereby certify that it is worthy of acceptance.

Advisor	Signature	Date
Internal Examiner	Signature	Date
External Examiner	Signature	Date

DECLARATION

I certify that research work titled "Surface irrigation Potential Mapping using GIS and Remote Sensing based Multi criteria Analysis in the Abbay Basin, Upper Blue Nile, Ethiopia" is my work which I submit to the School of Civil and Environmental Engineering of Addis Ababa University Institute of Technology for the requirement of the degree of Master of Science in Geodesy and Geomatics. This work has not been done elsewhere for analysis.

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Lists of Acronyms

ARC SWAT	Soil and Water Assessment Tool
CWR	Crop Water Requirement
DEM	Digital Elevation Model
FAO	Food and Agricultural Organization of United Nations
GIS	Geographic Information System
GPS	Global Positioning System
Hec-GeoHMS	Geospatial hydrologic Modeling Extension
ISRIC	International Soil Reference and Information Center
LU/LC	Land use Land cover
MCDM	Multi-criteria Decision Making
MODIS	Moderate Resolution Imaging Spectro Radiometer
NASA	National Aeronautics and Space Administration
OLI	Operational Land Imager
STRM	Shuttle Radar Topography Mission Shuttle
SCS-CN	Soil Conservation service –Curve Number
TIRS	Thermal Infrared Sensor
USGS	United States Geological Survey

Abstract

Multi-criteria irrigation land suitability analysis and mapping can play an important role not only in sustainable use of scarce resource, but also in overcoming the global problem of water scarcity and crop production caused due to high degree of rainfall variability and unreliability. The General objective of this work was to Map suitable land for Surface irrigation potential using GIS and remote sensing based multi criteria analysis in the abbay basin, upper Blue Nile, Ethiopia. The study employed Geographical information System-based multi criteria land suitability analysis method considering eight factors, namely, soil pH, soil drainage, soil depth, Cation Exchange capacity of the soil, texture classes, Runoff, slope, and distance from the main river to find suitable land for surface irrigation. Using the Weighted Overlay tool, the values of each dataset were weighted and combined to find the most suitable location for irrigation using the ArcGIS environment. The results of the study revealed that about 5741870.55 ha (29.26 % of the watershed area) highly suitable, 7013480.98 ha (35.74 % of the watershed area) moderately suitable, 5013834.33 ha (25.55 % of the watershed area) marginally suitable, 1854431.87 ha (9.45 % of the watershed area) not suitable. The findings drawn from this study can play an indispensable role in boosting irrigable land in the study area by considering suitable irrigable lands in terms of the eight factors described. About 38892.70ha of land can be irrigated at the gauge location of the rivers in South Gojam watersheds without further development on the downstream.

Keywords: Blue Nile Basin; Irrigation; Land suitability evaluation; Multi-criteria analysis.

1. INTRODUCTION

1.1 Background

The high dependency on rain-fed farming in the dry lands of Ethiopia and the erratic rainfall requires an alternative means to improve agricultural production and productivity. These can be achieved through an optimal development of surface irrigation potentiality (FAO, 2003). Surface irrigation is the application of water by gravity flow to the surface of a field either the entire field is flooded (basin irrigation) or the water is fed into small channel (furrow) or strip of land (borders). These irrigation scheme can be developed up to end user with a minimal capital investment (Kalkhajeh et al., 2012). Proper land suitability evaluation of land resources in irrigation command area is a prerequisite for better utilization of land resources which help to optimize and sustain the productivity of these land resources. Availability of irrigation leads to land use change as well as intensive cropping system. Improper use of irrigation water has resulted in degradation of natural resources that leads to decline in the productivity of land resources and deterioration of land quality for its future use (Sulieman et al., 2015). So as to address this water challenge, Geographic Information System (GIS) based Multi-Criteria Land Suitability Analysis (MCLSA) techniques were applied.

The techniques can handle large volumes of datasets considering all spatial factors to select surface irrigation site. Kumi-Boateng et al. (2016) suggested that GIS based Multi-Criteria Evaluation Land Suitability Analysis (MCELSA) techniques are possible way of making optimal decisions in selecting suitable land for surface irrigation. GIS based Multi-criteria evaluation (MCE) techniques are the numerical algorithms that define suitability of solution based on input criteria and weights together with some mathematical or logical means of determining tradeoffs when conflicts arise. In this technique, weight can be assigned to the geospatial dataset from various sources to reflect their relative importance (Abeyou et al., 2012) and overlaid using GIS-based multi-criteria analysis techniques in the ArcGIS software environment. Therefore, this study was aimed at identifying suitable areas on GIS and remote sensing-based MCE for surface irrigation along the Upper Blue Nile River Basin, Ethiopia

1.2 Problem of the Statement

It is estimated that the eight major river basins of Ethiopia can irrigate about 5.3 million hectares of land (Awulachew *et al*., 2010). However, combination of population growth, land degradation, and more frequent droughts will result in more frequent food-related crises. Surface irrigation development is therefore perceived as one of the strategies with the potential for solving the paradox (Makombe *et al*., 2007).

According to Awulachew *et al*. (2010) irrigation could represent a cornerstone of the agricultural development of the country. However, there is no consistent and reliable inventory and well-studied document in water and irrigation related potentials in the Ethiopian context (Haile and Kasa 2015). Awulachew *et al*. (2007) similarly indicated that the methods used to estimate the surface irrigation potential in the master plans underestimate the actual potential, and there is significant potential to increase irrigation through surface water schemes. The study revealed that national water resources master plan was a desk study without significant field investigation and these studies did study the Surface water potential of the rivers of their respective areas (selected watershed).

1.3 Objectives

1.3.1 General objective

The General objective of this Study was to Map suitable area for Surface irrigation potential using GIS and remote based multi criteria analysis in the abay basin, upper Blue Nile.

1.3.2 Specific objective

The following were the specific objectives of the study:

- To identify areas potentially suitable for surface irrigation.
- To quantify the amount of water available for irrigation.
- To identify area suitable for irrigation based on the available water and land resources.

1.4 Questions

- How much of land in the Blue Nile river basin is potentially suitable for Surface irrigation potential?
- How much area surface water can irrigate in the basin using surface irrigation methods at the upper part of the basin (of south Gojam watersheds)?

1.5 Significance

The land and water resources of the basin could be used for future irrigation project expansion/development. The research will also build the capacity of researchers in identifying and mapping potential irrigable lands at catchment and river basin levels in Ethiopia.

1.6 Thesis Organization

Chapter one discusses the background information of the study area. Chapter two provides a brief review of the literature. Chapter three highlights the characteristics of the study area as well as datasets used in the study, their sources and methods of collection and analysis. Chapter four present and discusses results of analysis on the irrigable area irrigation potential with available water resources. Chapter five presents the main conclusions drawn from the study and recommendations proposed for future consideration.

2. LITERATURE REVIEW

2.1 Definition of irrigation potential

Surface irrigation is the process by which water is convey from a perennial river and for the purpose of agricultural production (FAO, 1986).

2.2 GIS-based Land Suitability Analysis for Irrigation

Land capability classification is the grouping of specific areas of land by the fitness of a given type of land for defined uses (FAO, 1985) based on the evaluation of the biophysical resources (FAO, 2007). Parametric evaluation approach (Sys et al., 1991) and Multi-Criteria analysis (Malczewski, 2004) are the common approaches for land suitability analysis.

2.2.1Parametric evaluation approach

Parametric evaluation approach (Sys et al., 1991) is a method of evaluation for irrigation purposes based on the standard granulometrical and physico-chemical characteristics of a soil properties. The factors affecting soil suitability for irrigation purposes are physical properties determining the soil-water relationship in the soil and chemical properties interfering with the salinit y/alkalinity status, drainage properties, and environmental factors such as slope.

2.2.2 Multi-Criteria analysis approach

Multi criteria analysis is one of the most important procedures for GIS-based decision making processes (Jankowski, 1995; Malczewski, 2000). MCA can be used to define the most suitable areas for irrigation potential analysis. In MCA technique, generation of the suitability maps for given irrigation potential is the very first step. Combining these maps to decide which crop to be best fitting for a specific location is a difficult task, so relative importance of various criteria can be well evaluating to determine the suitability by MCA techniques (Ceballos and Blanco, 2003).

2.3 Past works on land evaluation for irrigation.

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 demand topographic factor (slope) in identifying potential irrigable sites in downstream side of the dam.

Negash, (2004) He conducted GIS and remote sensing land suitability analysis on irrigation in Chamo basin, northern part of Ethiopia. In this work, water resource potential was assessed monthly flow as well as the 70%, 80%, 90% time of non-exceedance flow accuracy by maintaining about 20% of the flow. According to the study in order to exaggerate the irrigable land for irrigation the storage requirement was estimated with respect to many flow accuracy.

3. MATERIALS AND METHODS

3.1 Description of the study area

The Abay basin which is of a strategic importance to Ethiopia is located in the north western part of Ethiopia between 7° 40’ N and 12°51’ N latitude, and 34° 25’ E and 39° 49’ E longitude. The river basin is the second largest in area coverage (199,812 km2) and the largest in annual runoff (54.5 BM3). It is well -known as the source of Nile. The basin occupies 20% of the country’s total surface area and it covers an area of 60% of Amhara regional state, 40% of Oromiya regional state and 95% of Benishangul-Gumuz regional states. The basin is subdivided into 16 sub basins based on the major rivers in the basin.

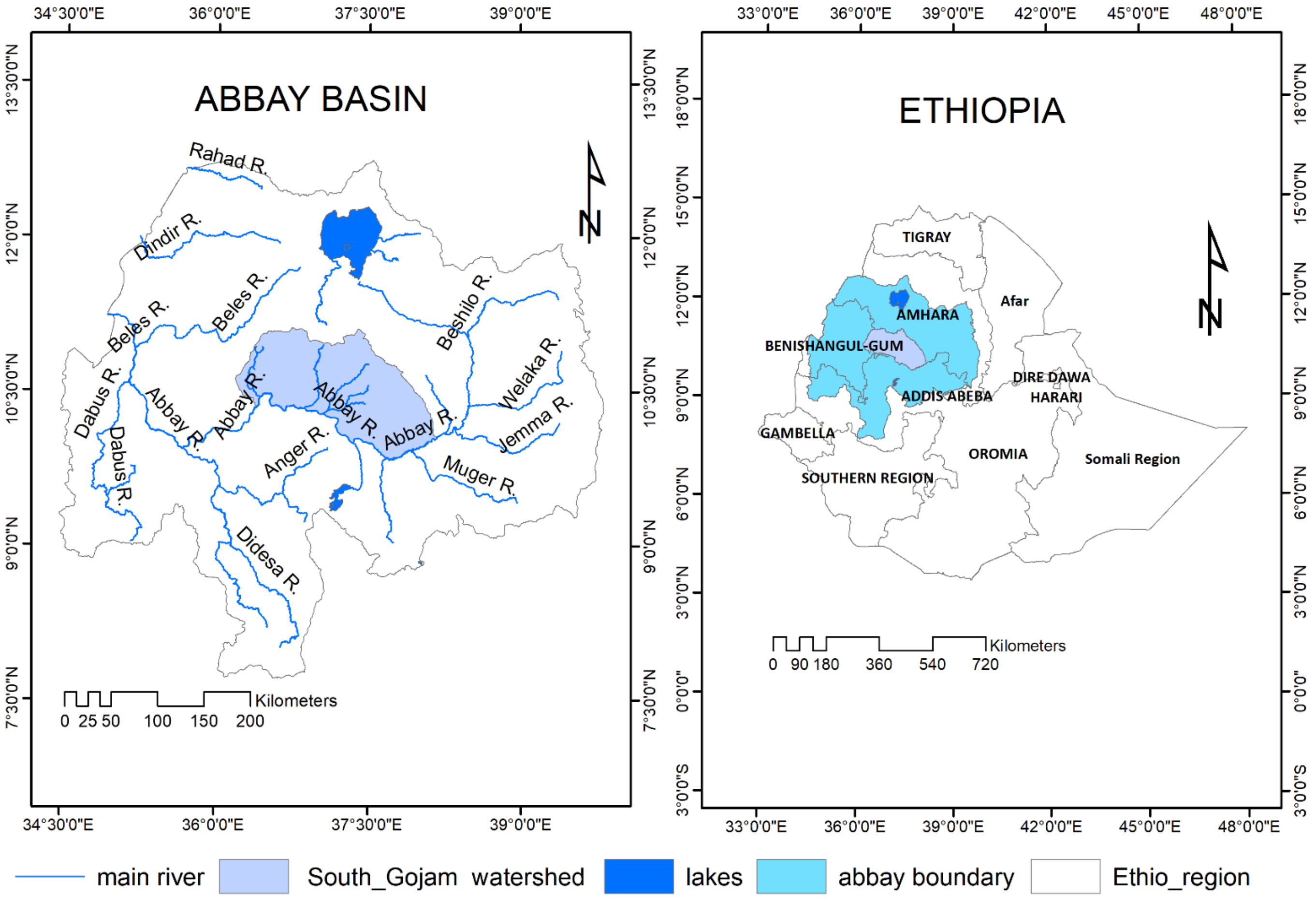


Figure 3. 1 : Study area.

3.1.1 Topography

The topography is generally rugged and mountainous and ranges from 489 m asl on the western part of the basin at Ethiopian–Sudan border to 4261 m asl on the north eastern part of the basin. Figure 3.2.

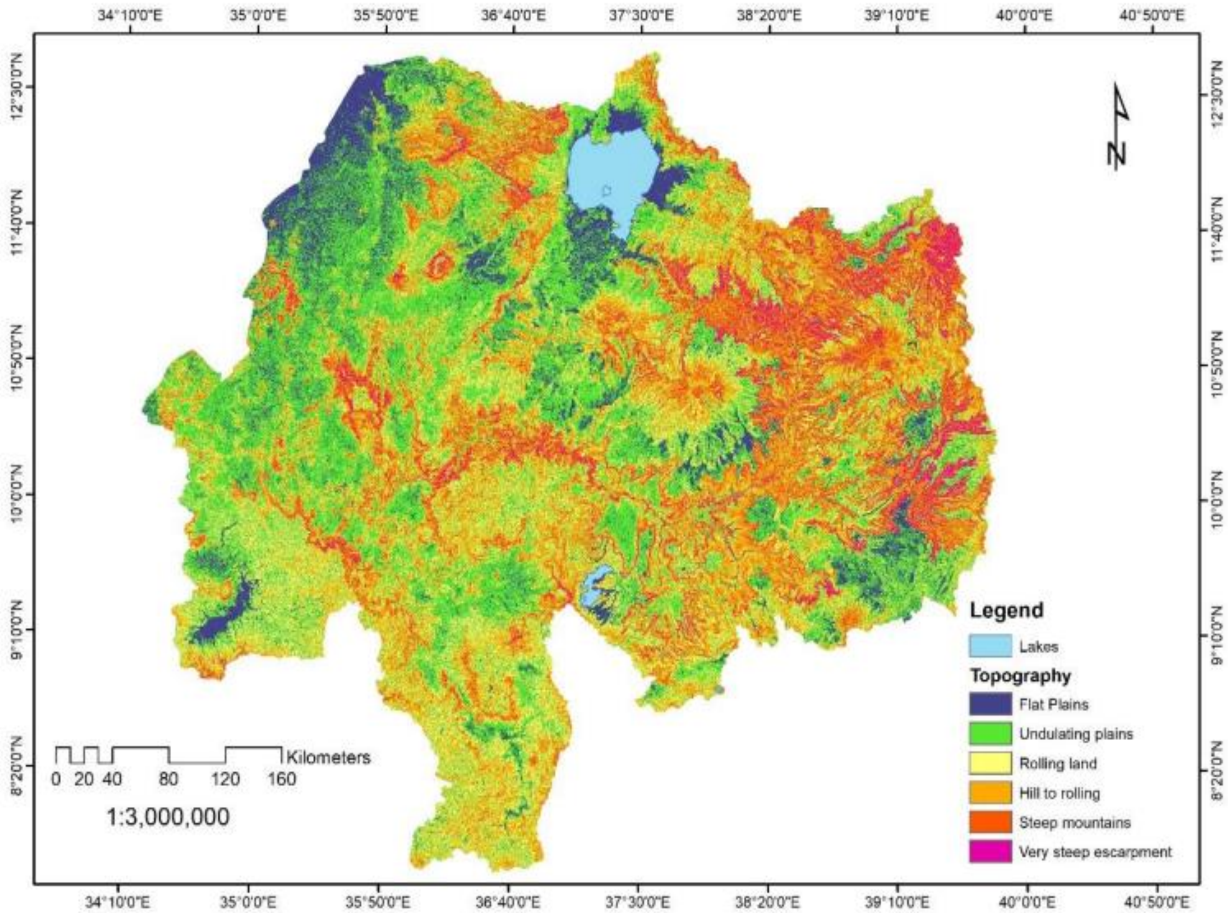


Figure 3. 2: Topographic map of Abay Basin.

Source: Generated from SRTM DEM using Brhane and Mekonen (2009).

3.1.2 Hydrology

The Abay river emerges from Lake Tana as an outflow and is fed by major tributaries like Welaka, Jemma, Beshilo, Muger, Guder, Fincha, Dedissa and Dabus joining river Abay at the left bank, and Bir, Beles, Chemoga , and Jedeb are joining at the right bank. Dinder and Rahad originate from the highlands around the Northwestern part of Lake Tana sub-basin and join in Sudan (Gebrekristos, 2015).

3.2 Datasets

In this study, the irrigation potential of Blue Nile Basin was mapped using Geospatial data from ISRIC (Soil Properties Map of Africa at 250 m Resolution) (Hengl et al., 2015) , ISRIC-WISE derived soil property estimates on a 30 by 30 arcsec global grid (Batjes, 2015) and SRTM DEM (30m), CHIRPS Precipitation(0.05°resolution), Discharge data, MODIS Evapotranspiration (MOD16A2) (500 m) (Mu et al., 2011) and Land sat 8 Level 1C (15m) for Land use Land cover

3.2.1 Landsat 8 OLI/ TIRS Level one

Landsat 8 satellite was launched in February 2013 carrying Operational Land Imager (OLI) instrument consisted of nine spectral bands (band 1 –9). I was download 16 tiles land sat 8 from Earthexplorer.usgs.gov/ for all subasin.

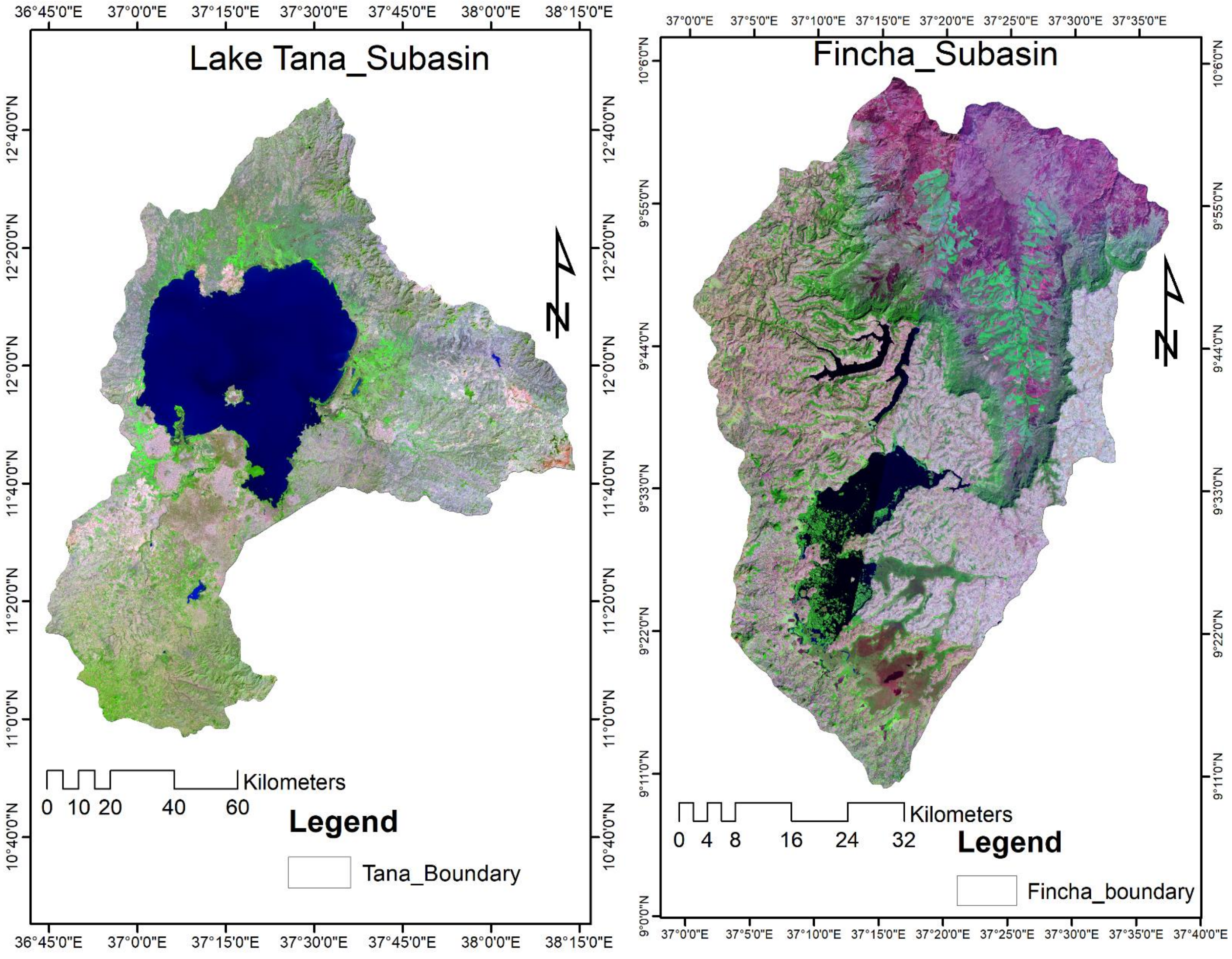


Figure 3. 3: False Natural Color Composite of Lake Tana and Fincha Sub-basins.

3.2.2 SRTM DEM

For 16 subasins thirty-two (32) NASA Shuttle Radar Topography Mission (SRTM) at 3 arc-second (approximately30 m) NASA JPL Version 3.0 tiles downloaded from Earthexplorer.usgs.gov/ and mosaicked to get Dem of the abay basin.

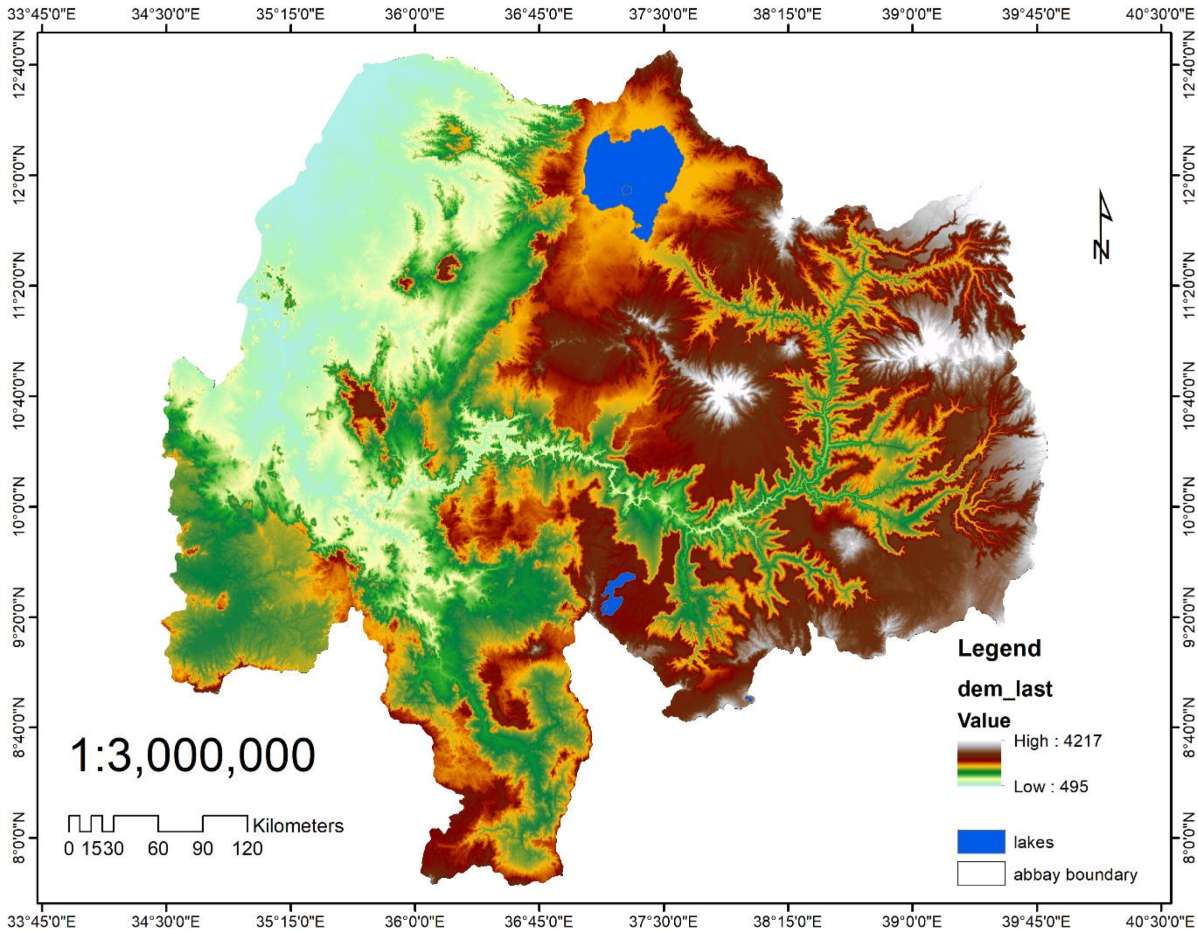


Figure 3. 4: Dem of study area.

3.2.3 Ground Truth for Accuracy

The 1st critical component for any remote sensing and GIS program is concrete ground truth data. Without ground data to identify land cover categories, to train the classifier and validate the output image products. Thus, minimum of 50 sample size for each land use land cover class have been collected combined from Google earth and GPS data collection.

3.2.4 MODIS Evapotranspiration

The MOD16 global evapotranspiration (ET) datasets are regular 1-km2 land surface ET datasets for the 109.03 million km2 global vegetated land areas at 8-day, monthly and annual intervals (**Mu *et al.*, 2011**). The datasets are downloaded from https://lpdaac.usgs.gov/.

The ET algorithm is based on the Penman-Monteith equation and Potential ET extracted using ArcGIS extract sub-dataset extraction tool and multiplied 0.1 to get the real ET/PET values.

3.2.5 CHIRPS Precipitation

The climate hazards infrared precipitation with stations (CHIRPS) (Funk et al., 2015) is a 30+ year quasi-global rainfall datasets are downloaded from Earlywarning.usgs.gov/. CHIRPS incorporates 0.05° resolution satellite imagery with in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring.

3.2.6 Soil Properties Map of Africa

Soil property maps of Africa at 250 m (Hengl et al., 2015) produced by ISRIC. World Soil Information are downloaded from www.isric.org.

3.2.7 ISRIC-WISE Database

ISRIC-WISE derived soil property estimates on a 30 by 30 arcsec global grid (WISE30sec) (Batjes, 2015) datasets considers 20 soil properties and downloaded from www.isric.org.

3.2.8 Discharge Data

Monthly river flow data from 1960 to 2018 (years differ according to installation dates (Table 3.3) of the rivers in Dura, Ardy, Dondor, Buchiksi, Ayo, Missini, Fettam, L.fettam, Abbay, Lay, Leza, Birr, Chereka, Chemoga, Gudla, Jedeb, Muga, Abarim, Suha, Teme, Temcha, Bogena, and Yeda Rivers) were obtained from Ministry of Water, Irrigation and Electricity (MoWIE).

3.3 Methods

The methodology of the study was comprised of two different methodologies. The first method applied multi-criteria analysis approach to map suitability of land for surface irrigation methods. The second method was mainly hydrologic analysis i.e. precipitation, Potential evapotranspiration, coefficients of crops and stream flow to quantify the water resource potential for surface irrigation. The flow chart of the methods followed is shown Figure 3.5.

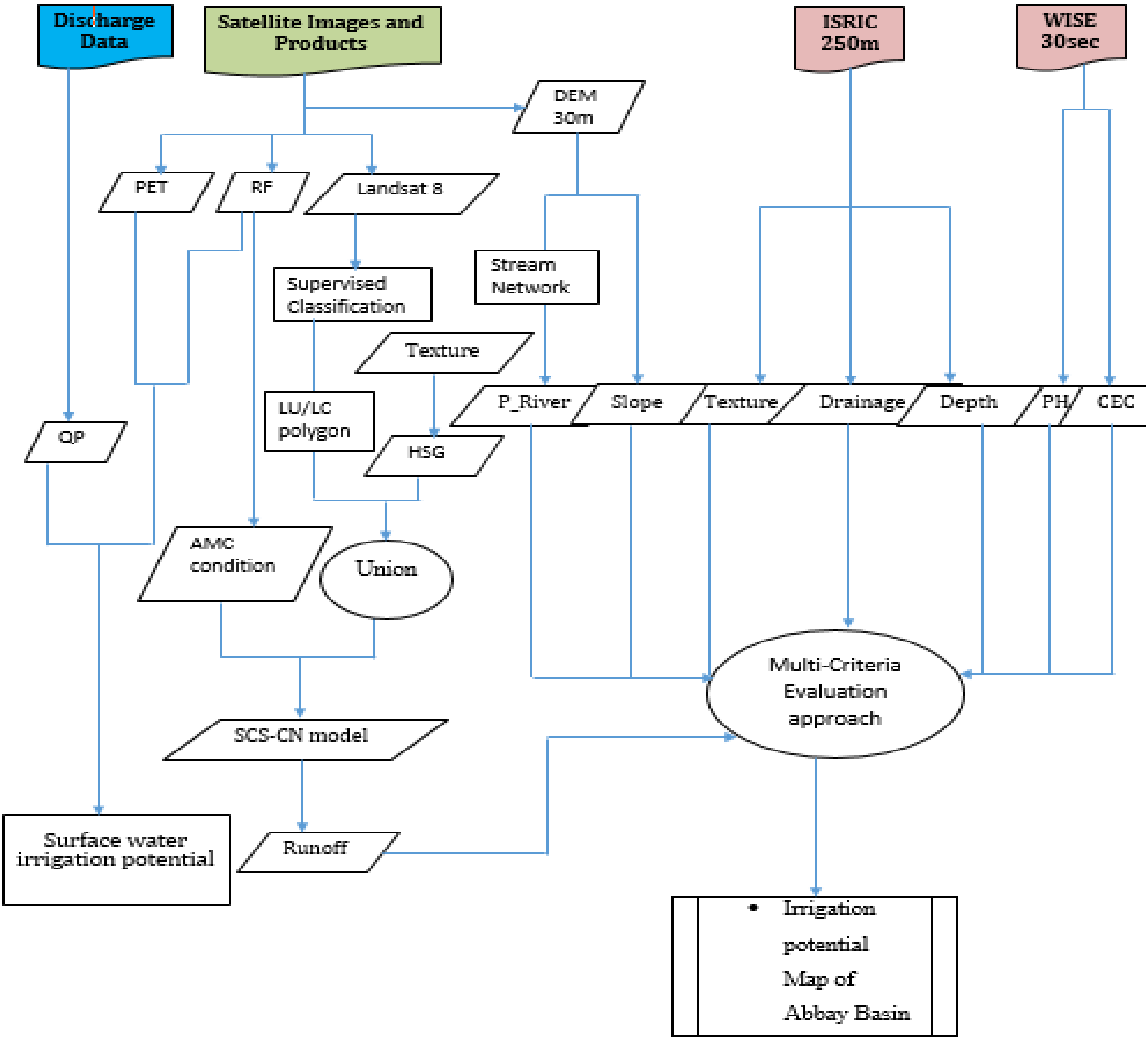


Figure 3. 5: methodology.

3.3.1 Land use land cover mapping

Landsat OLI (Operational Land Imager) data of 2018, band number 1–7 has been used. Supervised image classification technique with maximum likelihood method has been used to show the LULC. To get a different land-use class number of a signature has been collected.

3.3.2 Classification of Landsat images

To retrieve the LULC information, satellite images were used for the all subasin, Landsat OLI/TIRS of 2018 over Abbay Basin, upper Blue Nile River. Once preprocessing was finished, LULC mappings were conducted using supervised classification (maximum likelihood algorithm). All images used were classified into different categories based on images of subasin: built-up (BU), forest, grassland, agricultural land, bare land, and water bodies.

3.3.3 Validation of land use land cover maps

For the execution of the accuracy assessment of each LULC class, a stratified random sampling method was carried out to extract the LULC classification accuracy. For the assessment of accuracy, a total of sample points were selected by visual interpretation of each class from Landsat datasets of all sixteen sub basin individually (Lillesand et al., 2004). User accuracy, producer accuracy, overall accuracy, and the Kappa coefficient were calculated to indicate the level of classification accuracy.

$$Overall\ Accuracy = \frac{\sum CCP(Diagonal)}{\sum CRP} * 100 \quad \text{eq(1)}$$

Where; CCP (Diagonal) is the correctly classified pixels (diagonals) and CRP is the correct reference pixels (the column total).

$$User\ Accuracy = \frac{\sum CCP(Category)}{\sum CPC(Row)} * 100 \quad \text{eq(2)}$$

CCP (Category) the correctly classified pixels and CPC (Row) the classified pixels in that Category (Row total).

$$Producer\ Accuracy = \frac{\sum CCP(Category)}{\sum CPC(Column)} * 100 \quad \text{eq(3)}$$

CCP (Category) is the correctly classified pixels and CPC (Column) is the

Classified pixels in that category (the column total)

$$Kappa\ Coefficients = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+} * x_{+i})} \quad \text{eq(4)}$$

Where; N is the total samples, r is the number of rows in the error matrix, x_{ii} is the total corrected samples in the i^{th} row, and column, N^2 is the square of total samples; x_{i+} is the column total, and x_{+i} is the row total.

3.4 Runoff-BY SCS

This model involves relationship between land cover, hydrologic soil class and curve number. The method is based on an assumption of proportionality between retention and runoff in the form. Normally the SCS model computes direct runoff with the help of following relationship (Hand book of Hydrology, 1972).

S = (24500/CN) - 254 --eq(5)

Q = ((P - 0.2S) ^2/ (P + 0.8S) ------------------- - - ---eq(6)

Where, CN = Weighted curve number for the watershed, which is a function of soil type, land cover and antecedent moisture condition (AMC); Q, actual direct runoff, mm; P, rainfall, mm; and S, the potential maximum retention of water by the soil, mm after runoff begins. To compute the CN values of the different micro watersheds as follows

Where, CN = (Σ (Ci * Ai))/A ---eq(7)

CNi = Curve number for specific land use feature Ai = Area of the specific land use feature failing in the specific HSG A = the total area of the micro watershed

3.5 Analytical Hierarchy Process

The analytical hierarchy process (AHP) is the way to compare parameters by pairwise methods. The evaluation was made on the priority of scale 1–9 this shows occurrence of a layer is important than the other (Saaty, 1980).

3.6 Irrigation water demand

The assessment of the irrigation potential, based on soil and water resources, can only be done by simultaneously assessing the irrigation water requirements (FAO, 1997). The crop water requirement (CWR) is calculated as a product of the Reference evapotranspiration (ETo) and the crop coefficient (Kc) (Allen et al., 1998).

CWR(mm)=$K \times ETo$……………………………………………………………………..eq(8)

NIR (mm)=$CWR - Peff$…………………………………………………………………..eq(9)

Where, CWR is crop water requirement for the growing period, Kc is crop coefficient for crop, ETo is reference evapotranspiration, Peff is effective rainfall. Effective rainfall was calculated according to FAO/AGLW formula (Smith, 1992):

=0.6$*P$–10 for Pmonth<=70 mm…………………………………………………….eq(10)

$=0.8*P-24$ for Pmonth>70 mm……………………………………….…………...eq(11)

P is precipitation (mm)

MOD16 data downloaded for dry season specifically for the irrigation season (December to March) according to Ethiopia calendar. MODIS evapotranspiration (MOD16A2) data used from data from 2000-2018 from NASA LPDAAC. The data distributed in Hierarchical Data Format (HDF), thus a model developed to extract the Potential evapotranspiration data using ArcMap model builder with iterator. Here, Extract Potential evapotranspiration from datasets included in Hierarchical Data Format, scaled with scale factor (0.1), extract values by removing water bodies, urban, barren land and wetlands.

3.7 Water Resources Potential

Prior to irrigation development, the irrigation potential of the rivers has to be assessed because assessing the land suitability analysis is critical to the development of productive and economically viable irrigation schemes (FAO, 1997).

Information on low-flow of the rivers is required for the amount water available for surface water irrigation application during the dry season. The river water available during the dry season at exceedance probability of 80% monthly averaged stream flow data obtained from the Ethiopian Ministry of Water, Irrigation and Electricity (MoWIE) determined by cumulative frequency curve with probability distribution fitting software (CumFreq) (Oosterbaan, 1994).

Table 3 1 General information about Rivers studied in South Gojam watersheds.

Station No.	River	Site	Location		Installation Date	Drainage Area (km2)
			Latitude(N)	Longitude(E)		
113023	Dura	Nr.Metekel	1212511.109	224157.532	28/02/1988	539
113029	Ardy	Nr.Metekel	1212120.421	233118.972	27/11/1985	219
113028	Dondor	Nr. Metekel	1207887.079	233330.639	25/11/1989	184
113034	Buchiksi	Nr.Gidamaja	1196033.722	246242.332	28/11/1985	106
113035	Ayo	Nr.Kossober	1203442.07	265504.037	26/02/1990	41.4
113040	Missini	Nr. Kossober	1194128.718	275452.39	26/06/1988	16
113019	Fettam	Nr.Tilile	1207887.079	284554.075	15/02/1989	282
113036	L.fettam	Nr.Galibed	1149043.628	269102.378	17/04/1986	757

113022	Abbay	Nr.Bure	1139518.609	282225.737	01/12/2010	109.6
113017	Lay	Nr. Finot.Sel	1173597.011	295984.098	27/02/1984	288
113015	Leza	Nr.Giga	1176983.684	305720.784	12/04/1980	175
113013	Birr	Nr.Giga	1177830.353	310377.46	28/02/1989	978
113030	Zulu	Nr.Giga	1198785.394	327522.494	15/02/1990	220
112018	Chereka	Nr.Dembecha	1175936.316	327606.453	28/02/1982	209
113008	Chemoga	Nr. Debre Markos	1135294.276	353904.777	27/11/1960	364
113012	Gudla	Nr. Dembecha	1170432.971	327606.453	25/11/1960	256
113011	Jedeb	Nr. Amanuel	1148211.59	343283.874	28/11/1960	305
112017	Muga	Nr. Dejen	1107133.544	376417.592	26/02/1980	2800
112037	Bogena	Nr. Nr. Amber	1117784.139	356775.291	26/06/1987	209
112031	Suha	Nr. Bichena	1138164.79	398684.799	15/02/1985	359
112030	Teme	Nr. Motta	1144766.973	385193.382	17/04/1985	156
113014	Temcha	Nr. Dembecha	1164573.521	336107.588	01/12/1960	406
112019	Abahim	Nr. Debre Markos	1133571.967	362229.268	27/02/1982	350
112038	Yeda	Nr. Amber	1133284.916	370553.759	12/04/1988	125

3.8 Irrigation potential by Water Availability

The irrigation potential of the twenty four rivers was estimated as the quotient of the exceedance probability of 80% monthly averaged discharge and the total the depth irrigation (IR) of the dominant crops in the south Gojam for the growing season.

That is;

$$\text{Area}=\frac{Q(80)}{IR} * Eff \text{ .... eq (12)}$$

Where Q (80) is Runoff at gauge location at 80% exceedance probability (Million m3)

IR is irrigation requirement, and E_{ff} is irrigation efficiency are assumed to be 65% for surface irrigation (Brouwer et a., 1989).

4. RESULTS AND DISCUSSION

In this section results obtained on multi-criteria land evaluation for irrigation suitability and surface water potential for irrigation are presented, described and discussed. Zonal statistics have been done for each result to describe the results as sub-basin level data.

4.1 Accuracy assessment

Table 4 1: Confusion matrics for land cover of Tana subasin.

	Reference data							
		Built-up land	Forest land	Water body	Agricultural land	Bare land	Total	user's
Classified data	Built up area land	48	0	0	0	1	49	97.96%
	Forest land	2	46	0	1	3	52	88.46%
	Water body	0	0	47	1	0	48	97.92%
	Agricultural land	2	1	0	45	2	50	90%
	Bare land	1	1	0	1	48	51	94.12%
	Total	53	48	47	48	54	250	
	producer's	90.57%	95.83%	100%	93.75%	88.89%		

Overall classification accuracy = 93.6% Overall kappa statistics =92%

Table 4. 2: Confusion matrics for land cover of Fincha subasin.

	Reference data								
		Built-up land	Forest land	Water body	Agricultural land	Bare land	Grass Land	Total	User's (%)
Classified data	Built up area land	49	0	0	0	1	0	50	98.00
	Forest land	2	45	0	1	3	1	52	86.54
	Water body	0	0	48	1	0	0	49	97.96
	Agricultural land	2	2	0	46	2	0	52	88
	Bare land	1	1	0	1	48	1	52	92.31
	Grass land	0	0	1	2	0	47	50	94.00
	Total	54	48	49	51	54	49	305	
	Producer's (%)	90.74	93.75	98	90.20	88.89	95.92		

Overall classification accuracy = 92.79% Overall kappa statistics =91.56 %

4.2 Land Suitability Analysis for Irrigation

The rating thematic layer of Soil texture, soil depth, Cation exchange capacity/CEC/, (Salinity/Alkalinity (PH), Soil Drainage, Runoff, Proximity to rives and slope

Slope: Slope is important to soil formation and management because of its influence on runoff, soil drainage. Less slope with high surface irrigation potential and vice versa.

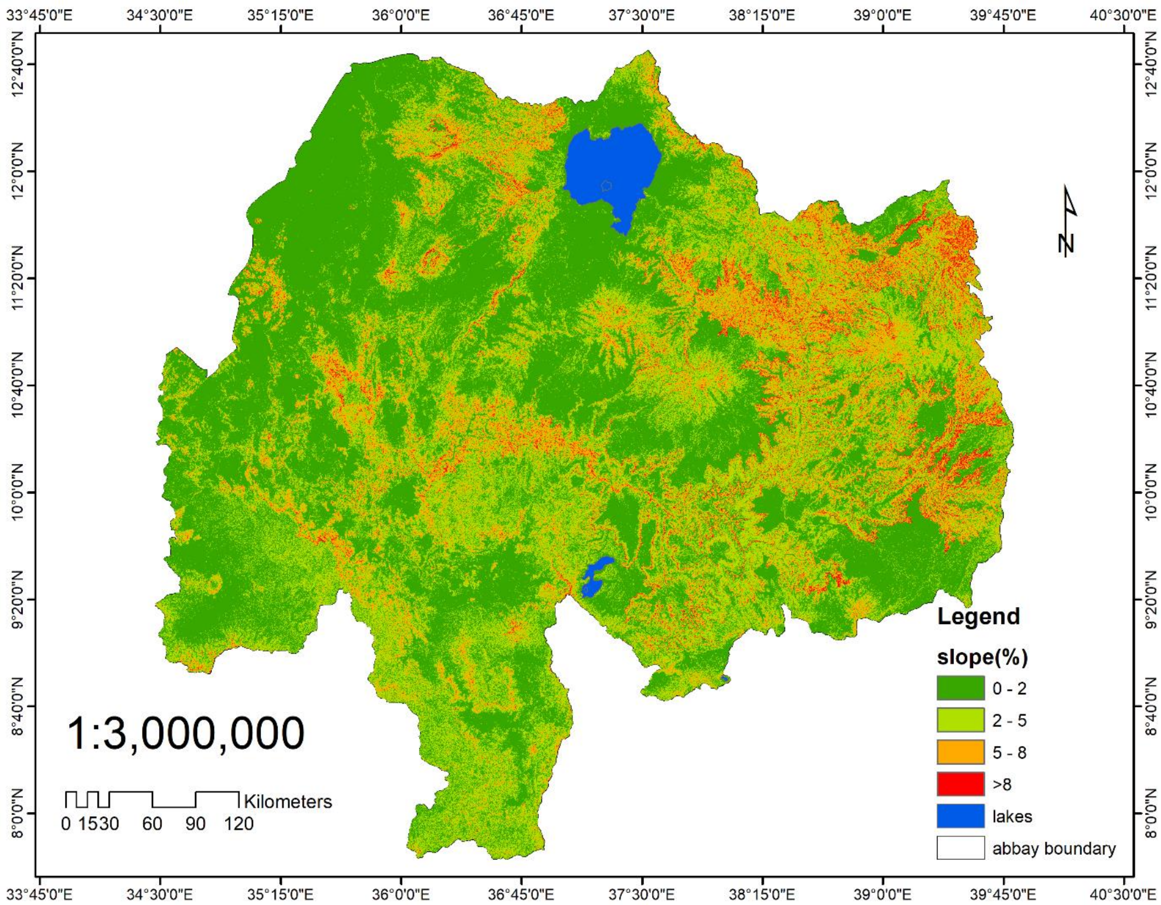


Figure 4 1 Slope Map of the basin

4.2.1 Reclassifying Slope

The slope output was reclassified, slicing the values into equal intervals. Value of 4 assigned to the highly suitable range of slopes (those with the lowest degree of slope) and value of 1 to the least suitable range of slopes (those with the steepest degree of slope) and ranked the values in between linearly (FAO 1996).

Table 4 3 Slope factor rating.

W	Slop	Des	F. Rating
4	0-2	H. suitable	S.1
3.	2-5.	Mo. suitable	S.2
2.	5-8.	Mar. suitable	S.3
1.	>8.	N. suitable	N.

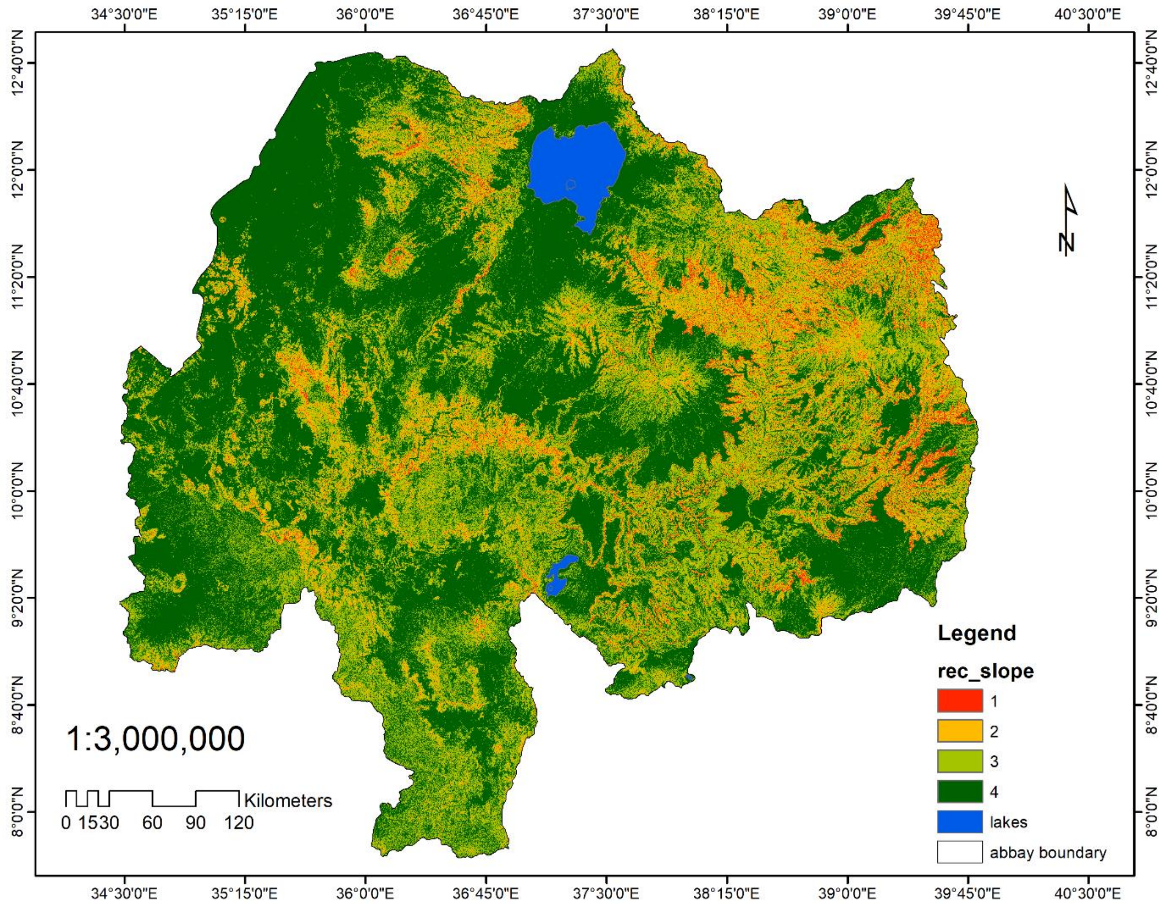


Figure 4 2 Reclass_Slope Map of the Basin.

4.3 Properties of the soil

Join the raster data to the derived soil properties files, as managed the MS-Access® database (WISE30sec.mdb). The linkage is done through the map unit code or grid cell identifier (NEWSUID) of the raster set and the NEWSUID of the various soil attribute data files.

4.3.1 Soil Physical properties

It is related to soil texture and to the depth and salinity status of the groundwater. It affects soil plant relationship and workability of soil. It refers to oxygen availability in the roots and in some cases could lead to reduced plant growth and yields (FAO (2002 Guideline for land evaluation and modified based on practical observation).

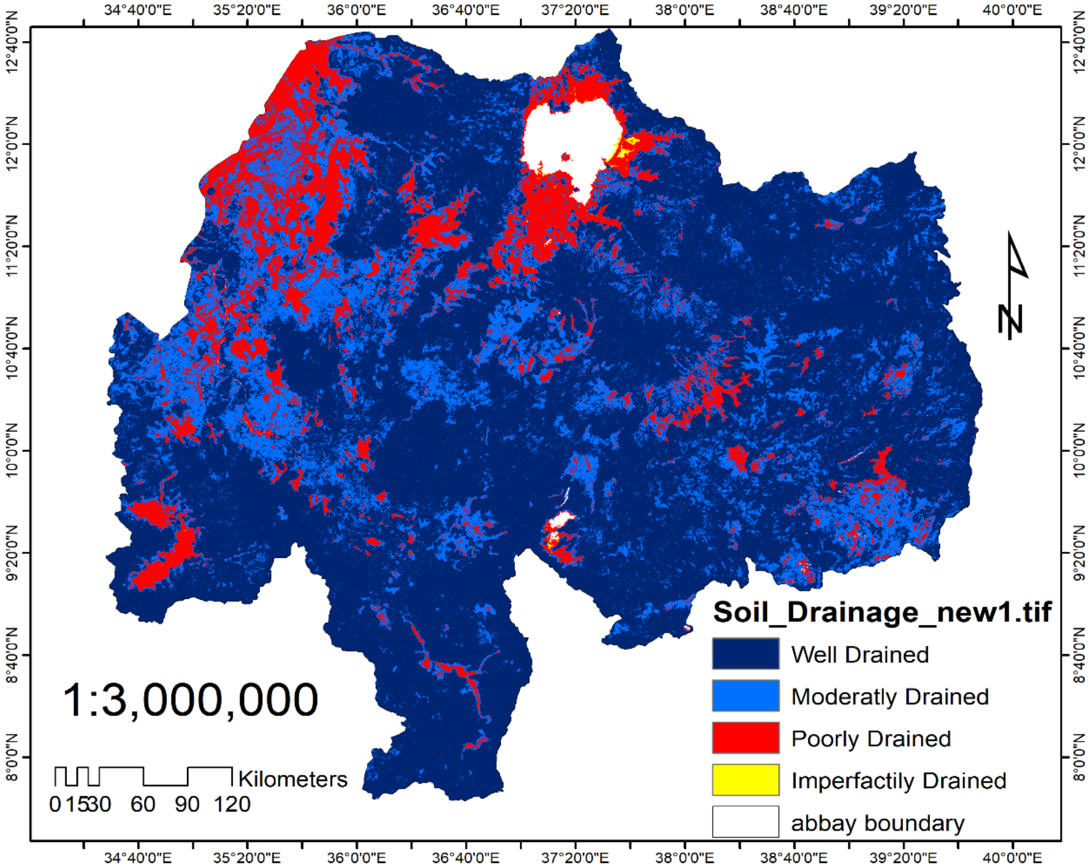


Figure 4 3 Drainage map of the Basin.

4.3.2 Reclassifying drainage

S. drainage refers to the flow of moisture inside the soil. S. Drain ability refers to the ability of soil and substrata to respond to subsurface drains.

Table 4 4 Soil drainage factor rating.

Weight	Description	Factor Rating
4	Well drained	S1
3	Moderately drained	S2
2	Poorly drained	S3
1	Imperfectly drained	N

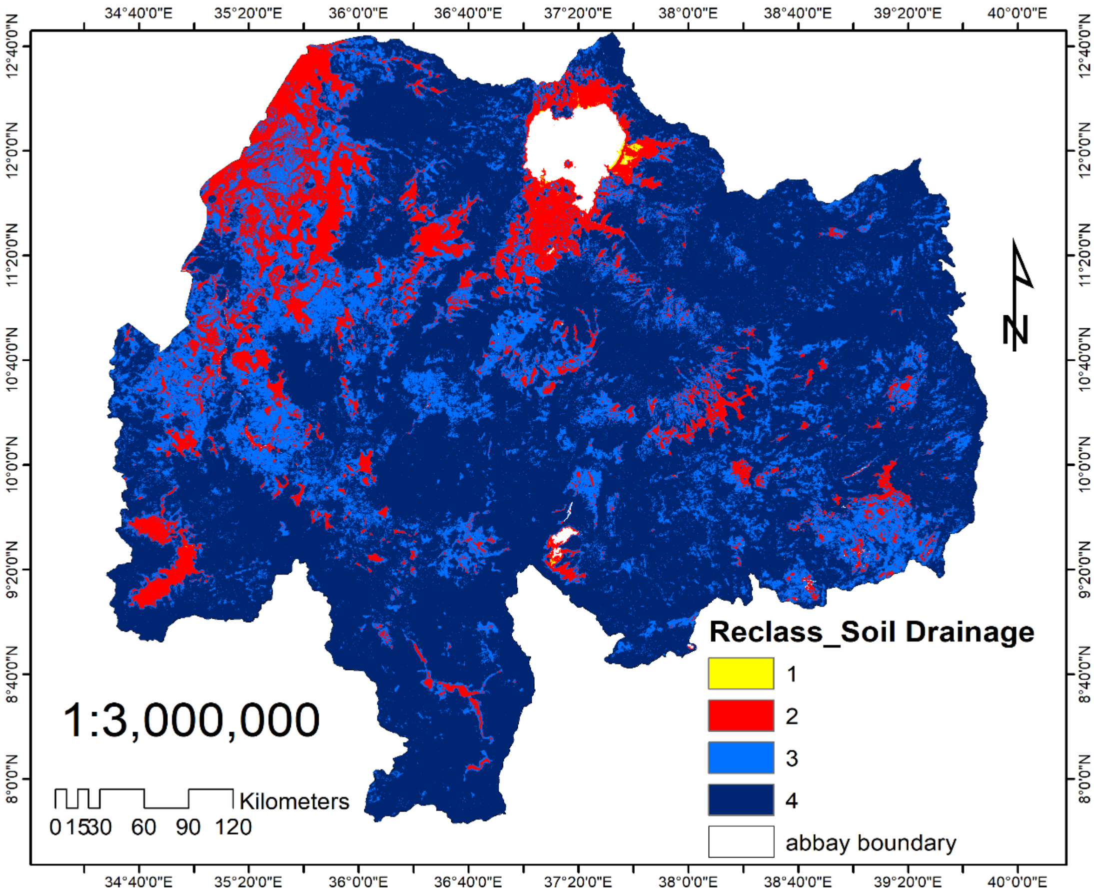


Figure 4 4 Reclass_ Drainage map of the basin.

Soil Texture: Most of the physical characteristics of the soil depend upon texture class Texture influences the movement of water through the soil, how much water can be stored in the soil, and how much of the stored water is available to plants (FAO, (1991).

4.3.3 Reclassified Soil Texture

Table 4 5 Soil texture Factor rating.

Texture	Weight	Description	Factor Rating
C, Sic, SC	4	Highly suitable	S1
Si-SCL	3	Moderately suitable	S2
SL	2	Marginally suitable	S3
Corse sand	1	Not suitable	N

C = Clay, SC = Sandy Clay, SiC = Silty Clay, Si = Silt, L = Loam, CL = Clay Loam, SiCL = Silty Clay Loam, SCL = Sandy Clay Loam, SiL = Silty Loam, SL = Sandy Loam (FAO, (1991).

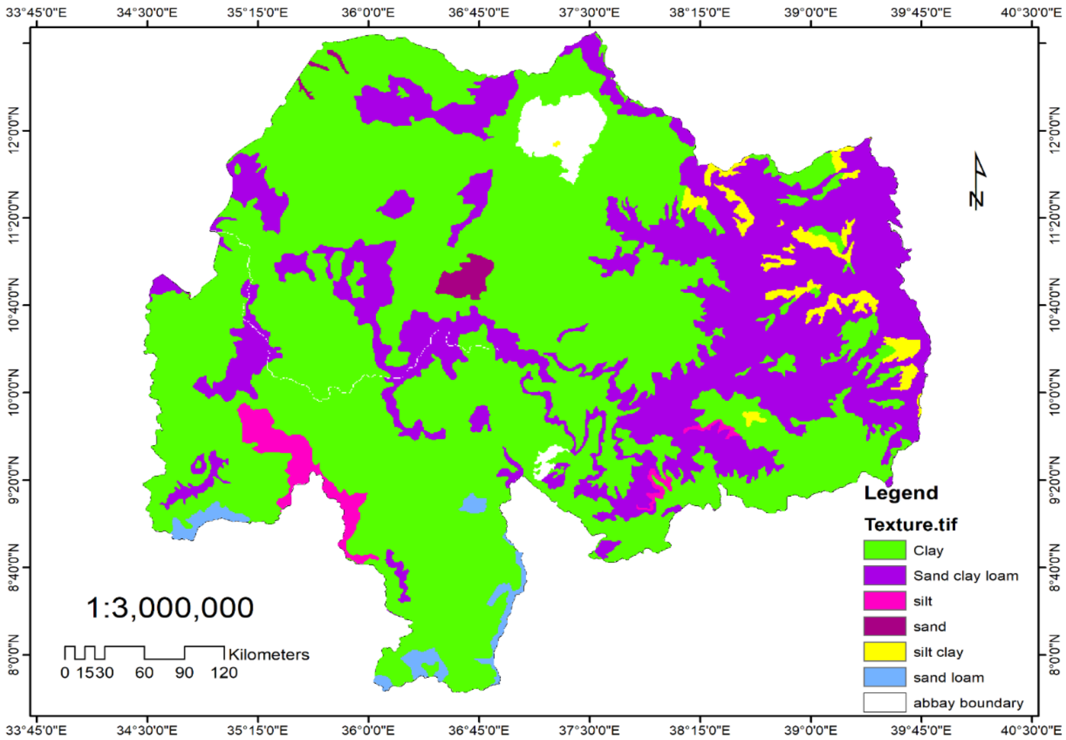


Figure 4 5 Texture Map of the Basin.

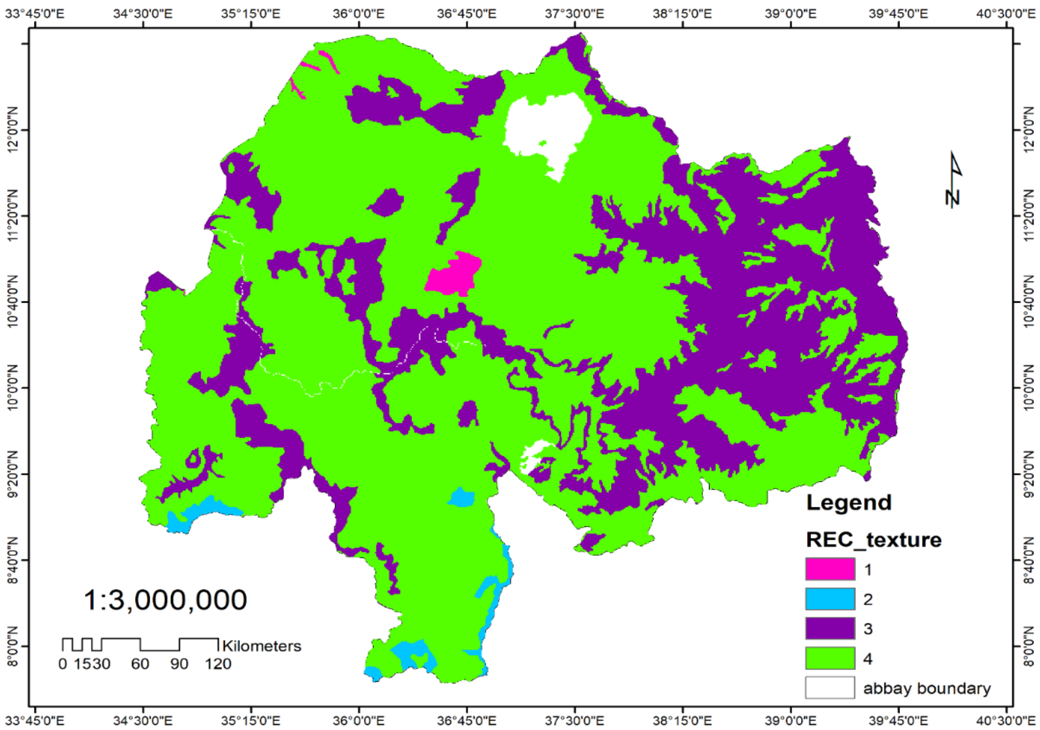


Figure 4 6 Reclass_ Texture Map of the Basin.

Soil Depth: soil depth determines the potential rooting depth of plants to be grown and any restrictions within the soil that may hinder rooting depth. Any discontinuities in the soil from layers of sand, gravel, or even bedrock can physically limit rooting irrigation.

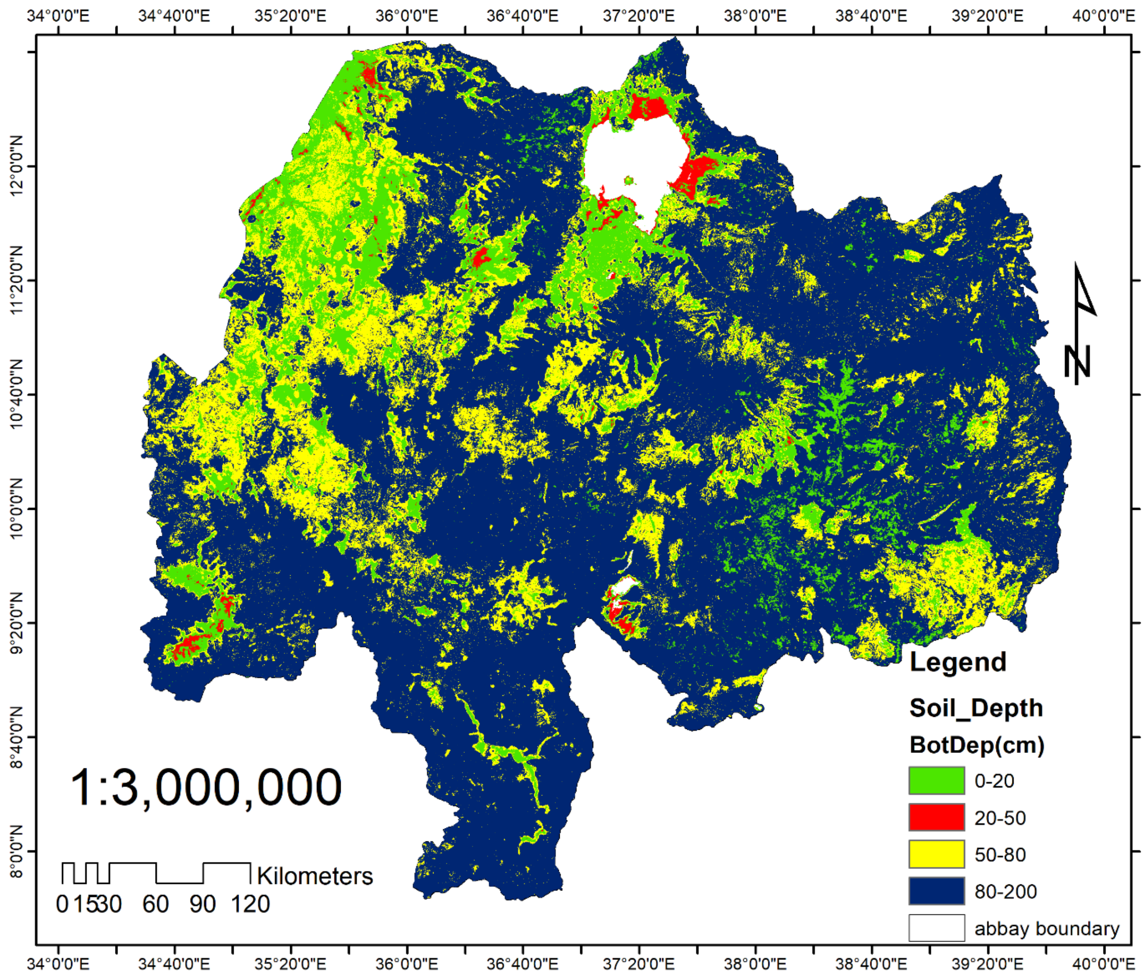


Figure 4 7 Soil Depth map of Abay Basin.

4.3.4 Reclassified Soil depth

It is identified as a key for many soil characteristics, such as soil drainage, irrigation conditions and yields for all crops (FAO, (1991).

Table 4 6 Soil depth factor rating.

Class Range (cm)	Weight	Description	Factor Rating
80 – 200 (very deep)	4	H. suitable	S.1
50 – 80. (D)	3.	Mo. suitable	S.2
20 – 50. (Mo. d)	2.	Mar. suitable	S.3
0 – 20. (Sh)	1.	N. suitable	N.

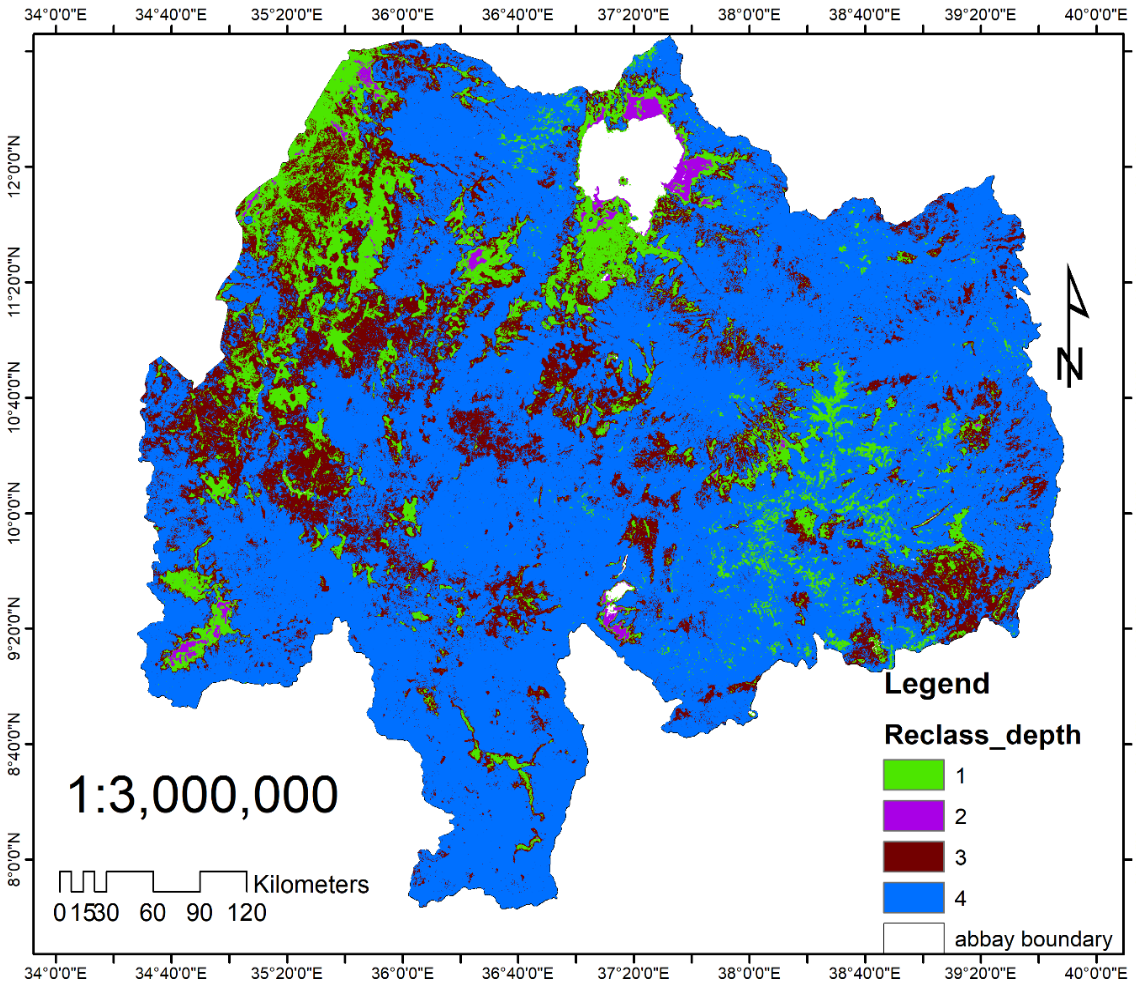


Figure 4 8 Reclassified Soil depth Map of Abay Basin.

4.4 Soil Chemical property

The chemical properties of soils can greatly influence how irrigable soils are by affecting the hydraulic characteristics and the suitability of the soil for crop production. In addition, some adverse effects due to salinity can include nutritional imbalances or toxicities caused by specific ions (e.g., boron, Many chemical elements are essential for plant growth and are necessary to obtain large and satisfactory crop yields.

Cation exchange capacity (CEC): is a measure of the soil's ability to retain and supply plant nutrients. CEC measurements are commonly made as part of the overall assessment of the potential fertility of a soil, and possible response to fertilizer application. Soils with a high value of CEC are considered fertile, and soils with a low value of CEC are considered infertile (London,1984).

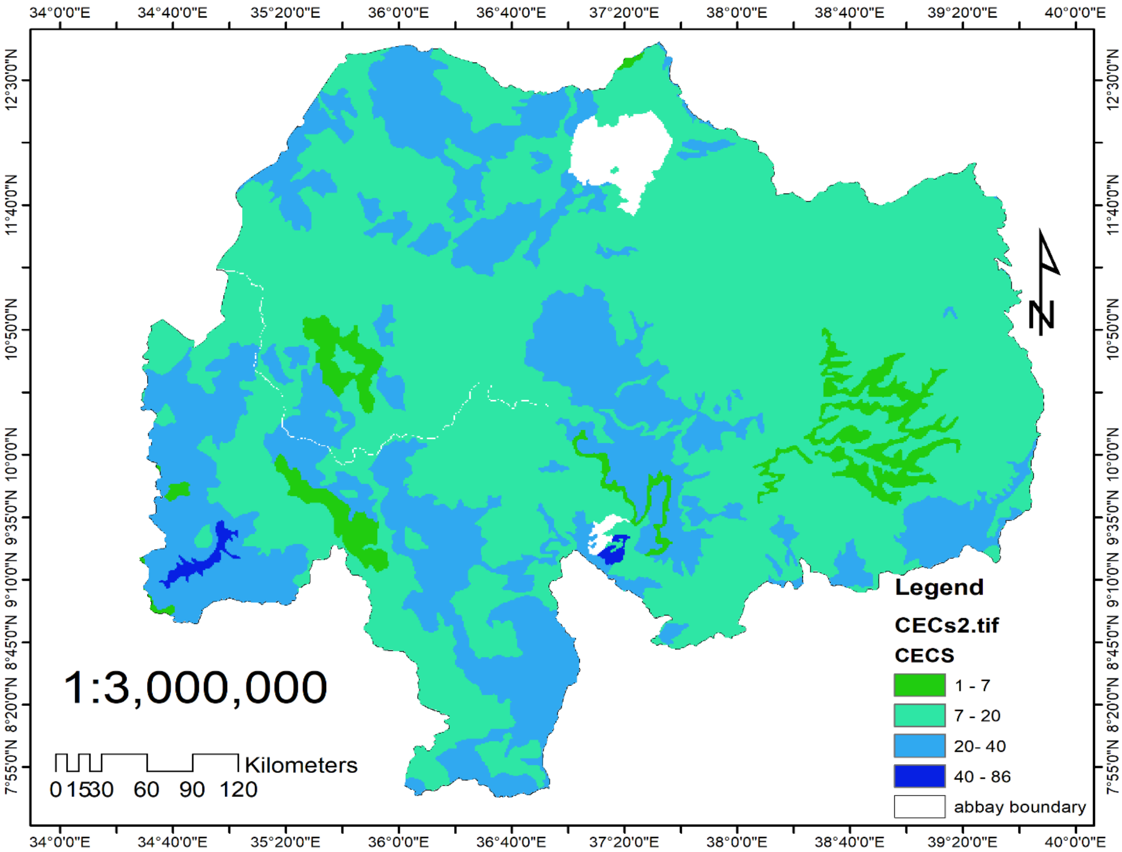


Figure 4 9 CEC Map of Abbay Basin.

4.4.1 Reclassifying Cation Exchange capacity of soil (CEC)

The following suitability rating for land quality and characteristic are used to distinguish different soil types suitable in this project adapted from FAO Guideline for soil evaluation for irrigation agriculture 1979, and FAO land and water bulletin No4 Irrigation potential in Africa a basin approach.

Table 4 7 CEC Factor rating.

Class Range (meq/100g)	Weight	Description	Factor Rating
40– 86	4	H. suitable	S.1
20 – 40.	3.	Mo. suitable	S.2
7– 20.	2.	Mar. suitable	S.3
1 – 7.	1.	N. suitable	N.

Source: FAO, (1997) guideline for land evaluation and modified by OWWDSE land evaluation team based on practical observation.

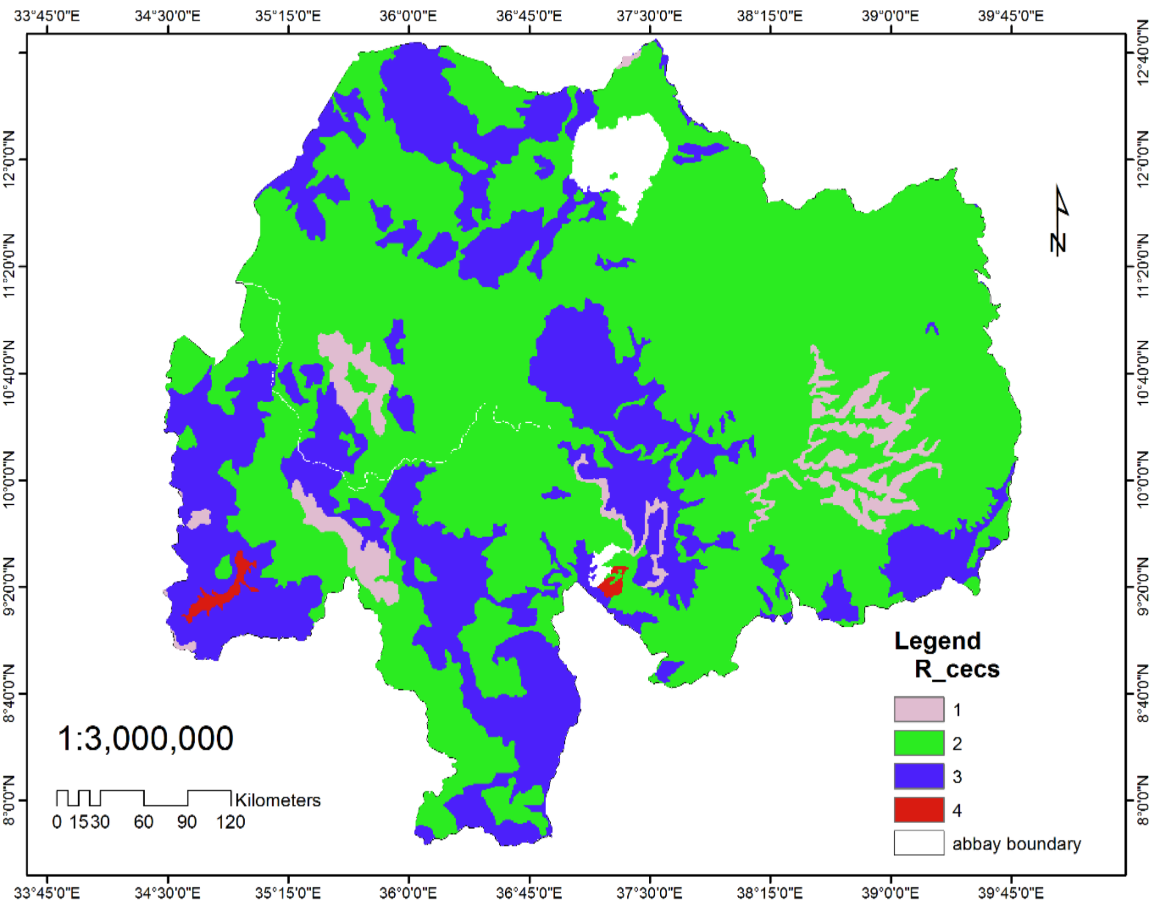


Figure 4 10 Reclassified Cation exchange capacity map of Abay Basin.

Soil reaction (pH): Soil pH is the most important soil criterion in land suitability analysis for irrigation and it controls many chemical soil characteristics and some physical soil properties. Soil reaction controls the solubility of most soil minerals; for example, high soil pH leads to low micronutrient availability and decreases the availability of macronutrients such as calcium, magnesium and phosphorus. The majority of plants prefer to grow in pH between 5 and 7.5.

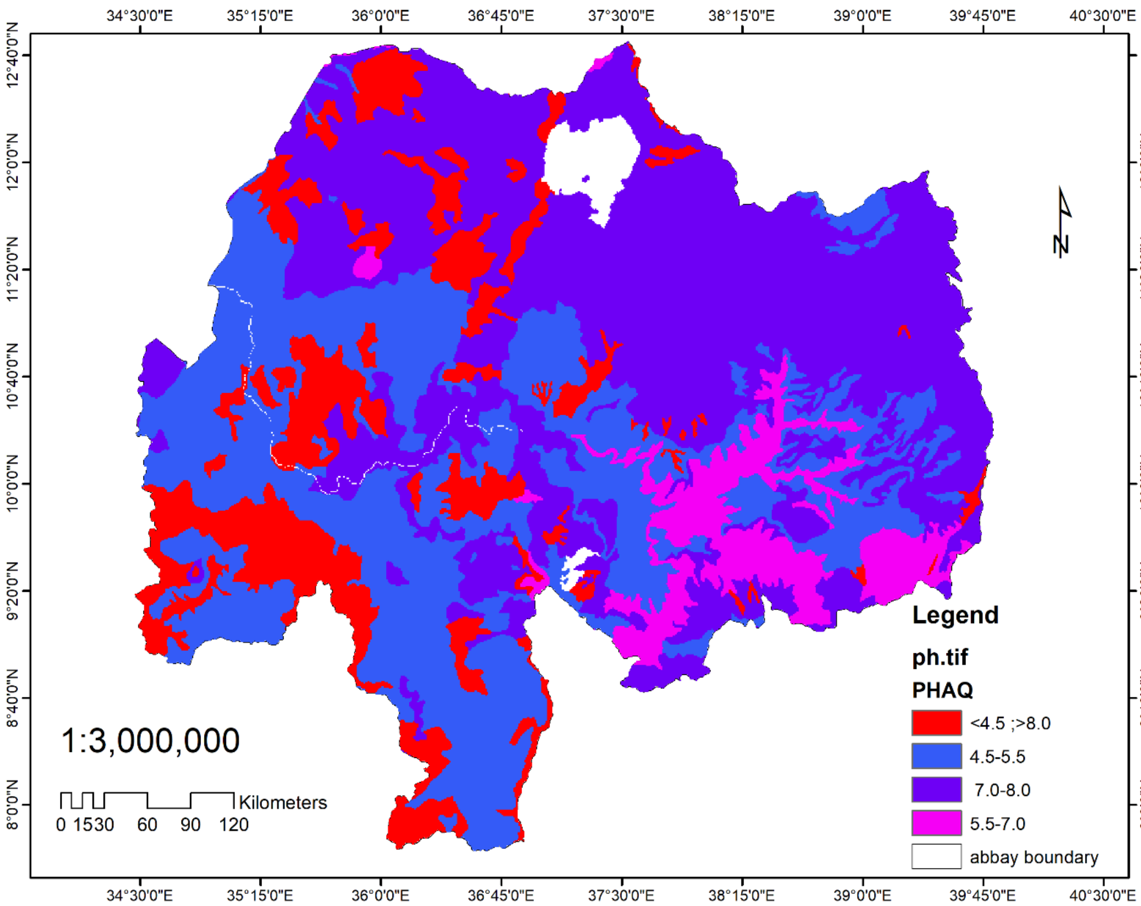


Figure 4 11 Soil PH Map of Abay Basin.

4.4.2 Reclassifying Soil PH

The degree of acidity or alkalinity of a soil is usually expressed as a pH value which is defined as the negative logarithm of the hydrogen ion activity. PH determination on soil samples is made to make some generalizations regarding the availability of nutrients. From 4.5 to 5.5, normally decrease crop yields or even prevent it. The same with alkaline soils (pH-water over 8.0), FAO, (1997).

Table 4 8 Soil PH Factor rating.

Class Range (pHaq)	Weight	Description	Factor rating
5.5-7.0	4	H. suitable	S.1
7.1-8.0	3.	Mo. suitable	S.2
4.55-5.55	2.	Mar. suitable	S.3
<4.55;>8.0	1.	N. suitable	N.

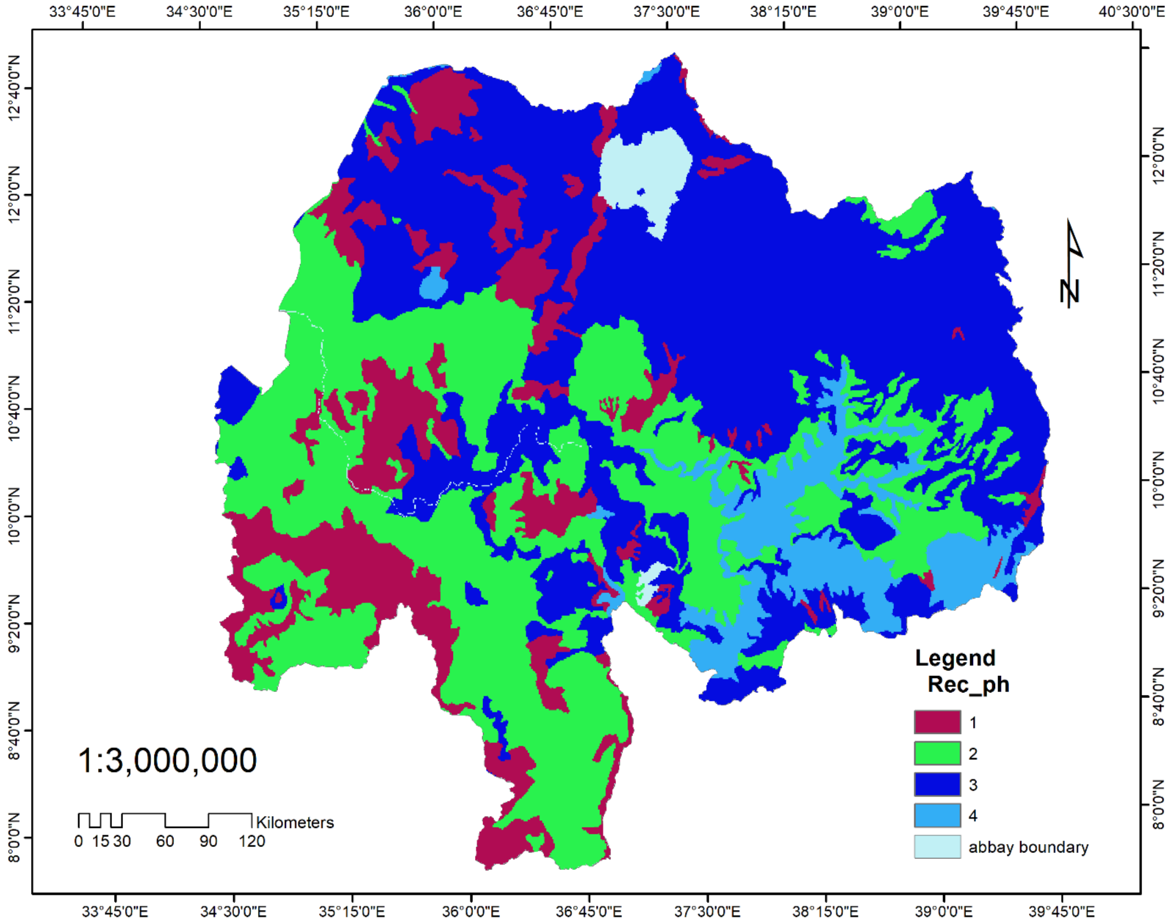


Figure 4 12 Reclassified PH Soil map of Abbay Basin.

Euclidian distance to perennial water: Euclidian distance to Perennial River sources were computed using geospatial overlay in terms of GIS layers. The Proximity to water suitable for surface irrigation suitability map of the watershed is shown in figure 4.13

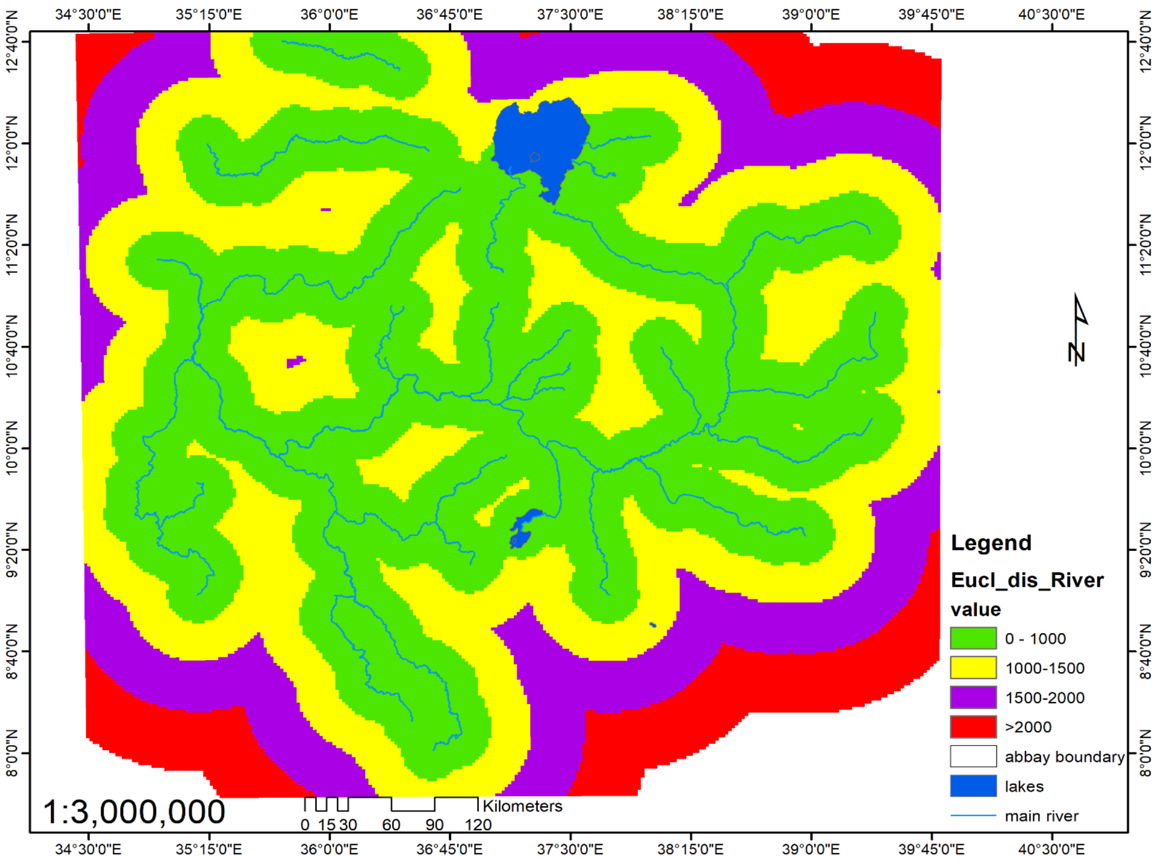


Figure 4 13 Map showing the suitability of study area based on Distance to rivers.

4.4.3 Reclassified Distance to Main River

Table 4 9 Criteria for distance to main rivers.

Class range (m)	Weight	Description	Factor Rating
0 – 1000.1	4	H. Suitable	S.1
1000.1 – 1500.1	3.	Mo. Suitable	S.2
1500.1 – 2000.1	2.	Mar. Suitable	S.3
>2000.1	1.	N. Suitable	N.

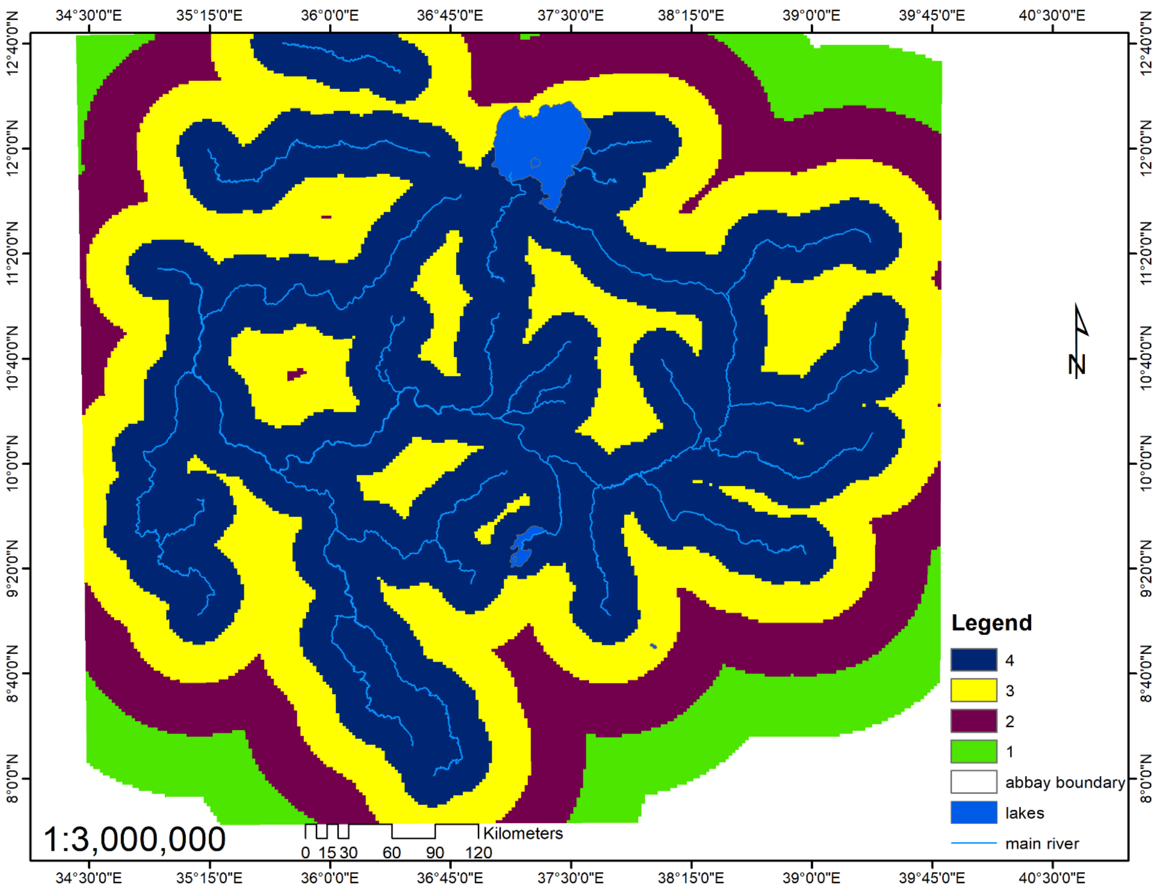


Figure 4 14 Reclassified Distance to main river Map of Abay Basin.

Runoff-BY SCS: The Soil Conservation Service (SCS) model developed by United States Department of Agriculture (USDA) computes direct runoff through an empirical equation that requires the rainfall and a watershed coefficient as inputs and the high runoff potential with high surface irrigation potential and vice versa (Hand book of Hydrology, 1972).

4.4.4 Hydrologic Soil Group (HSG)

Hydrological Soils group (HSG) are classified based on the ability of water flow in the soil and the other property of the soil but, My Study area only contains A, B and D.

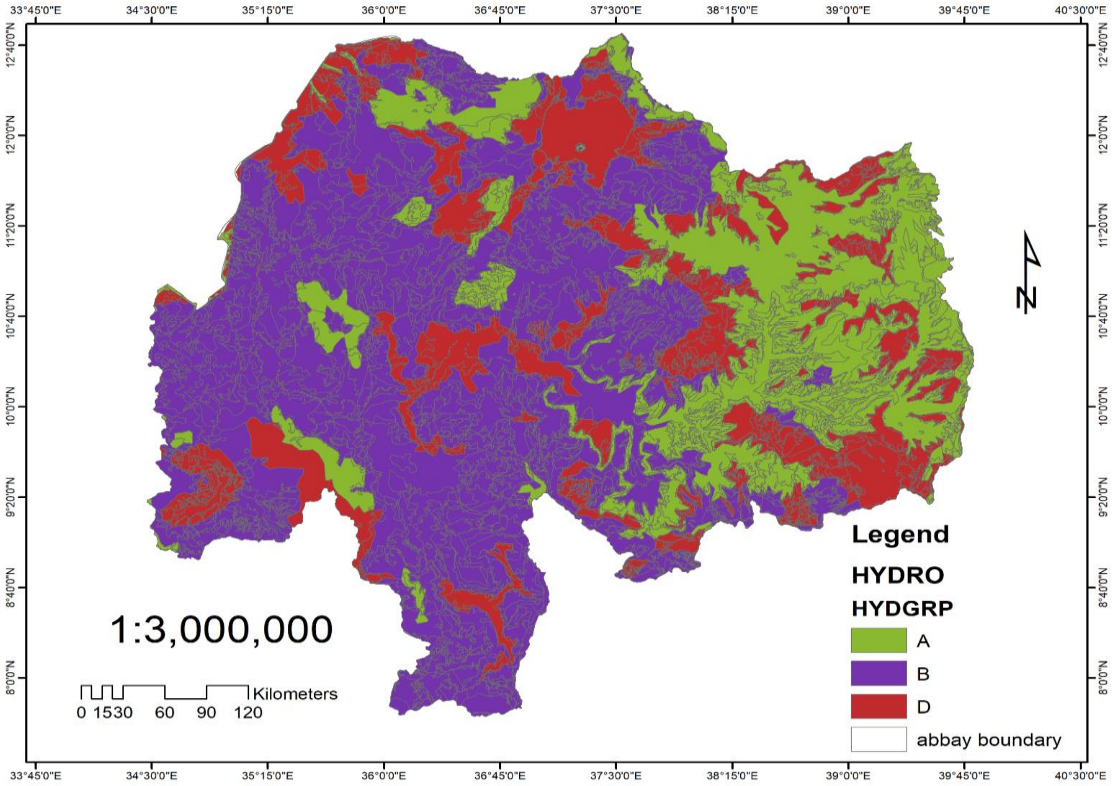


Figure 4 15 Hydrological soil Group of abbay basin.

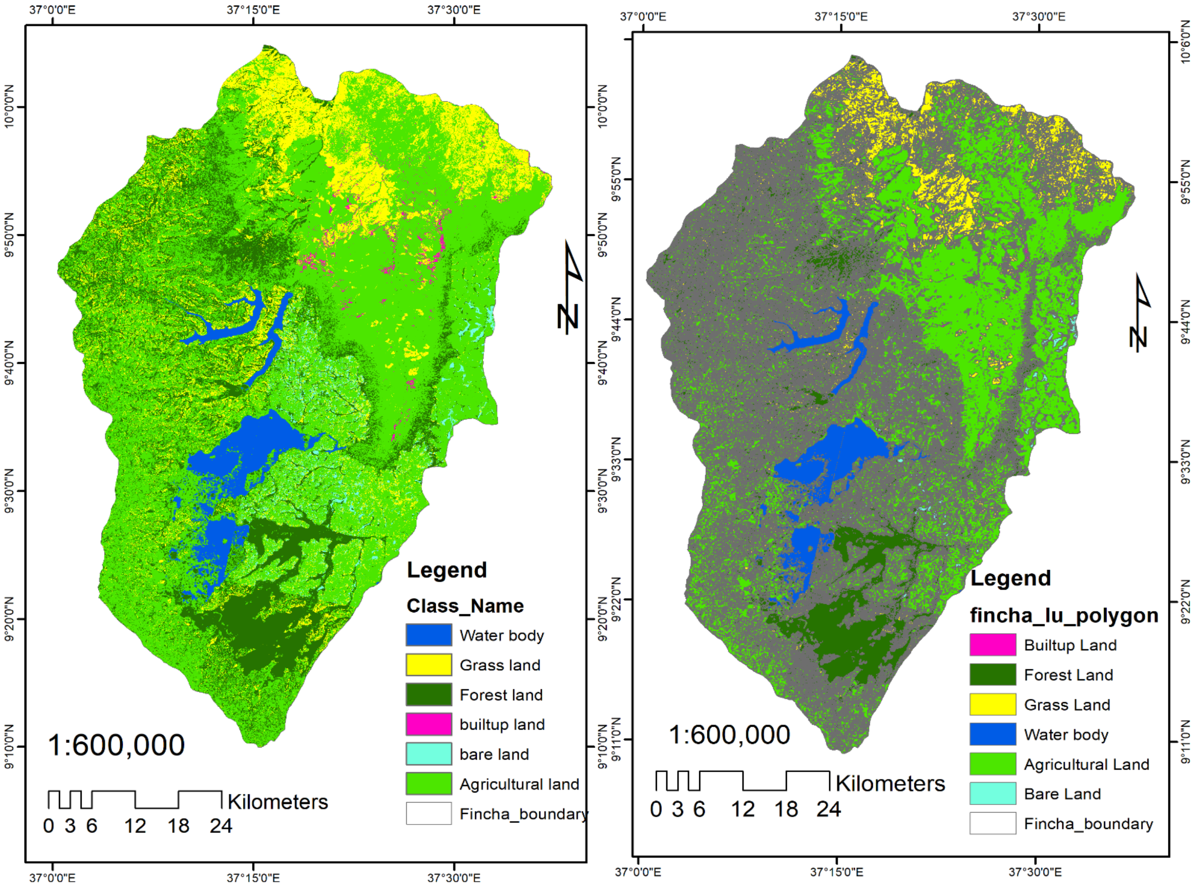


Figure 4 16 Land use land cover and its polygon map of fincha watersheds.

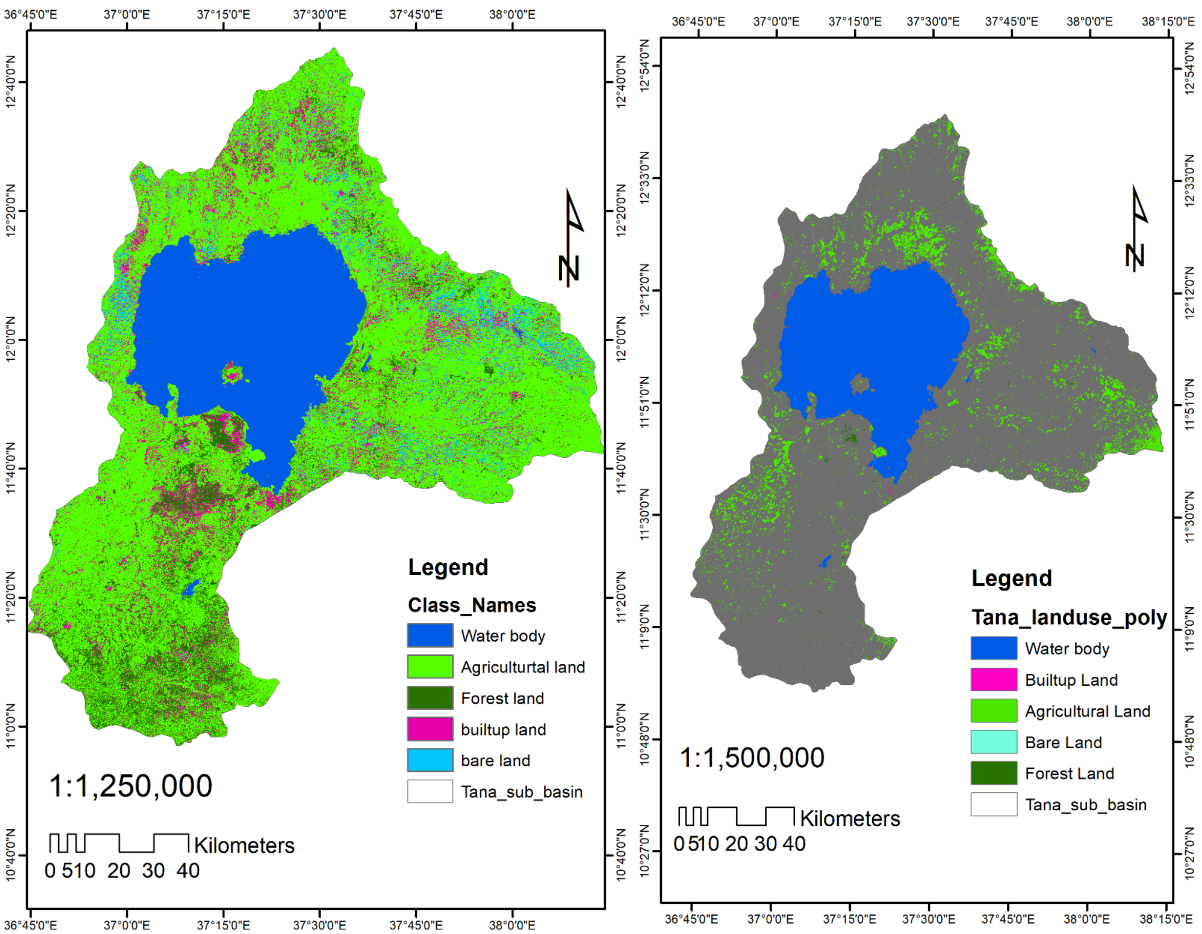


Figure 4 17 Land use land cover and its polygon map of Tana watersheds.

Antecedent Moisture Condition refers to the infiltration rate of soil at the beginning of the precipitation event. AMC for determination of curve number is given in Table 4.10.

Table 4 10 AMC for determination of CN Value.

AMC	Total Rain in Previous 5 days	
	Dormant Season	Growing Season
I	Less than 13 mm	Less than 36 mm
II	13 to 28 mm	36 to 53 mm
III	More than 28 mm	More than 53 mm

SCS runoff CN for hydrologic soil cover complex under AMC II condition for the study area is given in Table 4.11 Area weighted composite curve number for various conditions of land use and hydrologic soil conditions are computed as follows:

Table 4 11 Curve Number for HSG (Lookup table).

Land Use	Hydrologic Soil Group (HSG)

	A	B	D
Water Body	100	100	100
Agricultural Land	49	72	84
Forest Land	30	55	77
Grass Land	68	69	84
Built-up Land	89	92	95
Bare Land	77	86	94

Source: (United States Department of Agriculture, 1986; Soulis and Valiantzas, 2012)

4.4.5 Preparing soil data for CN grid

The information needed to determine a weighted curve number is the hydrologic soil group, which indicates the amount of infiltration that occurs in each type of soil. Four fields named Percentage of A, Percentage of A, Percentage of A, and Percentage of A were created. Area, only one soil group assigned to each polygon so a polygon with soil group "A" have Percentage of A = 100, Percentage of A = 0, and Percentage of A = 0. Similarly for a polygon with soil group D, only Percentage of A = 100, and the other three Percentage of A are zero. The attribute table below was obtained. After the calculations were done, the Soil Code populated with letters A, B, D. Merging of Hydrological Soil Group with land use land cover data: Curve number Lookup table was created using Arc Catalogue.

4.4.6 Creating CN grid

After combining Land Use /land cover and hydrologic soil group maps using GIS, a CN grid was created using Hec-geoHMS of individual subasin. Hec-geoHMS uses the merged feature class (Land Use /land cover _soil group_union) and the lookup table (CNLookUp) to create the curve number grid. I created a field named "Land Use /land cover" in the Land Use /land cover _ soil group _union that have land use category information to link it to "Cuerve number LookUp". HecgeoHMS look for this information in Land Use /land cover field while it is stored in GRIDCODE field. I added field named Land Use /land cover and equated it to GRIDCODE. By clicking on Utility Create parameter Grids, the author chose the lookup parameter as Curve Number, and Land Use /land cover _ soil group _Union for Curve number Polygon and left the default CNGrid name for the curve Number Grid. In hour A CN Grid added to the map document as shown in Fig.4:18.

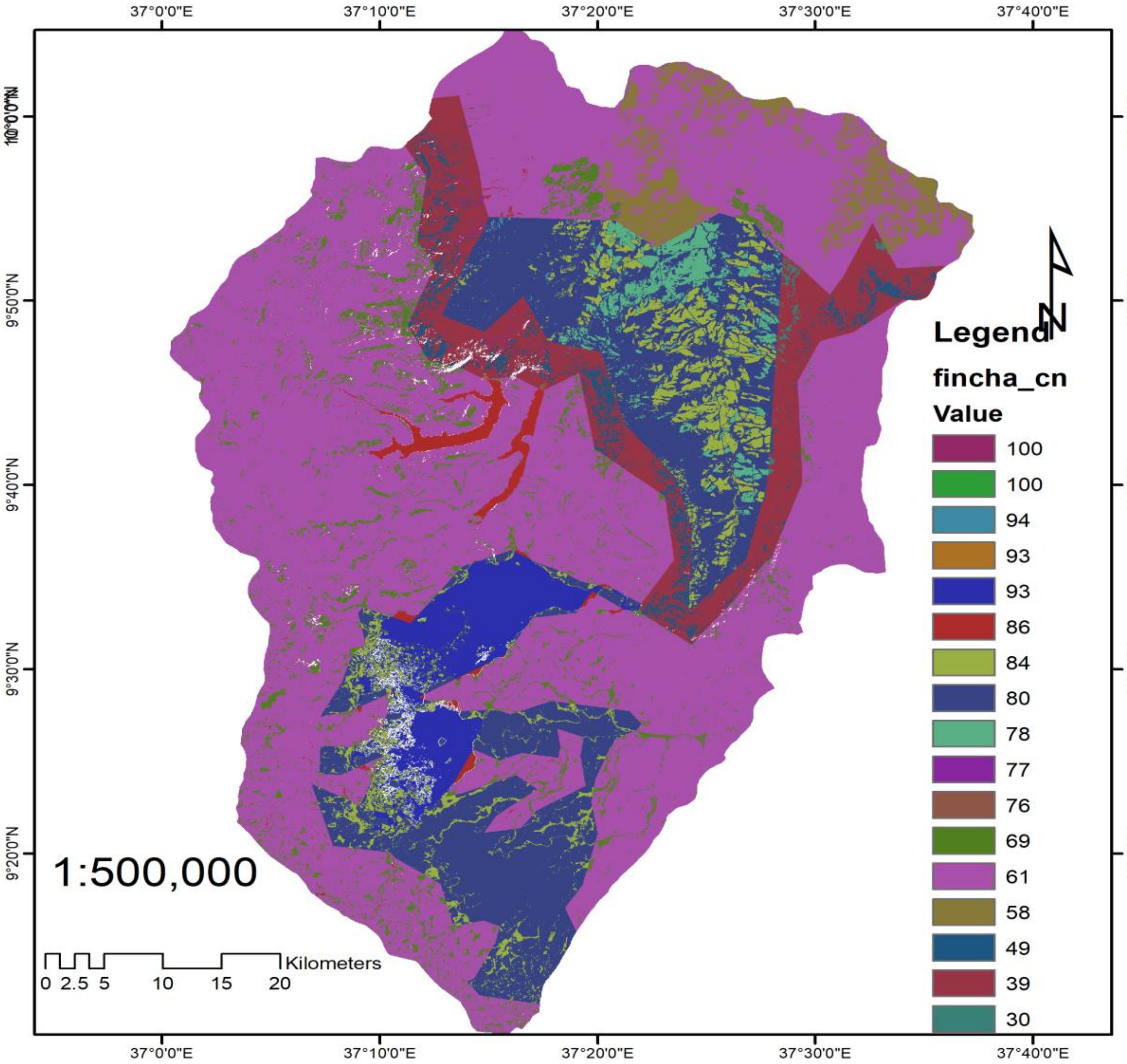


Figure 4 18 Curve Number Generated map of fincha watersheds.

Table 4 12 Sample of Curve number Computation of Fincha watershed.

Fincha_Watershed					
Hydrological soil Group_A					
Class_Name	AREA	CN	(AREA*CN)/TA		
Water Body	75.352	100	10.30595637		
Agricultural Land	175.223	49	11.74304452		
Forest Land	125.768	39	6.708544074		
Grass Land	126.546	30	5.192340833		
Builtup Land	121.945	78	14.84388292	Total Area of Watershed	4000.12
Bare Land	106.316	77	11.19651508	Altimate CN	75
TOTAL AREA	731.15		59.9902838		

Hydrological soil Group_B					
Class_Name	AREA	CN	(AREA*CN)/TA		
Water Body	200.875	86	8.393789609		
Agricultural Land	712.512	69	23.88773718		
Forest Land	542.648	61	16.08354506		
Grass Land	352.543	58	9.935136259		
Builtup Land	123.536	93	5.522237754		
Bare Land	125.985	86	5.264426055		
TOTAL AREA	2058.099		69.08687191		
Hydrological soil Group_D					
Class_Name	AREA	CN	(AREA*CN)/TA		
Water Body	313.234	93	22.40481433		
Agricultural Land	427.692	84	27.63121087		
Forest Land	252.876	80	15.55919431		
Grass Land	230.739	84	14.90698438		
Builtup Land	65.236	76	4.766509178		
Bare Land	10.424	94	0.753618864		
TOTAL AREA	1300.201		86.02233193		

Table 4 13 Sample of Curve number Computation of Tana watershed.

Tana_Watershed					
Hydrological soil Group_A					
Class_Name	AREA	CN	(AREA*CN)/TA		
Water Body	299.555	100	16.29661022		
Agricultural Land	732.124	69	27.4823863		
Forest Land	414.945	30	6.772242421		
Builtup Land	234.234	68	8.665219191	Total Area of Watershed	14750
Bare Land	157.285	77	6.588684885	Altimate CN	82
TOTAL AREA	1838.143		65.80514302		
Hydrological soil Group_B					
Class_Name	AREA	CN	(AREA*CN)/T		

			A		
Water Body	261.3856	86	5.068472385		
Agricultural Land	2139.2746	72	34.72929813		
Forest Land	1153.5716	55	14.30553882		
Builtup Land	361.9906	92	7.50899985		
Bare Land	518.8736	86	10.06136724		
TOTAL AREA	4435.096		71.67367642		
Hydrological soil Group_D					
Class_Name	AREA	CN	(AREA*CN)/TA		
Water Body	3103.7796	94	33.22816481		
Agricultural Land	4717.7916	84	45.13419145		
Forest Land	400.6206	77	3.513270832		
Builtup Land	292.0846	49	1.630017877		
Bare Land	266.0846	94	2.848624607		
TOTAL AREA	8780.361		86.35426958		

Table 4 14 Sample of Daily Rainfall Runoff Computation of Fincha Subasin.

Date	Rain-fall	5-day rainfall	AMC	Conditional CN	S	0.2s	VQ
	mm						
01/05/2018	0.00000000	0	1	57	191.614	38.32281	0
02/05/2018	0.00000000	0	1	57	191.614	38.32281	0
03/05/2018	4.37753677	0.000000000	1	57	191.614	38.32281	0
04/05/2018	4.75807571	4.377536770	2	75	84.66667	16.93333	0
05/05/2018	20.18050766	9.135612480	2	75	84.66667	16.93333	0.119937
06/05/2018	13.50059414	29.316120140	1	57	191.614	38.32281	0
07/05/2018	12.39593220	42.816714280	2	75	84.66667	16.93333	0
08/05/2018	11.24349213	55.212646480	3	88	34.63636	6.927273	0.478267
09/05/2018	14.30460739	62.078601840	3	88	34.63636	6.927273	1.295412
10/05/2018	12.89464855	71.625133520	3	88	34.63636	6.927273	0.877002
11/05/2018	8.34945297	64.339274410	3	88	34.63636	6.927273	0.056092
12/05/2018	20.20951080	59.188133240	3	88	34.63636	6.927273	3.681615
13/05/2018	21.78752136	67.001711840	3	88	34.63636	6.927273	4.461457
14/05/2018	1.23456667	77.545741070	3	88	34.63636	6.927273	0
15/05/2018	5.12345167	64.475700350	3	88	34.63636	6.927273	0
16/05/2018	6.09876555	56.704503470	3	88	34.63636	6.927273	0
17/05/2018	4.18029404	54.453816050	3	88	34.63636	6.927273	0
18/05/2018	4.38561487	38.424599290	2	75	84.66667	16.93333	0
19/05/2018	4.38561487	21.022692800	1	57	191.614	38.32281	0
20/05/2018	4.38561487	24.173741000	1	57	191.614	38.32281	0
21/05/2018	11.34567770	23.435904200	1	57	191.614	38.32281	0
22/05/2018	13.45678890	28.682816350	1	57	191.614	38.32281	0
23/05/2018	22.56789999	37.959311210	2	75	84.66667	16.93333	0.351583
24/05/2018	19.02121735	56.141596330	3	88	34.63636	6.927273	3.129949
25/05/2018	31.70787430	70.777198810	3	88	34.63636	6.927273	10.33507
19/09/2018	30.63390923	161.239521030	3	88	34.63636	6.927273	9.632769
20/09/2018	29.06831932	162.254306800	3	88	34.63636	6.927273	8.634172
21/09/2018	23.22098351	158.541410450	3	88	34.63636	6.927273	5.212736
22/09/2018	30.68256950	149.280765540	3	88	34.63636	6.927273	9.664293
23/09/2018	32.15754700	145.410490040	3	88	34.63636	6.927273	10.63308
24/09/2018	28.98876381	145.763328560	3	88	34.63636	6.927273	8.584265
25/09/2018	28.09171295	144.118183140	3	88	34.63636	6.927273	8.027367
26/09/2018	24.34774971	143.141576770	3	88	34.63636	6.927273	5.829647
27/09/2018	30.90629101	144.268342970	3	88	34.63636	6.927273	9.809598
28/09/2018	10.09309483	144.492064480	3	88	34.63636	6.927273	0.265128
29/09/2018	17.16543579	122.427612310	3	88	34.63636	6.927273	2.335846
30/09/2018	16.25263786	110.604284290	3	88	34.63636	6.927273	1.97814
Total							1207.276

Table 4 15 Sample of Daily Rainfall Runoff Computation of Tana Subasin.

Date	Rain_faill	5-day rainfall	AMC	Conditional CN	S	0.2s	VQ
	mm						mm
01/05/2018	27.25503922	3.24899456	1	66	130.8485	26.1697	0.008928
02/05/2018	24.34260750	30.50403378	1	66	130.8485	26.1697	0
03/05/2018	21.44286346	52.593214370	2	82	55.7561	11.15122	1.603657
04/05/2018	19.68277168	75.172910180	3	92	22.08696	4.417391	6.238749
05/05/2018	22.46224976	98.280961860	3	92	22.08696	4.417391	8.113685
06/05/2018	18.75472450	115.185531620	3	92	22.08696	4.417391	5.643463
07/05/2018	13.98012733	106.685216900	3	92	22.08696	4.417391	2.889315
08/05/2018	12.36170959	96.322736730	3	92	22.08696	4.417391	2.101549
09/05/2018	11.59917068	87.241582860	3	92	22.08696	4.417391	1.76222
10/05/2018	10.72657490	79.157981860	3	92	22.08696	4.417391	1.401803
11/05/2018	13.00550747	67.422307000	3	92	22.08696	4.417391	2.404419
12/05/2018	11.38551235	61.673089970	3	92	22.08696	4.417391	1.671127
13/05/2018	14.75895023	59.078474990	3	92	22.08696	4.417391	3.297957
14/05/2018	11.72999001	61.475715630	3	92	22.08696	4.417391	1.818874
15/05/2018	7.98371458	61.606534960	3	92	22.08696	4.417391	0.495791
16/05/2018	7.30189562	58.863674640	3	92	22.08696	4.417391	0.333195
17/05/2018	7.35053205	53.160062790	3	92	22.08696	4.417391	0.343856
18/05/2018	6.91408253	49.125082490	2	82	55.7561	11.15122	0
19/05/2018	6.24238682	41.280214790	2	82	55.7561	11.15122	0
20/05/2018	5.47189474	35.792611600	1	66	130.8485	26.1697	0
21/05/2018	6.89672709	33.280791760	1	66	130.8485	26.1697	0
22/05/2018	5.37371111	32.875623230	1	66	130.8485	26.1697	0
23/05/2018	5.98716259	30.898802290	1	66	130.8485	26.1697	0
24/05/2018	5.79279852	29.971882350	1	66	130.8485	26.1697	0
25/05/2018	6.45223093	29.522294050	1	66	130.8485	26.1697	0
19/09/2018	16.22311783	79.290534030	3	92	22.08696	4.417391	4.11225
20/09/2018	17.51610756	77.978055010	3	92	22.08696	4.417391	4.876313
21/09/2018	22.04823303	79.988232620	3	92	22.08696	4.417391	7.82638
22/09/2018	21.11829185	87.316846850	3	92	22.08696	4.417391	7.190912
23/09/2018	21.31723213	92.203664780	3	92	22.08696	4.417391	7.325675
24/09/2018	16.72947884	98.222982400	3	92	22.08696	4.417391	4.406736
25/09/2018	21.91013718	98.729343410	3	92	22.08696	4.417391	7.731138
26/09/2018	18.72952843	103.123373030	3	92	22.08696	4.417391	5.627538
27/09/2018	19.60585785	99.804668430	3	92	22.08696	4.417391	6.188783
28/09/2018	22.18373299	98.292234430	3	92	22.08696	4.417391	7.92012
29/09/2018	21.02007675	99.158735290	3	92	22.08696	4.417391	7.124624
30/09/2018	22.86257362	103.449333200	3	92	22.08696	4.417391	8.39395
Total							497.4043

Join and relate the raster data to the derived Runoff of individual subasin level, as managed the Excell. The linkage is done through the map of subasin name.

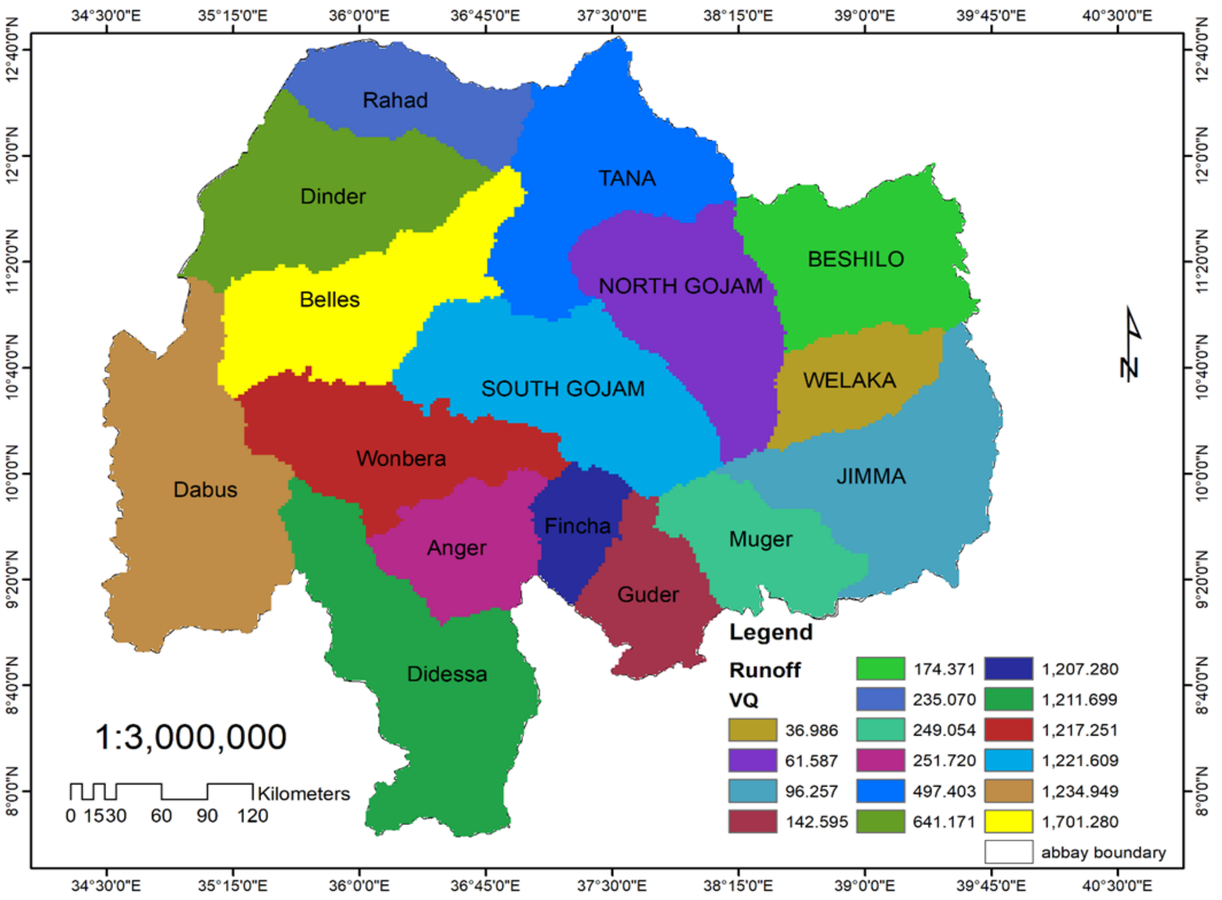


Figure 4 19 Runoff of map of abbay basin.

4.4.7 Reclassified Runoff

Table 4 16 Runoff Factor Rating.

Class (mm)	W	Des	F. Rating
1,211.6999511- 1,701.280029	4	H. Suitable	S.1
251.7209931 - 1,211.699951	3.	Mo. Suitable	S.2
142.5959931 - 251.720993	2.	Mar. Suitable	S.3
36.98699951 - 142.595993	1.	N. Suitable	N.

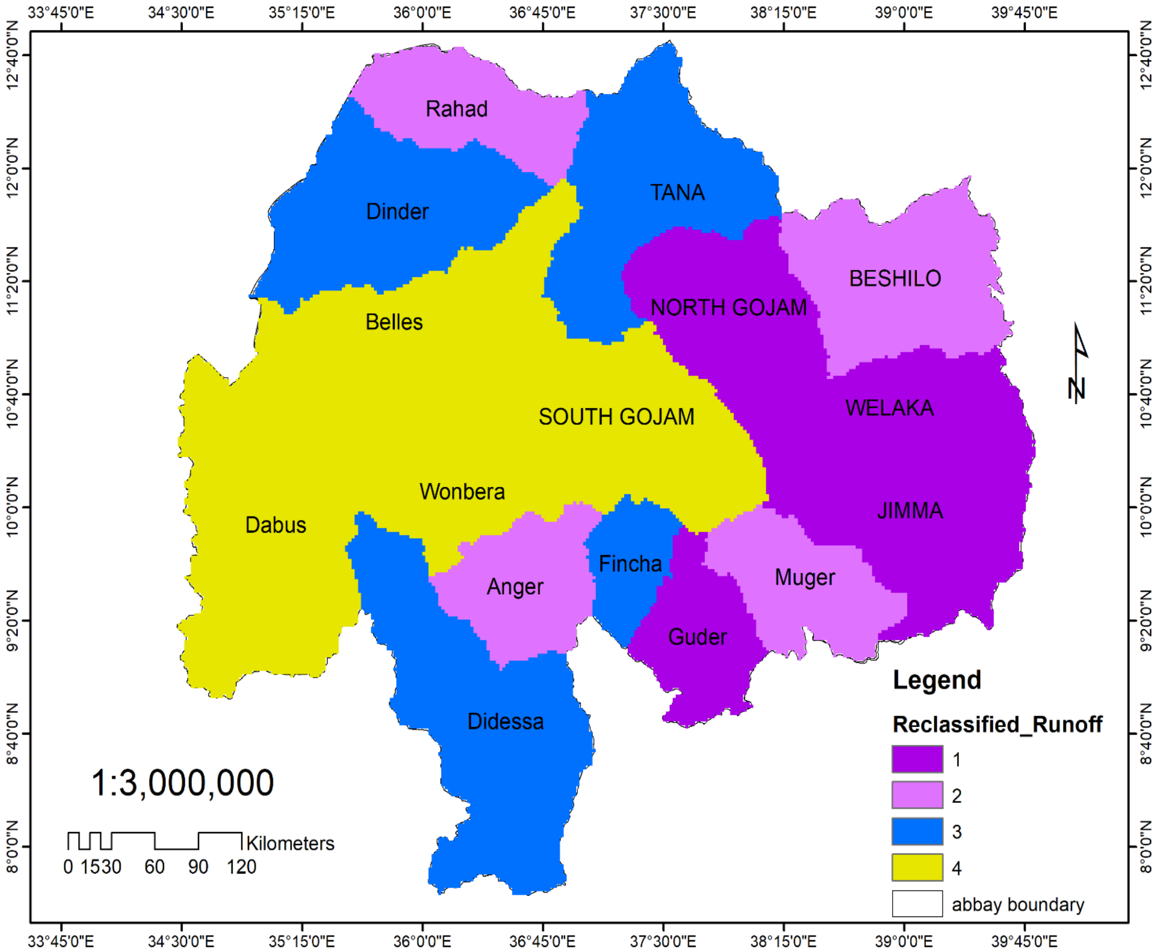


Figure 4 20 Reclassified Runoff Potential map of abbay basin.

4.5 Weight Assessments

The Relative weight for thematic layers are runoff, Slope, CEC, soil depth, Soil texture, soil PH, proximity to main river and soil Drainage were assigned according to their relative importance for each analyzed based on the judgment of knowledge of expert gained through interview on land suitability analysis for surface irrigation (Tesfaye, 2012).

Table 4 17 Pairwise comparison matrix and normalized weight.

Parameter	Slope	Proximity to river	Soil Texture	Soil Depth	Soil Drainage	PH	CEC	Runoff	Wt	Wt (%)
Slope	0.363	0.441	0.313	0.441	0.351	0.215	0.258	0.212	0.32	32
Proximity to river	0.181	0.221	0.209	0.265	0.293	0.269	0.258	0.212	0.238	23.8
Soil Texture	0.120	0.111	0.104	0.044	0.117	0.215	0.086	0.091	0.111	11.1
Soil Depth	0.073	0.073	0.209	0.088	0.117	0.107	0.086	0.091	0.105	10.5
Soil	0.060	0.044	0.052	0.044	0.059	0.107	0.129	0.121	0.077	7.7

Drainage										
PH	0.091	0.044	0.026	0.044	0.029	0.054	0.129	0.121	0.067	6.7
CEC	0.060	0.037	0.052	0.044	0.019	0.018	0.043	0.121	0.049	4.9
Runoff	0.051	0.031	0.035	0.029	0.015	0.013	0.011	0.031	0.027	2.7
Total	1	1	1	1	1	1	1	1	1	100

4.6 Surface Irrigation potential

As shown in Table 4.18 and Table 4.19 for surface irrigation the basin area classified as not suitable (9.45%), marginally suitable (25.55%), moderately suitable (35.74%) and highly suitable (29.26%). Total area of highly suitable, moderately suitable, marginally suitable, and not suitable land estimated by the analysis that can be developed by surface irrigation is about 5741870.55ha, 7013480.98ha, 5013834.33ha, 1854431.87ha respectively. Fincha Sub-basin has the highest percentage 56.16% of its total area of highly suitable followed by Didessa, Guder, and Anger sub basins having 41.23 %, 39.49%, and 36.50% respectively. North Gojam, Beshilo, South Gojam, and Rahad are sub-basins with the lowest percentage of surface irrigation potential having 0.40 %, 1.47%, 2.32, and 8.61 % of their area, respectively. Bashilo Sub-basin has the highest percentage 63.24 % of its total area of unsuitable followed by north Gojam, Welaga, and Jimma sub basins having 42.94 %, 31.31 %, and 11.84 % respectively.

Table 4 18 Surface Irrigation Suitability of Abay Basin.

No.	Class	Area	Area (%)
1.	H .suitable	5741870.55	29.26
2.	Mo. suitable	7013480.98	35.74
3.	Mar. suitable	5013834.33	25.55
4.	N. suitable	1854431.87	9.45

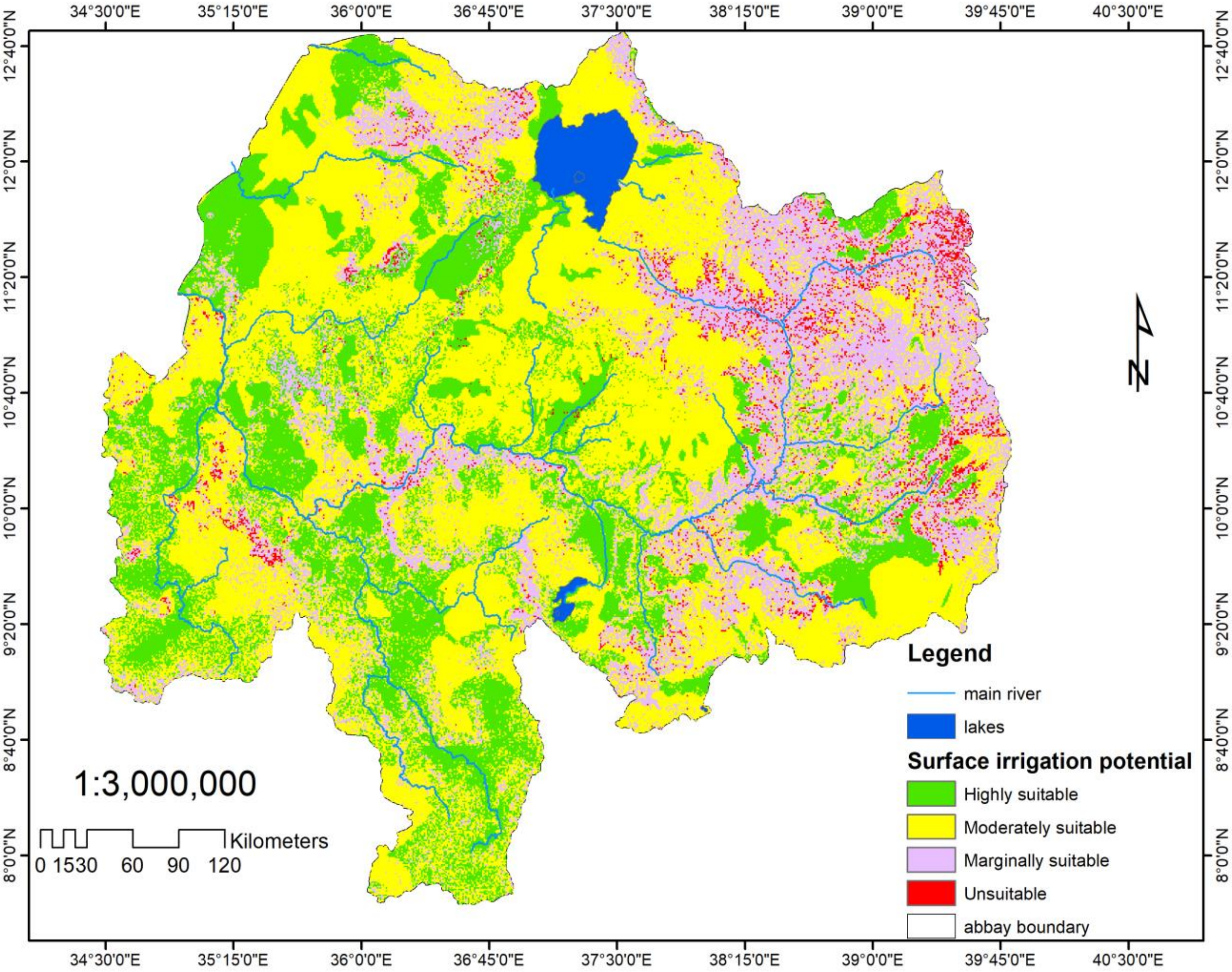


Figure 4 21 Surface irrigation potential Map of Abbay basin.

Table 4 19 Sub-basin Summary for Surface Irrigation Suitability.

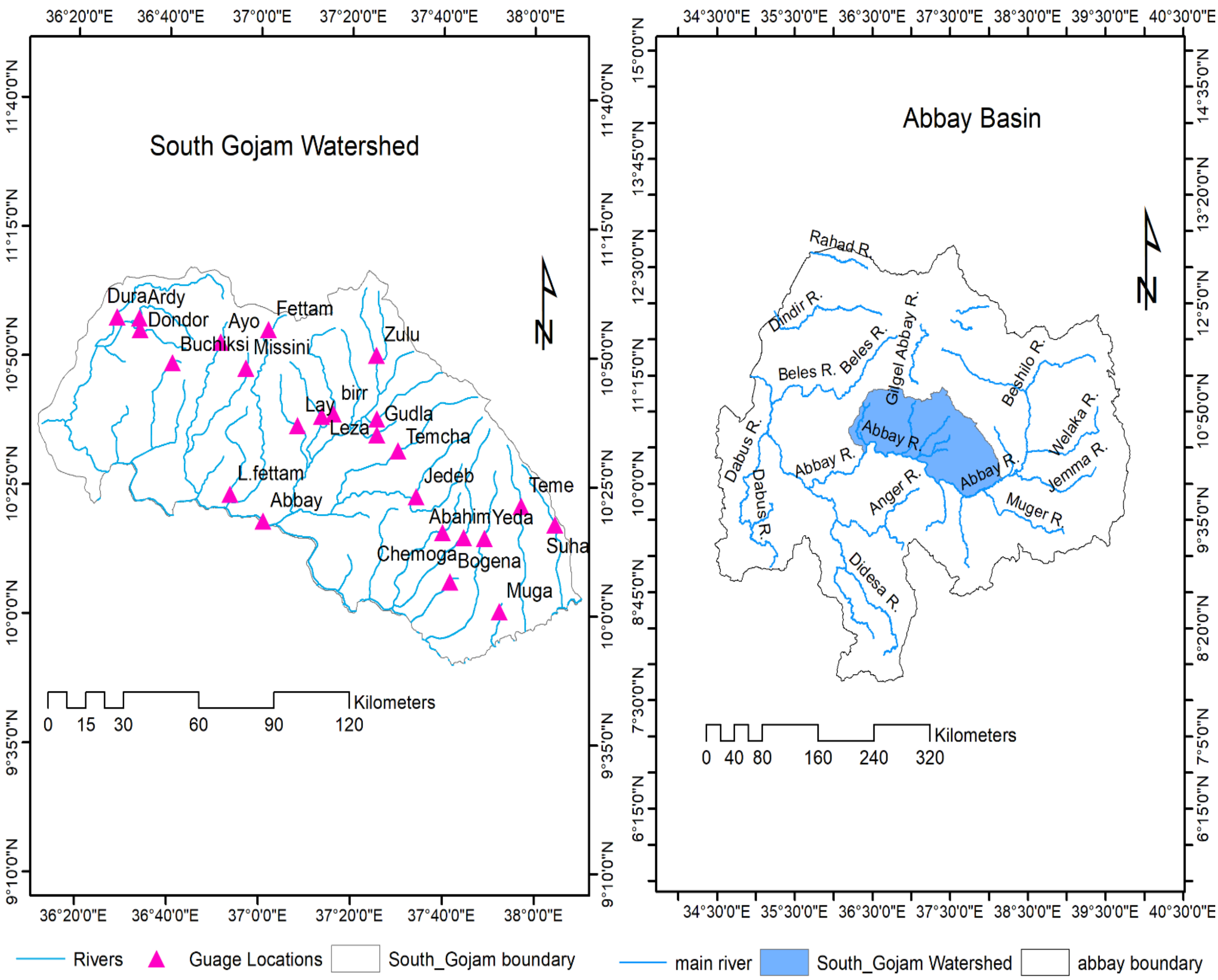
Area (1000ha)

Sub-Basin	Highly suitable	Moderately suitable	Marginally suitable	Suitable Total	Not suitable	Total
Anger	286.908	306.432	102.068	685.408	90.595	786.003
Belles	200.018	1095.417	313.6	1409.035	10.394	1419.429
Beshilo	19.099	18.099	440.482	477.68	821.803	1299.483
Dabus	652.87	1314.945	72.2	2040.015	20.34	2060.355
Didessa	790.986	713.617	401.758	1906.361	12.275	1918.636
Dinder	437.846	907.906	129.088	1474.84	12.308	1487.148
Fincha	219.525	156.916	13.704	390.145	0.750	390.895
Guder	273.406	372.787	25.153	671.346	20.904	692.25

Jemma	514.559	615.983	236.406	1366.948	183.677	1550.625
Muger	212.009	515.32	25.595	752.924	52.369	805.293
North Gojam	5.895	413.226	401.681	820.802	617.735	1438.537
Rahad	70.999	400.448	304.577	776.024	48.273	824.297
South Gojam	38.888	1620.189	10.957	1670.034	5.332	1675.366
Tana	224.508	741.959	202.463	1168.93	10.374	1179.304
Welaka	125.749	125.903	189.032	440.684	200.939	641.623
Wonbera	571.284	493.167	205.947	1270.398	25.103	1295.501

4.7 Surface Water Resource Irrigation Potential

Potential irrigable area of twenty four river was calculated by dividing the volume of water that could be supplied at 80% exceedance probability during the irrigation period by the irrigation water the requirement for the major crops grown in South Gojam watersheds.



4.8 Runoff Analysis

The minimum flow for Chereka, Chemoga, Gudla, Jedeb, Muga, Bogena, Suha, Teme, Temcha, Abahim, Yeda, Dura, Ardy, Dondor, Buchiksi, Ayo, Missini, Fettam, L.fettam, Abbay, Lay, Leza, Birr and Zulu Rivers at 80% exceedance probability calculated by Cumfreq software. The CumFreq program calculates the cumulative (non-exceedance) probability distribution fitting a given data series (Oosterbaan, 1994). Therefore, cumulative frequency at 20% used as a means to calculate exceedance probability of 80% to calculate the water resource potential for irrigation in a sustainable basis and avoid crop failure because of shortage of water.

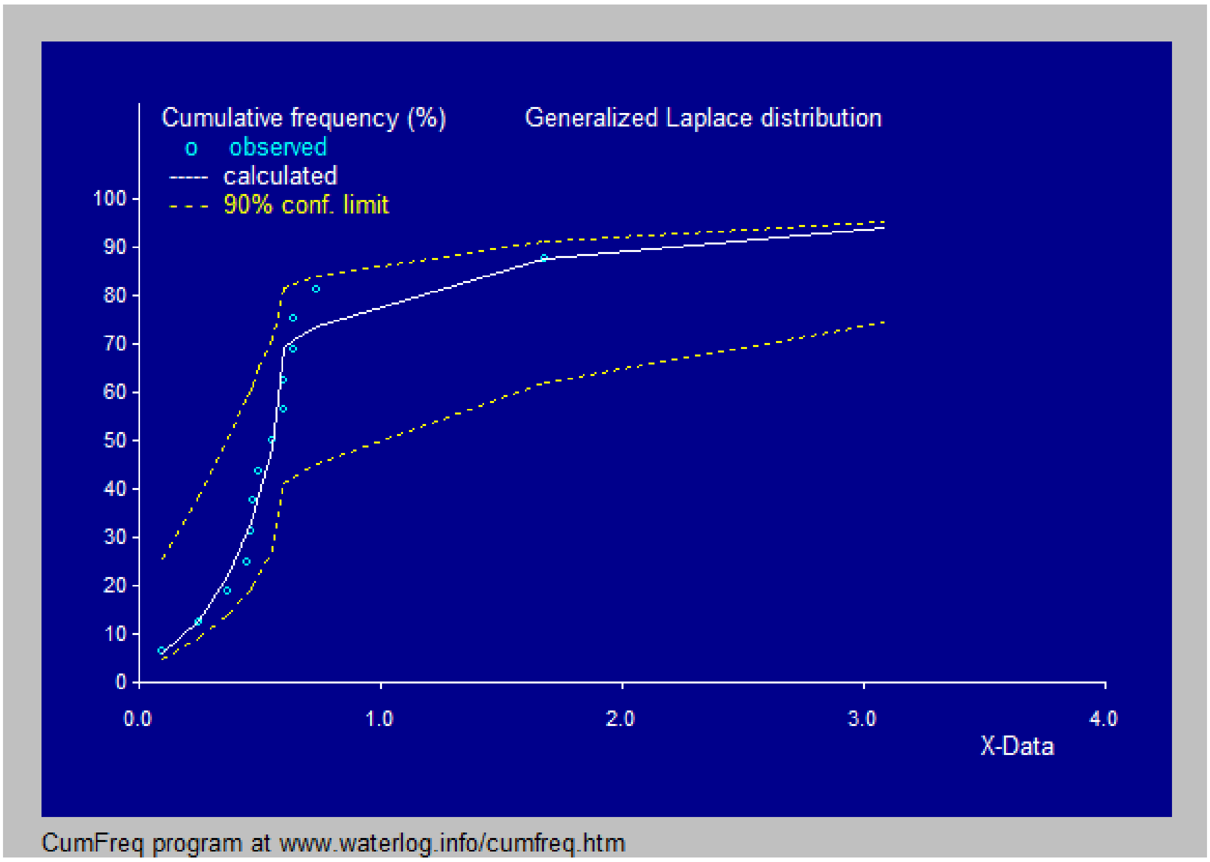


Figure 4 23 Cumulative Curve of Dura at January

Table 4 20 River flows at 80% exceedance probability for South Gojam Subasin.

River Name	80% Exceedance Probability (Million m^3)											
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Dura	0.350	0.251	0.166	0.144	0.193	0.120	0.727	4.360	5.063	0.989	0.540	0.659
Ardy	0.152	0.090	0.129	0.126	0.278	0.491	7.207	10.992	3.472	0.693	0.257	0.190

Dondor	0.362	0.207	0.167	0.129	0.277	0.783	13.817	27.336	2.696	3.817	1.244	0.577
Buchiksi	0.298	0.103	0.111	0.097	0.180	0.444	14.005	25.654	5.574	1.433	0.500	0.376
Ayo	0.574	0.301	0.728	0.502	0.855	1.175	25.661	49.641	18.494	4.982	2.033	0.981
Missini	1.738	0.207	1.167	5.129	8.277	10.783	15.817	28.336	2.696	3.817	1.244	0.577
Fettam	0.955	0.826	0.926	0.491	1.643	5.37	55.854	107.441	47.732	19.172	6.956	0.842
L.fettam	1.251	1.992	1.855	0.147	0.332	1.005	17.793	18.49	10.856	2.159	1.425	1.749
Abbay	79.378	53.103	118.12	120.09	100.18	270.44	750.16	400.654	2230.75	475.12	337.51	87.532
Lay	2.141	3.569	2.482	1.126	0.278	0.491	9.207	11.992	4.472	1.693	1.257	1.19
Leza	2.151	1.391	0.656	3.144	0.193	0.12	0.727	5.36	6.063	1.989	1.54	2.169
Birr	1.189	1.153	0.798	2.688	1.246	3.682	28.819	44.777	39.03	10.053	3.405	1.74
Zulu	0.574	0.301	0.728	0.502	0.855	1.175	25.661	49.641	18.494	4.982	2.033	0.981
Chereka	1.491	1.437	1.574	6.444	4.606	8.629	21.033	27.444	9.158	2.929	1.31	0.842
Chemoga	0.923	0.765	0.808	0.292	0.498	1.165	22.627	57.004	20.972	3.794	1.378	1.258
Gudla	0.486	0.434	1.47	4.338	4.681	4.801	58.767	84.114	43.88	9.875	3.112	1.532
Jedeb	1.199	0.694	0.862	0.688	1.246	3.682	36.819	63.777	41.03	10.053	3.405	2.042
Muga	0.574	0.346	0.418	0.502	0.855	1.175	26.661	47.641	17.494	2.982	1.033	0.821
Bogena	0.362	1.207	0.167	0.129	0.277	0.783	13.817	27.336	2.696	3.817	1.244	3.577
Suha	1.298	1.103	0.111	6.097	7.18	5.444	14.005	25.654	5.574	1.433	0.5	1.376
Teme	1.251	1.132	2.115	3.147	4.332	5.005	15.793	16.49	8.856	1.159	0.425	0.293
Temecha	1.355	0.656	0.826	0.491	1.643	5.37	55.854	108.441	45.732	17.172	4.956	2.042
Abahim	0.491	0.437	0.574	0.126	0.278	0.491	7.207	10.992	3.472	0.693	0.257	0.933
Yeda	0.35	2.251	3.166	5.144	5.193	3.12	2.727	4.36	5.063	0.989	0.54	0.659

4.9 Estimation of Irrigable area with available stream flow

To calculate the crop water requirement a potential evapotranspiration should be multiplied with coefficients of crops (kc) grown with irrigation. Crops grown with irrigation in the south Gojam watersheds were maize, sugarcane, onion, potato and cabbage and the crop coefficients for the initial, mid and late seasons and growing period were extracted from the FAO – 66 (Steduto et al., 2012). **Thus, Kc average of the major crops is 0.83.**

About 38888.12 ha of land can be irrigated at the gauge location of these rivers without further development on the downstream part of these rivers (Table 4.22).

Table 4 21 Irrigable Area by surface water for South Gojam watersheds.

River Name	**PET (mm)**	**CWR (mm)**	**Peff (mm)**	**IR (mm)**	**Q (80) (Millionm3)**	**Irrigable Area(ha)**
						Surface irrigation
Dura	788.821	654.7214	15.345	639.376	1.426	144.97
Ardy	956.324	793.7489	13.721	778.028	0.561	46.75
Dondor	910.976	756.1101	12.543	743.567	1.313	114.78
Buchiksi	850.821	706.1814	10.372	695.809	0.888	82.95
Ayo	789.679	655.4336	15.666	639.768	2.584	262.53
Missini	985.342	817.8339	12.652	805.182	3.689	297.80
Fettam	899.657	746.7153	14.261	732.454	3.549	314.95
L.fettam	935.654	776.5928	18.999	757.594	6.847	587.46
Abbay	880.123	730.5021	18.221	712.281	338.053	30849.40
Lay	884.345	734.0064	17.642	716.364	9.382	851.28
Leza	962.951	799.2493	10.62	788.629	6.367	524.78
Zulu	855.345	709.9364	12.38	697.556	4.880	454.73
birr	885.533	734.9924	9.55	725.442	2.584	368.26
Chereka	909.475	754.8643	13.96	740.904	5.344	468.83
Chemoga	960.381	797.1162	12.83	784.286	3.754	311.12
Gudla	894.341	742.303	6.22	736.083	3.922	346.33
Jedeb	870.374	722.4104	18.21	704.200	4.797	442.78
Muga	945.562	784.8165	4.04	780.776	2.159	179.74
Bogena	888.591	737.5305	8.92	728.611	5.313	473.98
Suha	925.828	768.4372	13.55	754.887	3.888	334.78
Teme	956.347	793.768	15.59	778.178	4.791	400.18
Temcha	912.475	757.3543	16.6	740.754	4.879	428.12
Abarim	923.955	766.8827	15.34	751.543	2.334	202.73
Yeda	952.195	790.3219	10.48	779.842	6.426	535.61

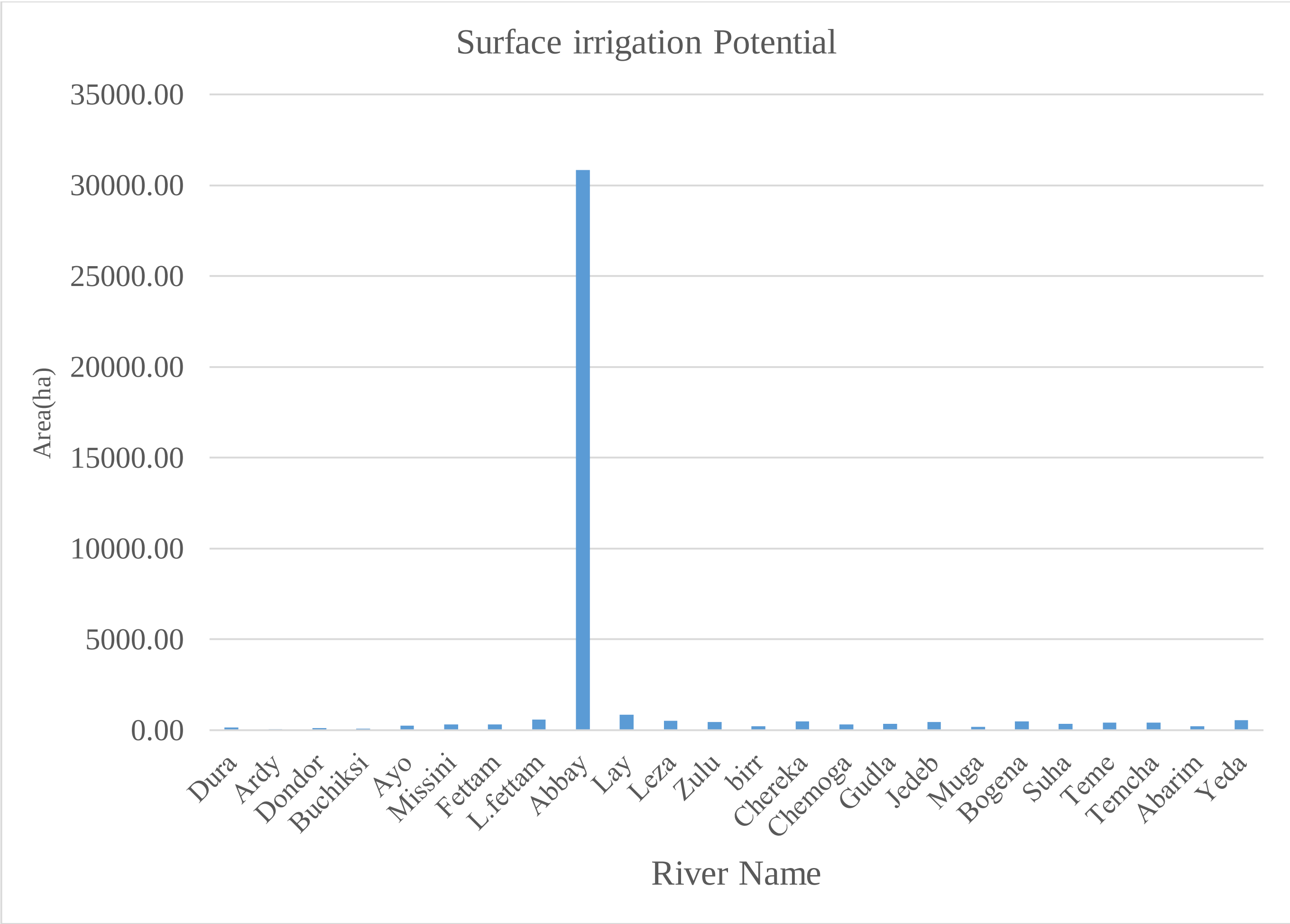


Figure 4 24 Surface irrigation Potential of rivers in South Gojam watersheds

As indicated above, Abbay, Lay, and L.fettam Rivers have the highest water resource potential for Surface irrigation. When I relate available water resource with what I have obtained from land capability analysis about 38888.12 ha can be irrigated and specific area can be irrigated as shown figure 4.24.

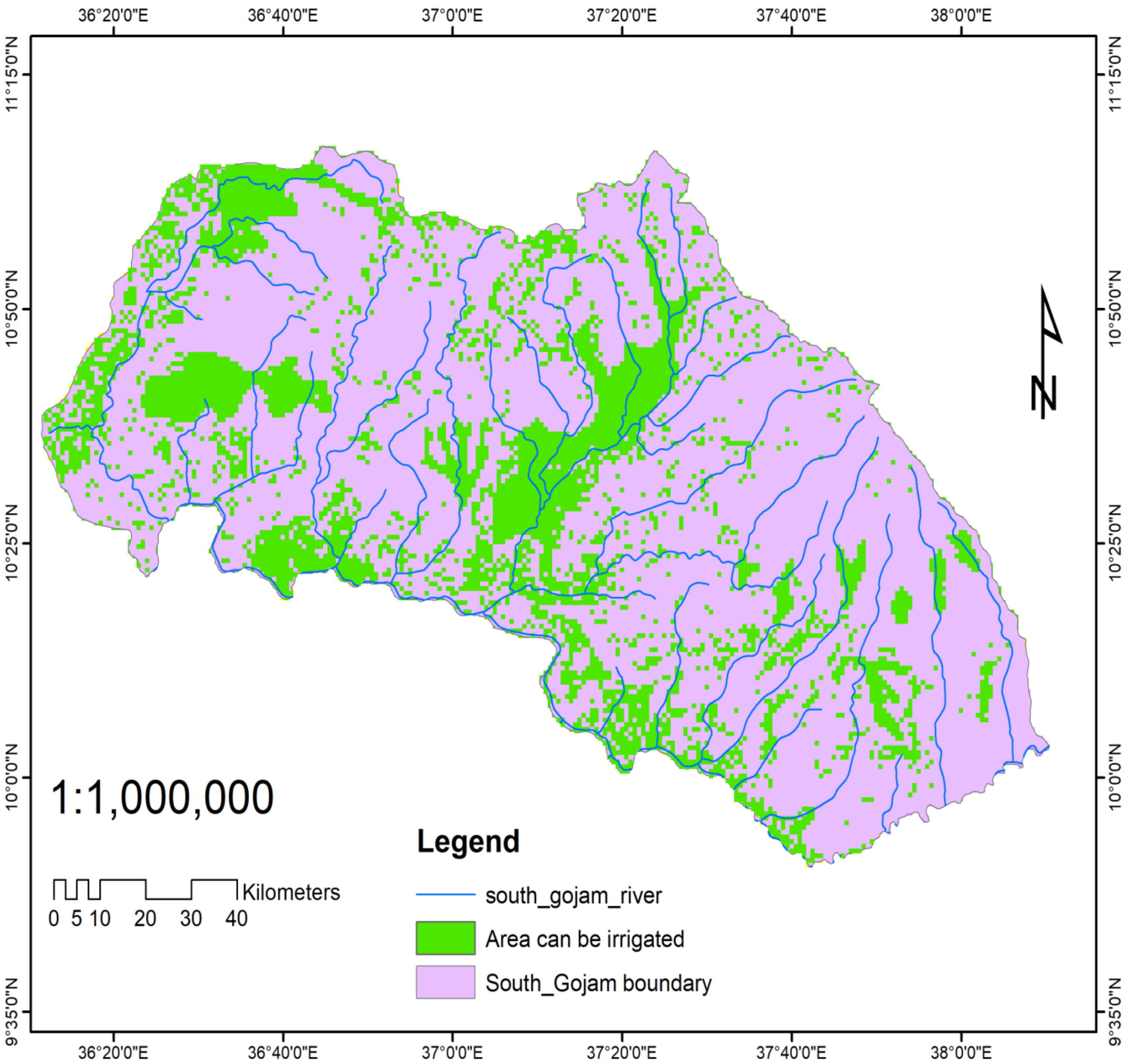


Figure 4 25 Area can be irrigated with available water potential of South Gojam watershed

5. CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The study has demonstrated that GIS techniques are an essential tool for the surface irrigation site suitability evaluation. Eight factors were used to assess the land suitability site for surface irrigation. The most important limiting factors were Slope, distance from water source, Soil texture, soil depth, Soil drainage, Soil PH, Cation exchange capacity and Runoff with weight of influence of 32%, 23.8%, 11.1%, 10.5%, 7.7%, 6.7%, 4.9%, 2.7% respectively. The results of the study revealed that about 5741870.55 ha (29.26 % of the watershed area) highly suitable, 7013480.98 ha (35.74 % of the watershed area) moderately suitable, 5013834.33 ha (25.55 % of the watershed area) marginally suitable, 1854431.87 ha (9.45 % of the watershed area) not suitable. Using the Weighted Overlay tool, the values of each dataset were weighted and combined to find the most suitable location for surface irrigation using the ArcGIS environment. The findings drawn from this study can play an indispensable role in boosting irrigable land in the study area by considering suitable irrigable lands in terms of the eight factors described.

The hydrologic analysis done to surface water irrigation potential estimated about 38888.12 ha of land can be irrigated by surface irrigation at the gauge location of rivers in South Gojam watersheds without further development on the downstream part of these rivers. Most of irrigation practice have been observed at upper of rivers or watersheds.

Generally, using GIS with the aid of remote sensing data provides spatially explicit irrigation area suitability, and water resources potential for large areas with short period of time and limited budget.

5.2 RECOMMENDATIONS

- Physical land suitability analysis based on topography, soil physical and chemical properties and crop specific requirement is more focused in this paper. But other factors like socio-economic, market infrastructure etc. are recommended to be included.
- Only 29 % of the area from total area of abbay basin was H. suitable for surface irrigation. It's recommended to analysis to for sprinkler and drip irrigation.
- Stream flows of twenty four rivers at Gauged Site were analyzed for surface water potential. But un-gauged sites were not estimated. However, future research should test other methods such as runoff coefficient method, regional regression analysis, base flow correlation and development of unit hydrograph to estimate discharges at ungauged sites from gauged sites.

So, GIS and remote sensing application is hopeful for land capability analysis of future irrigation maximal activities will increase these resources potential more than the present study and water resources potential in the area and elsewhere.

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APPENDICES

Appendix 1: Curve number conversions for different antecedent moisture conditions

CN for AMC II	CN for AMC I	CN for AMC III	CN for AMC II	CN for AMC I	CN for AMC III
100	100	100	76	58	89
99	97	100	75	56	88
98	94	99	74	55	88
97	91	99	73	54	87
96	89	99	72	53	86
95	87	98	71	52	86
94	85	98	70	51	85
93	83	98	69	50	84
92	81	97	68	48	84
91	80	97	67	47	83
90	78	96	66	46	82
89	76	96	65	45	82
88	75	95	64	44	81
87	73	95	63	43	80
86	72	94	62	42	79
85	70	94	61	41	78
84	68	93	60	40	78
83	67	93	59	39	78
82	66	92	58	38	76
81	64	92	57	37	75
80	63	91	56	36	75
79	62	91	55	35	74
78	60	90	54	34	73
77	59	89	50	31	70

Source: SCS-NEH4. Table 10.1

Appendix2: Hydrometric Discharge Data (Million m3)

Station Name: Dura Nr. /@ Metekel

Year	Ja	Fe	Ma	Ap	Ma	Ju	Ju	Au	Se	Oc	No	De
1988	0.097	0.361	0.522	1.122	1.24	6.06	26.147	37.8	36.265	23.704	11.631	0.897
89	0.26	0.361	0.511	1.047	1.24	6.525	30.554	47.5	38.018	21.587	12.538	0.897
90	0.368	0.366	0.511	1.035	1.24	11.037	35.375	44.9	42.398	19.431	12.425	0.89
91	0.452	0.37	0.506	1.06	1.24	12.597	38.482	43.2	42.398	19.044	10.974	0.849
92	0.463	0.392	0.471	1.187	1.24	13.131	41.2	41.7	48.229	18.666	10.234	0.836
93	0.469	0.401	0.438	1.06	1.268	13.555	43.149	42.9	57.147	19.198	10.65	0.796
94	0.504	0.428	0.433	1.035	1.455	13.495	42.9	46.0	54.721	20.208	9.791	0.789
95	0.552	0.433	0.428	1.023	1.594	12.892	38.649	41.4	52.376	20.208	7.743	0.789
96	0.598	0.433	0.401	0.953	1.741	13.495	30.4	42.0	51.52	19.351	7.434	0.789
97	0.67	0.438	0.392	0.941	1.932	13.617	26.793	47.7	47.901	19.505	7.607	0.783
98	0.641	0.471	0.366	0.953	1.694	13.435	25.035	55.9	46.145	18.519	8.916	0.751
99	0.645	0.506	0.361	1.023	1.34	11.305	23.096	68.4	49.005	17.073	10.602	0.777
2000	0.746	0.511	0.361	1.06	1.532	5.884	21.826	84.6	52.965	14.697	10.755	0.745
001	1.683	0.511	0.37	1.214	1.516	6.878	21.577	68.8	49.005	14.963	10.031	0.739
002	3.091	0.522	0.433	1.254	1.725	6.248	20.6	61.1	45.36	12.262	9.383	0.732

Station Name: Ardy Nr. /@Metekel

Years	Ja	Fe	Ma	Ap	Ma	Ju	Ju	Au	Se	Oc	No	De
1985	0.897	0.5	0.591	0.591	0.532	2.503	12.69	62.95	57.84	58.699	26.314	2.036
86	0.897	0.5	0.597	0.597	0.586	1.137	7.978	29.07	55	78.687	25.974	2.026
87	0.89	0.5	0.597	0.597	0.597	1.05	12.42	33.82	70.66	60.628	27.003	2.026
88	0.849	0.5	0.597	0.597	0.608	1.315	16.36	36.53	72.76	44.686	27.525	2.004
89	0.836	0.5	0.591	0.591	0.666	1.15	25.9	31.91	51.6	37.874	26.486	1.878
90	0.796	0.5	0.559	0.559	0.608	1.418	55.76	34.55	48.56	43.058	25.554	1.858
91	0.789	0.5	0.548	0.548	0.586	4.12	27.12	39.31	54.67	51.035	23.943	1.858
92	0.789	0.5	0.517	0.517	0.522	3.225	18.22	28.25	42.25	56.205	23.496	1.858
93	0.789	0.5	0.511	0.511	0.511	1.993	9.325	59.03	36.05	51.507	23.698	1.847
94	0.783	0.5	0.511	0.511	0.511	1.821	16.57	54.1	43.89	46.551	23.657	1.777
95	0.751	0.5	0.511	0.511	0.506	2.934	21.14	60.5	43.91	42.63	23.176	1.707
96	0.777	0.5	0.511	0.511	0.471	6.46	20.05	49.18	42.45	42.184	23.017	1.697
97	0.745	0.5	0.511	0.511	0.438	8.105	33.55	25.72	50.3	41.091	22.426	1.697
98	0.739	0.5	0.511	0.511	0.433	8.638	33.25	23.97	38.81	41.473	21.573	1.688
99	0.732	0.5	0.511	0.511	0.428	6.679	37.4	35.06	35.62	39.219	21.039	1.62
2000	0.696	0.5	0.511	0.511	0.401	5.396	36.62	45.89	59.84	37.596	21.152	1.554
001	0.69	0.5	0.511	0.511	0.392	6.985	36.49	49.62	54.25	35.309	20.963	1.545
002	0.69	0.5	0.511	0.511	0.366	8.571	31.26	61.93	64.29	32.952	20.887	1.545
003	0.69	0.5	0.511	0.511	0.361	9.219	33.23	54.99	50.67	31.098	20.662	1.536
004	0.69	0.5	0.506	0.506	0.361	4.003	25.78	40.21	38.71	31.66	20.624	1.481

Station Name: Dondor **Nr. /@Metekel**

Years	Ja	Fe	Ma	Ap	Ma	Ju	Ju	Au	Se	Oc	No	De
89	0.263	0.092	0.06	0.044	0.015	0.484	16.783	29.709	53.605	37.93	2.459	0.771
90	0.26	0.091	0.059	0.044	0.013	0.344	7.178	32.716	48.79	37.417	2.547	0.731
91	0.241	0.091	0.052	0.043	0.013	0.439	5.383	31.003	48.648	39.432	2.851	0.65
92	0.222	0.091	0.051	0.038	0.016	1.031	5.16	30.461	38.19	34.292	3.234	0.579
93	0.219	0.091	0.05	0.037	0.02	2.341	9.965	31.073	32.856	35.839	3.234	0.564
94	0.219	0.089	0.046	0.036	0.024	1.077	28.621	29.589	34.413	37.02	2.864	0.531
95	0.219	0.082	0.049	0.031	0.02	2.809	22.303	36.919	41.751	34.388	2.624	0.5
96	0.219	0.089	0.045	0.031	0.016	1.409	20.977	29.166	38.288	34.456	2.423	0.495
97	0.219	0.089	0.043	0.03	0.013	0.792	11.485	27.195	47.082	33.094	2.209	0.495
98	0.219	0.08	0.038	0.026	0.012	0.754	19.851	37.027	45.268	33.203	1.921	0.495
99	0.219	0.071	0.037	0.025	0.01	1.052	20.92	39.202	56.986	29.795	1.858	0.491
2000	0.217	0.069	0.037	0.025	0.01	2.469	25.702	37.056	53.433	30.698	1.737	0.461
001	0.199	0.069	0.037	0.021	0.009	2.936	30.065	36.909	38.244	29.257	1.717	0.432
002	0.182	0.071	0.037	0.02	0.008	4.034	27.808	28.907	36.586	28.132	1.66	0.428
003	0.18	0.078	0.037	0.02	0.012	9.635	29.45	35.436	32.686	27.479	1.306	0.428
004	0.18	0.08	0.037	0.017	0.051	4.508	40.36	35.913	15.297	25.942	1.072	0.428

Station Name: Buchiksi **Nr. /@Gidamaja**

Years	Ja	Fe	Ma	Ap	Ma	Ju	Ju	Au	Se	Oc	No	De
1985	0.083	0.138	0.081	0.08	0.152	1.637	10.33	5.58	9.178	4.903	1.792	0.702
86	0.111	0.087	0.08	0.08	0.119	5.889	8.621	8.469	8.177	3.957	1.776	0.692
87	0.142	0.087	0.081	0.08	0.142	2.166	4.159	5.52	5.917	3.267	1.759	0.656
88	0.147	0.133	0.091	0.08	0.142	1.56	3.998	4.082	5.128	2.729	1.662	0.621
89	0.163	0.111	0.085	0.081	0.111	1.736	3.342	4.502	3.925	2.637	1.63	0.606
90	0.248	0.091	0.103	0.091	0.083	1.462	5.005	6.849	4.666	2.498	1.521	0.549
91	0.163	0.129	0.083	0.085	0.081	2.054	3.134	5.321	12.235	2.353	1.408	0.514
92	0.147	0.087	0.08	0.103	0.095	4.057	4.128	8.633	5.686	2.651	1.342	0.372
93	0.149	0.081	0.08	0.087	0.109	4.634	7.67	14.12	7.511	4.679	1.292	0.395
94	0.162	0.093	0.08	0.103	0.115	3.221	3.745	9.27	16.756	2.574	1.285	0.395
95	0.154	0.095	0.081	0.087	0.152	4.45	3.434	9.523	15.973	2.176	1.278	0.338
96	0.183	0.097	0.091	0.107	0.223	2.863	5.721	12.398	10.192	2.05	1.237	0.26
97	0.185	0.111	0.083	0.107	0.234	3.29	3.048	16.418	4.874	1.919	1.223	0.194
98	0.169	0.122	0.091	0.083	0.234	2.917	2.802	8.861	3.789	1.957	1.182	0.167
99	0.169	0.105	0.081	0.08	0.24	2.905	4.007	5.797	4.547	2.794	1.168	0.147
2000	0.18	0.131	0.08	0.08	0.342	2.876	2.864	11.708	4.282	3.686	1.128	0.128
001	0.154	0.087	0.081	0.083	1.058	2.272	3.151	7.65	8.376	2.196	1.115	0.111
002	0.167	0.08	0.095	0.111	2.76	3.268	6.403	5.6	4.445	2.376	1.07	0.098
003	0.185	0.08	0.109	0.158	1.678	10.946	3.722	7.629	3.737	1.896	1.025	0.109

Station Name: Ayo **Nr. /@Kossober**

Years	Ja	Fe	Ma	Ap	Ma	Ju	Ju	Au	Se	Oc	No	De
1990	0.067	0.036	0.028	0.016	0.045	0.051	0.596	4.343	2.646	1.266	0.349	0.166
91	0.052	0.041	0.023	0.017	0.056	0.05	1.157	2.514	5.424	1.919	0.434	0.164
92	0.044	0.041	0.025	0.026	0.045	0.05	2.122	1.824	2.819	2.295	0.303	0.175
93	0.042	0.035	0.018	0.027	0.042	0.098	1.346	2.196	5.832	2.618	0.351	0.301
94	0.042	0.035	0.02	0.029	0.042	0.484	1.256	4.175	2.513	1.759	0.756	0.218
95	0.044	0.041	0.016	0.05	0.042	0.374	2.599	3.438	4.375	2.197	0.351	0.197
96	0.051	0.042	0.015	0.118	0.04	1.446	9.01	3.376	10.392	1.622	0.275	0.171
97	0.057	0.041	0.008	0.104	0.03	0.295	4.098	3.709	6.534	2.55	0.239	0.162
98	0.047	0.036	0.007	0.064	0.033	0.18	3.369	3.995	6.626	1.556	0.208	0.135
99	0.056	0.039	0.007	0.045	0.03	1.145	1.81	7.554	4.276	1.719	0.225	0.11
2000	0.046	0.031	0.007	0.042	0.04	1.191	2.103	3.135	4.942	1.247	0.281	0.107
001	0.054	0.04	0.007	0.041	0.042	0.778	2.602	2.454	8.24	1.263	0.345	0.104
002	0.074	0.042	0.007	0.036	0.042	0.622	2.703	4.414	7.334	1.639	0.382	0.088
003	0.054	0.042	0.007	0.039	0.042	0.346	1.549	6.736	5.407	1.27	0.325	0.104
004	0.046	0.042	0.007	0.03	0.042	0.207	1.594	3.061	2.883	0.96	0.262	0.104

Station Name: Missini **Nr. /@Kossober**

Years	Ja	Fe	Ma	Ap	Ma	Ju	Ju	Au	Se	Oc	No	De
1988	0.046	0.031	0.024	0.037	0.03	0.051	0.549	1.508	2.048	1.547	1.282	0.098
89	0.042	0.031	0.024	0.032	0.025	0.049	0.534	7.582	1.558	1.806	1.306	0.115
90	0.046	0.031	0.024	0.031	0.024	0.049	0.488	12.236	2.156	1.505	1.016	0.098
91	0.039	0.031	0.024	0.03	0.024	0.122	0.488	3.855	2.439	0.734	0.91	0.094
92	0.033	0.032	0.025	0.025	0.024	0.632	0.576	2.715	8.601	0.546	0.9	0.094
93	0.038	0.037	0.03	0.024	0.025	0.537	0.819	2.465	2.264	0.481	0.91	0.098
94	0.041	0.032	0.031	0.024	0.03	3.308	1.155	3.865	3.023	0.423	0.932	0.119
95	0.045	0.031	0.032	0.024	0.031	0.479	4.318	1.367	2.07	0.379	0.711	0.119
96	0.033	0.031	0.037	0.024	0.031	0.82	1.697	1.249	1.597	0.399	0.657	0.094
97	0.031	0.031	0.032	0.023	0.064	7.642	0.887	3.279	5.533	0.441	0.558	0.072
98	0.031	0.031	0.033	0.018	0.328	5.64	0.875	2.756	1.604	0.43	0.534	0.071
99	0.031	0.031	0.047	0.018	0.426	0.764	0.784	2.932	1.075	0.448	0.47	0.08
2000	0.031	0.031	0.055	0.018	1.008	0.2	0.734	7.896	2.286	0.441	0.354	0.081
001	0.033	0.031	0.044	0.018	0.498	0.294	0.99	4.335	1.578	0.376	0.293	0.081
002	0.046	0.031	0.054	0.018	0.088	1.096	0.876	11.836	1.04	0.35	0.238	0.083
003	0.047	0.031	0.043	0.018	0.17	2.137	0.812	2.897	0.907	0.363	0.23	0.093
004	0.039	0.031	0.045	0.02	1.108	7.119	1.68	2.758	1.742	0.347	0.23	0.091

Station Name: Fettam **Nr./@Tillile**

Years	Ja	Fe	Ma	Ap	Ma	Ju	Ju	Au	Se	Oc	No	De
1989	0.906	0.423	0.351	0.224	0.346	1.009	18.496	25.675	26.506	19.172	7.16	1.251
90	0.994	0.418	0.346	0.224	0.346	1.148	17.477	33.141	20.209	20.878	4.519	1.151
91	0.994	0.418	0.351	0.224	0.346	1.642	17.914	35.244	16.348	15.594	2.969	1.126
92	0.906	0.418	0.364	0.224	0.346	1.429	18.379	32.466	18.241	9.301	2.556	1.078
93	0.891	0.418	0.294	0.224	0.346	1.704	41.388	31.02	15.868	7.242	2.533	1.078
94	0.891	0.414	0.282	0.224	0.338	2.572	41.773	25.57	16.593	6.304	3.315	1.126
95	0.884	0.391	0.282	0.224	0.29	3.568	30.166	25.116	29.41	6.062	4.616	1.142
96	0.835	0.414	0.286	0.224	0.29	3.441	30.722	26.16	30.02	5.292	2.879	1.217
97	0.788	0.418	0.313	0.224	0.398	6.854	27.282	26.609	24.793	4.68	2.277	1.356
98	0.781	0.418	0.347	0.224	0.794	8.803	28.228	31.79	23.947	4.173	2.148	1.375
99	0.781	0.418	0.391	0.224	0.769	6.633	28.736	43.02	14.143	4.149	2.058	2.186
2000	0.781	0.418	0.488	0.224	0.856	4.32	20.553	37.796	11.098	5.68	1.959	1.457
001	0.768	0.414	0.53	0.224	0.763	5.099	16.971	47.07	14.266	6.226	1.82	1.234
002	0.704	0.386	0.519	0.228	0.564	8.296	20.033	39.364	17.26	5.059	1.789	1.347
003	0.762	0.382	0.614	0.249	0.567	11.435	17.706	31.003	13.202	4.527	1.717	1.503
004	0.723	0.382	0.625	0.252	0.954	9.986	24.615	26.047	13.035	5.618	1.637	1.374

Name: Lower Fettam **Nr. /@Galibed**

Year	Ja	Fe	Ma	Ap	Ma	Ju	Ju	Au	Se	Oc	No	De
1986	1.669	0.921	0.628	0.486	0.998	1.856	24.233	51.295	33.913	28.642	10.443	2.419
87	1.657	0.864	0.583	0.48	0.922	1.767	29.445	83.155	28.786	22.891	11.284	2.435
88	1.657	0.808	0.576	0.486	0.893	1.785	26.223	94.829	27.752	18.217	13.814	3.784
89	1.646	0.801	0.576	0.515	1.571	2.894	22.632	66.512	31.657	17.568	10.721	3.046
90	1.576	0.793	0.564	0.486	2.808	5.239	24.122	49.896	44.383	15.621	8.177	2.774
91	1.553	0.7	0.492	0.48	2.212	3.583	21.047	33.199	58.522	14.189	6.53	2.439
92	1.463	0.406	0.48	0.48	1.637	2.83	22.694	52.452	75.947	18.39	6.26	1.241
93	1.314	0.223	0.486	0.48	1.553	3.264	18.513	61.622	58.378	21.631	6.002	1.128
94	1.232	0.296	0.515	0.474	1.442	11.958	14.746	63.309	37.365	22.007	6.131	1.499
95	1.213	0.662	0.498	0.421	1.184	8.84	24.345	51.448	31.242	21.356	5.482	1.564
96	1.145	0.697	0.57	0.319	1.126	15.933	30.18	52.122	36.566	19.613	5.676	1.542
97	1.079	0.712	0.615	0.416	0.991	15.488	26.597	49.895	45.024	21.741	5.849	1.409
98	1.061	0.609	0.583	0.436	0.809	7.467	31.806	36.166	40.426	28.761	5.7	1.409
99	1.007	0.669	0.576	0.436	0.697	11.266	37.964	41.4	38.379	25.137	5.457	1.519
2000	1.007	0.69	0.589	0.441	0.663	11.986	59.339	38.851	37.617	21.798	5.01	1.442
001	1.061	0.733	0.669	0.474	0.546	12.393	55.772	38.809	44.078	19.338	4.874	1.635
002	1.061	0.733	0.712	0.48	0.521	7.675	68.069	49.045	74.813	14.179	4.479	1.694
003	1.007	0.69	1.079	0.486	0.464	8.202	63.338	56.087	68.277	10.807	4.523	1.431
004	0.998	0.676	2.214	0.54	0.346	9.458	42.725	50.17	49.001	9.707	5.174	1.366
005	0.99	0.642	1.485	0.656	0.375	7.88	42.673	35.923	40.937	9.108	5.125	1.253

Station Name: Abbay **Nr. /@Bure**

Years	Ja	Fe	Ma	Ap	Ma	Ju	Ju	Au	Se	Oc	No	De
2010	91.575	54.513	121.206	125.183	191.984	414.888	768.011	5499.256	3290.442	907.978	371.499	154.695
2011	87.016	52.718	118.589	122.525	205.249	431.438	1008.552	4244.663	2778.577	861.202	550.384	145.965
2012	83.669	53.612	113.434	119.894	212.037	326.168	697.67	5802.227	2570.879	848.051	588.426	137.472
2013	85.893	64.884	117.29	123.851	200.226	291.504	758.656	6852.382	2870.733	805.965	477.888	144.533
2014	76.098	126.522	131.944	157.658	215.47	258.673	1208.963	4856.654	2312.742	521.331	338.837	87.016
2015	84.777	134.695	134.695	154.695	222.413	467.924	1459.935	5633.854	2219.249	503.228	351.733	82.566
2016	78.227	140.277	143.107	145.965	229.459	1132.753	1944.821	4168.294	2767.157	467.924	334.589	80.383
2017	81.471	130.578	148.849	140.277	229.459	691.703	1426.306	3241.118	2418.742	455.608	321.995	81.471
2018	87.016	78.227	121.206	121.206	208.63	336.71	841.511	4085.724	2830.241	774.277	400.943	140.277

Station Name: Lay **Nr. /@Finote Selam**

Year	Ja	Fe	Ma	Ap	Ma	Ju	Ju	Au	Se	Oc	No	De
1984	2.924	2.826	2.655	2.681	2.851	3.481	5.503	7.647	9.006	4.187	4.036	3.404
85	2.899	2.821	2.655	2.77	2.899	3.294	5.349	5.949	6.995	4.191	4.136	3.382
86	2.894	2.796	2.651	2.736	3.128	3.396	5.492	5.897	6.227	4.537	3.873	3.369
87	2.894	2.791	2.626	2.753	3.132	3.806	5.354	6.439	6.239	4.634	4.068	3.48
88	2.894	2.791	2.621	2.762	3.124	4.265	5.231	7.247	7.394	4.453	3.937	3.551
89	2.894	2.791	2.621	2.979	3.391	4.727	4.83	6.974	6.649	4.671	3.662	3.559
90	2.894	2.791	2.617	4.13	3.325	4.5	4.825	5.652	7.941	4.32	3.559	3.568
91	2.894	2.791	2.592	4.002	3.154	3.862	5.207	5.792	5.242	4.504	3.497	3.622
92	2.894	2.787	2.588	3.017	3.387	3.264	5.359	7.018	4.992	4.708	3.414	3.622
93	2.89	2.762	2.592	2.86	3.128	4.764	5.354	7.519	7.635	4.375	2.964	3.564
94	2.864	2.757	2.617	2.851	2.942	4.681	5.164	6.705	5.424	4.192	2.856	3.524
95	2.86	2.757	2.621	2.8	3.048	4.32	5.646	7.237	5.513	4.634	2.792	3.493
96	2.86	2.757	2.617	2.791	4.102	4.408	5.665	7.161	4.723	4.265	2.749	3.493
97	2.86	2.753	2.592	2.791	4.05	3.664	5.575	7.69	4.863	4.045	2.839	3.515
98	2.86	2.728	2.588	2.791	3.712	4.362	4.808	8.64	5.856	3.846	2.817	3.488
99	2.86	2.723	2.588	2.783	3.453	4.957	5.595	8.666	6.803	3.977	2.736	3.449
2000	2.856	2.723	2.588	2.723	3.409	5.435	4.864	9.362	4.966	3.707	2.728	3.387
001	2.83	2.723	2.588	2.672	3.343	5.326	4.98	9.846	5.317	3.662	2.766	3.347
002	2.826	2.719	2.588	2.706	3.242	4.718	4.91	10.733	5.622	3.941	2.882	3.418
003	2.83	2.694	2.734	2.668	3.145	4.453	5.24	7.814	5.791	3.676	3.119	3.942

Station Name: Leza **Nr. /@Giga**

Years	Ja	Fe	Ma	Ap	Ma	Ju	Ju	Au	Se	Oc	No	De
1980	1.186	0.366	0.173	0.116	0.195	0.401	8.097	41.297	151.02	15.141	2.435	1.332
81	1.051	0.366	0.173	0.116	0.195	0.561	7.212	44.496	171.26	13.513	1.57	1.655
82	0.925	0.333	0.173	0.438	0.195	0.703	8.097	71.183	123.55	8.328	0.987	1.655
83	0.925	0.301	0.152	0.703	0.133	0.333	11.423	46.487	162.39	5.094	0.755	1.488
84	0.755	0.301	0.152	0.654	0.116	0.245	16.173	30.967	185.10	4.124	0.438	1.332
85	0.703	0.301	0.152	0.654	0.1	0.133	20.322	19.133	64.398	3.974	0.703	1.258
86	0.606	0.245	0.173	0.606	0.085	0.438	22.404	37.65	44.496	3.147	1.332	1.258
87	0.703	0.245	0.152	0.561	0.072	0.477	35.903	48.531	38.243	2.66	1.57	1.655
88	0.81	0.245	0.152	0.518	0.072	0.703	34.208	49.225	29.421	2.435	1.117	1.655
89	0.703	0.219	0.219	0.518	0.06	1.655	32.025	55.743	33.106	1.655	1.408	1.742
90	0.654	0.195	0.333	0.477	0.06	2.022	40.674	54.251	41.925	1.742	2.66	2.121
91	0.654	0.152	0.606	0.438	0.1	1.332	42.559	51.342	40.058	2.328	2.435	2.435
92	0.606	0.152	0.606	0.401	0.301	1.655	33.106	63.58	33.106	4.124	2.435	4.124
93	0.606	0.133	0.703	0.366	0.518	5.445	21.557	98.326	28.916	6.193	2.328	3.685
94	0.561	0.116	0.925	0.366	0.606	4.593	20.729	71.183	25.07	6.589	2.328	3.409
95	0.518	0.116	0.81	0.301	0.606	3.409	87.018	89.011	26.951	6.389	2.223	3.147
96	0.561	0.085	0.703	0.272	0.81	2.435	108.218	35.333	24.161	5.445	2.121	3.277
97	0.561	0.085	0.654	4.277	0.703	18.746	116.32	37.062	18.364	7.869	2.121	3.974
98	0.561	0.072	0.606	3.409	0.755	2.223	47.844	38.842	14.806	7.646	2.022	2.435
99	0.561	0.06	0.606	1.655	1.332	1.408	41.297	71.183	10.324	11.998	2.022	2.223
2000	0.518	0.06	0.518	0.561	0.755	1.833	32.025	87.018	15.48	28.916	1.926	2.121
001	0.518	0.116	0.438	0.518	0.654	4.277	27.923	181.97	13.201	10.592	1.833	2.022
002	0.518	0.195	0.366	0.518	0.925	4.124	102.651	134.912	11.998	8.097	1.833	1.833
003	0.518	0.195	0.333	0.518	1.488	3.546	43.844	118.701	11.142	10.592	1.742	1.655

Station Name: Birr **Nr. /@Giga**

Years	Ja	Fe	Ma	Ap	Ma	Ju	Ju	Au	Se	Oc	No	De
1989	0.564	0.193	0.173	0.007	0.154	0.034	0.8	38.009	19.338	20.593	2.566	0.523
90	0.485	0.412	0.193	0.003	0.238	0.034	3.163	41.267	19.751	20.593	2.456	0.485
91	0.485	0.379	0.215	0.001	0.348	0.034	5.469	68.277	19.338	19.751	2.456	0.448
92	0.853	0.348	0.215	0.001	0.348	0.049	5.84	88.461	19.338	18.528	2.349	0.485
93	0.8	0.348	0.193	0.001	0.412	0.069	10.469	125.37	20.593	16.602	2.246	0.749
94	0.749	0.348	0.173	0.007	0.485	0.08	18.93	78.96	33.149	15.158	2.047	0.652
95	0.607	0.29	0.154	0.003	0.485	0.08	13.148	70.145	26.141	14.467	1.952	0.607
96	0.564	0.348	0.154	0.013	0.564	0.049	13.47	264.131	22.801	14.467	1.861	0.564
97	0.523	0.318	0.137	0.013	0.485	0.022	16.976	52.891	19.751	13.797	1.771	0.564
98	0.485	0.29	0.121	0.007	0.564	0.013	15.869	49.809	16.602	13.47	1.685	0.607
99	0.564	0.263	0.121	0.007	0.564	0.069	64.637	29.242	16.602	13.797	1.602	0.523
2000	0.749	0.263	0.092	0.007	0.749	0.092	69.207	37.378	16.602	7.709	1.521	0.523
001	0.652	0.238	0.08	0.003	0.968	0.173	86.289	84.152	15.158	6.837	1.685	0.523
002	1.156	0.238	0.069	0.002	0.853	0.154	84.152	37.378	16.602	5.469	1.602	0.485
003	1.091	0.215	0.058	0.002	0.968	0.215	78.96	26.141	16.233	5.469	1.602	0.485
004	1.028	0.193	0.049	0.001	0.968	0.193	84.152	39.943	17.356	5.289	1.521	0.448
005	0.853	0.193	0.041	0	1.224	0.263	107.113	42.619	12.831	5.289	1.443	0.448
006	0.749	0.173	0.034	0	1.685	0.263	13.797	41.94	18.132	5.114	1.091	0.485

Station Name: Zulu **Nr. /@Giga**

Years	Ja	Fe	Ma	Ap	Ma	Ju	Ju	Au	Se	Oc	No	De
1990	0.684	1.454	1.105	0.805	0.906	5.329	14.951	28.714	52.863	27.135	19.326	4.242
91	0.546	1.439	1.105	0.741	0.906	5.701	14.532	31.738	49.758	28.394	18.026	4.211
92	0.523	1.346	1.105	0.741	0.906	5.442	14.26	37.28	50.672	30.47	17.087	4.026
93	0.501	1.331	1.105	0.805	0.894	9.142	13.128	30.183	48.847	34.158	18.273	3.966
94	0.369	1.331	1.092	0.815	0.827	11.042	14.019	27.24	47.971	35.118	20.862	3.788
95	0.347	1.316	1.015	0.805	0.784	11.055	19.051	28.613	56.493	37.102	20.767	3.73
96	0.347	1.229	1.002	0.741	0.607	14.988	23.028	31.94	67.124	35.256	20.509	3.531
97	0.326	1.215	1.002	0.721	0.589	23.342	23.39	35.12	72.591	30.371	18.415	3.312
98	0.211	1.201	1.002	0.662	0.653	30.161	21.342	35.239	63.135	27.345	12.181	3.127
99	2.179	1.119	1.002	0.653	0.731	26.758	17.531	37.102	58.116	28.394	10.581	3.076
2000	0.179	1.105	1.002	0.643	0.805	22.479	26.204	35.975	50.085	29.905	10.303	2.925
001	0.179	1.105	1.002	0.589	0.815	20.433	18.142	36.228	50.901	30.805	9.283	2.852
002	2.159	1.092	1.002	0.58	0.827	17.564	16.19	39.028	64.065	33.829	8.722	2.569
003	1.039	1.028	1.002	0.571	0.894	15.263	19.355	37.989	66.348	27.795	8.088	2.501
004	2.019	1.092	1.002	0.52	0.918	12.07	23.219	38.251	58.499	26.722	7.9	2.39

Station Name: Bogena **Nr. /@ Amber**

Years	Ja	Fe	Ma	Ap	Ma	Ju	Ju	Au	Se	Oc	No	De
1987	2.497	1.625	1.352	1.609	0.875	2.787	22.415	40.658	50.947	29.521	10.028	4.565
88	2.455	1.707	1.352	1.578	0.875	3.792	21.013	40.776	50.243	32.631	9.978	4.504
89	2.332	1.707	1.338	1.47	1.011	4.48	19.352	65.846	52.237	29.324	9.677	4.293
90	2.311	1.609	1.254	1.352	1.047	3.596	19.431	47.903	53.437	28.442	9.627	4.088
91	2.311	1.593	1.24	1.241	1.162	3.789	21.502	41.291	44.222	34.398	9.677	4.059
92	2.311	1.593	1.24	1.135	1.489	5.226	23.008	59.171	43.918	36.715	9.978	3.774
93	2.292	1.593	1.227	1.035	1.934	6.244	24.315	66.046	43.023	25.248	10.079	2.438
94	2.155	1.593	1.135	0.953	2.004	6.787	25.03	68.776	46.598	21.747	10.336	3.582
95	2.022	1.593	1.047	0.93	2.022	12.4	25.396	91.478	55.945	20.214	9.881	3.834
96	2.004	1.593	1.035	0.864	2.155	12.953	26.513	77.566	50.877	18.078	8.496	3.806
97	2.004	1.593	1.035	0.853	2.292	14.32	23.534	70.129	31.243	16.849	7.231	3.67
98	1.986	1.593	1.035	0.853	2.292	16.716	23.534	64.375	44.605	16.29	6.782	3.834
99	1.861	1.593	1.035	0.853	2.136	16.018	26.147	50.02	57.179	16.085	6.508	3.947
2000	1.74	1.593	1.035	0.842	1.879	16.78	22.365	77.822	50.979	15.212	6.431	3.512
001	1.74	1.593	1.035	0.78	1.724	17.779	22.453	158.701	48.714	14.819	6.203	3.59
002	1.826	1.593	1.035	0.77	1.594	17.779	47.106	151.156	47.486	15.961	6.166	3.59

Station Name: Abahim **Nr. /@ Gumde-Woin**

Years	Ja	Fe	Ma	Ap	Ma	Ju	Ju	Au	Se	Oc	No	De
1982	2.684	1.454	1.105	0.805	0.906	5.329	14.951	28.714	52.863	27.135	19.326	4.242
83	2.546	1.439	1.105	0.741	0.906	5.701	14.532	31.738	49.758	28.394	18.026	4.211
84	2.523	1.346	1.105	0.741	0.906	5.442	14.26	37.28	50.672	30.47	17.087	4.026
85	2.501	1.331	1.105	0.805	0.894	9.142	13.128	30.183	48.847	34.158	18.273	3.966
86	2.369	1.331	1.092	0.815	0.827	11.042	14.019	27.24	47.971	35.118	20.862	3.788
87	2.347	1.316	1.015	0.805	0.784	11.055	19.051	28.613	56.493	37.102	20.767	3.73
88	2.347	1.229	1.002	0.741	0.607	14.988	23.028	31.94	67.124	35.256	20.509	3.531
89	2.326	1.215	1.002	0.721	0.589	23.342	23.39	35.12	72.591	30.371	18.415	3.312
90	2.2	1.201	1.002	0.662	0.653	30.161	21.342	35.239	63.135	27.345	12.181	3.127
91	2.179	1.119	1.002	0.653	0.731	26.758	17.531	37.102	58.116	28.394	10.581	3.076
92	2.179	1.105	1.002	0.643	0.805	22.479	26.204	35.975	50.085	29.905	10.303	2.925
93	2.179	1.105	1.002	0.589	0.815	20.433	18.142	36.228	50.901	30.805	9.283	2.852
94	2.159	1.092	1.002	0.58	0.827	17.564	16.19	39.028	64.065	33.829	8.722	2.569
95	2.039	1.028	1.002	0.571	0.894	15.263	19.355	37.989	66.348	27.795	8.088	2.501
96	2.019	1.092	1.002	0.52	0.918	12.07	23.219	38.251	58.499	26.722	7.9	2.39
97	2.019	1.119	0.99	0.512	1.029	12.875	25.324	41.834	47.99	26.62	7.351	2.501
98	1.999	1.201	0.942	0.622	1.422	14.123	28.406	44.188	46.767	25.913	7.217	2.523
99	1.885	1.215	1.08	1.32	2.556	13.585	31.023	42.591	48.394	24.645	6.912	2.523
2000	1.866	1.201	1.105	0.901	4.074	14.057	28.613	54.226	48.247	21.218	6.574	2.501
001	1.866	1.119	1.092	0.805	4.767	15.83	26.726	48.759	50.828	20.594	6.246	2.347
002	1.866	1.105	1.015	0.741	5.255	19.008	25.616	40.769	50.677	19.995	5.968	2.2