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Irrigation Potential Mapping using GIS-based Parametric Evaluation Approach in Upper Blue Nile River Basin, Ethiopia

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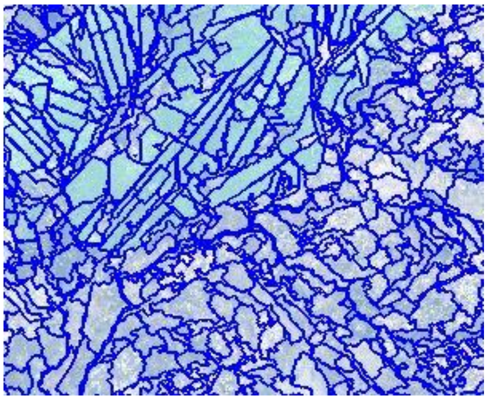

By: Yilkal Gebeyehu

ID No. GSR/4294/09

June, 2018

Addis Ababa

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Advisors: Dr. K. V. Suryabhagavan and Dr. Tena Alamirew

A Thesis submitted to the School of Graduate Studies in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Remote Sensing and Geoinformatics

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Approved by Board of Examiners:

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Co-advisor Land and Water Resource Center	Tena Alamirew (PhD)	_________	_________
Examiners		_________	__________

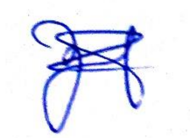
June, 2018

Addis Ababa

DECLARATION

I, Yilkal Gebeyehu, hereby declare that this thesis entitled "Irrigation Potential Mapping using GIS-based Parametric Evaluation Approach in Upper Blue Nile River Basin, Ethiopia" is my original work accompanied under the supervision of Dr. Suryabhagavan, School of Earth Sciences and Dr. Tena Alamirew, Water and Land Resource Center during the year 2018 as part of Master of Science Program in Remote sensing and Geoinformatics. I further declare that this work has not been submitted to any other university or institution for the award of any degree or diploma and all sources of materials used for the thesis have duly acknowledged.

Yilkal Gebeyehu



Signature

Dedicated

To

my late father

Ato Gebeyehu Mekonnen

Acknowledgments

I would like to express my sincere gratitude to a number of people, without whom this work would not have been completed. First, I would like to acknowledge Dr. K. V. Suryabhagavan and Dr. Tena Alamirew for their extensive help in helping me with the methodologies and suggestions. I extend sincere thanks for their inspiring guidance, constant interest, suggestions, and encouragement throughout the course of these investigations.

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Acronyms

CWR	Crop Water Requirement
CSA	Central Statistics Agency
DEM	Digital Elevation Model
EC	Electrical Conductivity
ESA	European Space Agency
ESP	Estimation of Scale Parameter
FAO	Food and Agriculture Organization of United Nations
FEWSNET	Famine Early Warning System Network
GDP	Gross Domestic Product
GFSAD30AFCE	Global Food Security-support Analysis Data @ 30-m for the African Continent, Cropland Extent
GIS	Geographic Information System
GPS	Global Positioning System
GSARS	Global Strategy to improve Agricultural and Rural Statistics
IWMI	International Water Management Institute
IR	Irrigation Requirement
ISRIC	International Soil Reference and Information Center
LPDAAC	Land Processes Distributed Archive Center
MODIS	Moderate Resolution Imaging Spectroradiometer
MRS	Multi Resolution Segmentation
NASA	National Aeronautics and Space Administration
NDBI	Normalized Difference Built-up Index
NDMI	Normalized Difference Moisture Index
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NIR	Near Infrared
OBIA	Object Based Image Analysis
SRTM	Shuttle Radar Topography Mission
SWIR	Short Wave Infrared
USGS	United Sates Geological Survey

Abstract

In Ethiopia, irrigation potential of many rivers has not been studied in depth, and the current extent of irrigated areas is not known, as the source of information for local level irrigated areas are official reports rather than actual areas that deviate from the real irrigated areas. The ability of GIS to manipulate various types of data helps to perform complex analysis extracting information about spatially distributed phenomena in greater efficiency, which enables suitability analysis for large areas. Similarly, remote sensing can deliver useful spatial information on exact locations of irrigated lands rather than mere totals within arbitrary political units due to their synoptic coverage and high revisiting frequency. The present study was aimed to assess land suitability for different types of irrigation systems including surface, drip, and sprinkler methods by parametric approach, and mapping irrigated areas using OBIA of upper Blue Nile basin. The study also evaluated surface water irrigation potential of selected rivers in Choke mountain watersheds. The study used soil texture, soil depth, Calcium Carbonate ($CaCO_3$) content, electrical conductivity, drainage and slope for suitability analysis. Multi-resolution segmentation and assign class algorithm to identify irrigated areas using spectral indices and mask features prepared for non-irrigable areas, using Sentinel 2A images. The analysis revealed that, 639,554.05 ha of the land was suitable for surface irrigation, 3,037,849.43 ha for sprinkler irrigation, and 5,506,189.33 ha for drip irrigation. The results show that the highest irrigation potential obtained on plain areas of Gojjam, Northern Shewa and lowlands of the basin. The main limiting factors were physical limitations of high slope and clay dominated soil texture. The total irrigated area is 310,707 ha for the year 2016/2017with overall accuracy of 91.04% was obtained. Major irrigated areas were identified in the north-eastern highlands of the basin mainly plain areas of Gojjam, while Abay valley and the western part of the basin are less irrigated. Validation was also done by comparing the final classified map of irrigated areas with official irrigation area statistics. The official statistics lacks spatial distribution and is a merely total of feasibility studies not the current status of irrigation schemes. It can there be concluded that satellite image processing using OBIA is a robust method for irrigated land mapping. Additional land of 2,398,295.38ha and 4,882,097.32 ha can be irrigated using sprinkler and drip irrigation, respectively. About 1800 ha of land can be irrigated at the gauge location of the rivers in Choke mountain watersheds without further development on the downstream.

Key words

Blue Nile Basin; Irrigation; Land suitability evaluation; OBIA; Parametric method; Sentinel 2

1. INTRODUCTION

1.1. Background

Ethiopia relies heavily on food aid, receiving 25 percent of global food aid for Sub-Saharan Africa, even though agriculture contributes approximately 44 percent of the national GDP, and 70 percent of export earnings and the irrigation sub sector accounting for only about three percent of the food crops (Mendes & Paglietti, 2015). Irrigation sector is characterized by small-scale, limited access to technology and weak institutional support services.

The planning process for irrigation has to integrate information about the suitability of the land that requires a thorough evaluation of soil properties and topography of the land within the field, water resources availability and water requirements of irrigable areas in time and place (FAO, 1985). The first planning requirements for irrigation are therefore knowledge of the physical resources that are available. Earth observation and geospatial data are frequently used to support these practices (Vuolo *et al*., 2015). Soil property mapping (Batjes, 2015; Hengl *et al*.,2015), terrestrial evapotranspiration (Mu *et al*., 2011), Land surface reflectance, land surface temperature (Wan, 2014) are among those that could contribute to map irrigated land and study irrigation potential land in regions with limited ground data availability like Ethiopia.

Spatial information on irrigation is highly important for policy and decision makers, who are facing the transition towards more efficient sustainable agriculture (Meier *et al*., 2018) to understanding trends in food production and their associated drivers (Jain *et al*., 2017). Remote sensing delivers useful spatial information on the exact locations of irrigated lands rather than mere totals within arbitrary political units (Ozdogan *et al*., 2010). Irrigation land suitability assessment and mapping could play an imperative role in the sustainable utilization of the scarce physical land resource. Remote sensing and the information derived from it play a role in the three major stages of development assistance: identification of the need, program development and execution, and post-completion program assessment and evaluation (Ryerson and Haack, 2016). Remote sensing provides repetitive mapping in time- and cost-saving modes (Yang *et al*., 2017) since it provides timely and detailed land-use information over large areas due to their synoptic coverage and high revisiting frequency (Bellón *et al*., 2017).

The ability of GIS to manipulate various types of data helps to perform complex analysis extracting information about spatially distributed phenomena in greater efficiency (Nandi *et al*., 2016) makes GIS a preferable technology to study irrigation potential of a basin with evaluation of water resources and currently irrigated area in combination with remote sensing.

1.2. Statement of the problem

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. 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, contributing up to 140 billion birr to the economy. 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 various surface water schemes. The study revealed that national water resources master plan was a desk study without significant field investigation. The irrigation potential of many rivers of Ethiopia was not studied in depth separately (Sultan, 2013). These previous studies revealed that there is a shortage of baseline data for development of hydraulic structures for irrigation.

Although several studies were conducted on irrigation potential assessments in different areas of the world using remote Sensing and geographic information system (Akomeash *et al*., 2010; Albaji *et al*., 2010; Altchenko and Villholth 2015), very few have been conducted in Ethiopia. Among these few studies; surface and sprinkler irrigation in Guang Watershed North Gondar Zone (Ayalew, 2014), surface and drip irrigation in Kilte Awulaelo District (Rabia *et al*., 2013); surface irrigation potential of Fogera Plain (Sultan, 2013), surface water irrigation potential of Lake Tana basin (Worqlul *et al*., 2015) and surface irrigation using groundwater in Ethiopia (Worqlul *et al*., 2017) are the published works. But these studies did not study the full potential of their respective areas for both surface and pressurized irrigation potentials and didn't study how much area is currently irrigated.

Meier *et al.* (2018) explains that the African continent shows the highest percentage discrepancy when compared to FAOSTAT. Differences between irrigation maps result from the quality and the spatial resolution of the input data, the assumptions made and from the different terms and definitions of irrigated areas. highest discrepancies to the statistics are generally found in developing countries.

The current extent of irrigated areas in Ethiopia is not clearly known. The source of information for local level irrigation are official reports. The first shortcoming is that estimates based on official figures, rather than actual areas. Deviations in the official statistics from the real irrigated areas can occur due to several reasons (Droogers, 2002). That is because, different offices record different data; Representative offices of Ministry of Agriculture and Natural Resources focus on small-scale irrigation, Representatives offices of Ministry of Water, Irrigation and Electricity report only modern schemes, and data is exposed to propagation error on the reports. This makes these official reports are too difficult to examine in a basin approach or watershed logic.

The irrigation potential of the basin under pressurized irrigation systems like sprinkler and drip irrigation was not studied separately. Similarly, no basin level irrigated areas map is not available in the entire country. Therefore, in this study, the surface and pressurized irrigation potential of Upper Blue Nile Basin studied for future irrigation expansion or development with the current state of irrigated areas. The study also determined surface water resource potential of rivers at the upper part of the basin.

1.3. Objectives of the study

General objective

The general objective of this study was to map irrigation potential of Blue Nile Basin under different irrigation systems.

Specific objectives:

The following were the specific objectives of the study:

i. To map current status and distribution irrigated areas of the basin using Sentinel 2 MSI satellite images and ancillary data;

ii. To estimate land suitable for surface and pressurized irrigation systems in the basin;

iii. To determine surface water potential of selected rivers in the basin for different irrigation systems.

1.4. Research Questions

- How much of land in the Blue Nile river basin is potentially suitable for surface and pressurized (sprinkler and drip) irrigation systems?
- How much area is currently irrigated from the potential land?
- How much area can surface water irrigate in the basin using surface irrigation methods at the upper part of the basin (Choke mountain watersheds)?

1.5. Significance of the study

All river basins in Ethiopia except the Nile basin face water shortages. There is also a potential to considerably expand and intensify rain-fed production in upstream areas of the basin (Awulachew *et al*., 2012). This makes the basin the most important basin to study. From identification of potentially irrigable land, policy and decision makers could be informed about the irrigation potential of the basin, and how much area has been utilized so far. Hence, 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. Organization of the Thesis

The thesis consists of five chapters; Chapter one discusses the background information of the study which includes an introduction, statement of the problem, objectives, research questions and significance of the study. Chapter two provides a brief review of the literature with emphasis on the need for irrigation development in Ethiopia. Besides, it covers irrigated area mapping using remotely sensed data, GIS-based land suitability assessment for irrigation and irrigation potential assessment using an integrated approach using GIS and auxiliary data and surface water irrigation potential assessment. Chapter three highlights the physical and socio-economic characteristics of the study area as well as datasets used in the study, their sources and methods of collection and analysis. Detail procedure on irrigated area mapping, land suitability analysis, hydrologic analysis and irrigation potential assessment by surface water are also described in this chapter. Chapter four present and discusses results of analysis on the currently irrigated area, irrigable area irrigation potential with available water resources. Comparisons are also done with previous related studies. Chapter five presents the main conclusions drawn from the study and recommendations proposed for future consideration.

2. LITERATURE REVIEW

2.1. The need for Irrigation development in Ethiopia

Ethiopia is endowed with a substantial amount of water resources but very high hydrological variability (Awulachew *et al*., 2012) compounded with lack of appropriate soil fertility management contribute to lower crop yield (Worqlul *et al*., 2017) resulting in high food insecurity and dependent country on food aid. Growing season rainfall has declined by 15–20 percent while temperature increases. This intensifies the impacts of droughts and could reduce the amount of productive cropland (FEWNET, 2012). It is explained that coincidence of densely-populated areas and observed declines in rainfall makes the agriculture sector dominated by subsistence rain-fed systems with low productivity in high levels of risk.

Irrigated agriculture represents 20% of the total cultivated land but contributes 40 percent of the total food produced worldwide (FAO, 2015). Thus, irrigation will play a significant role in the substantial increase in food production for food security enhancement and economic development of Ethiopia with the efficient use of land and water resources (Haile and Kasa, 2015; Sultan, 2013). The production function analysis done by Makombe *et al*. (2007) shows that irrigation could shift the agricultural production frontier to a higher level. However, its contribution to the national economy is not significant when compared to rainfed agriculture. But global agricultural production has doubled within an area that has only increased by 12%, and a part of this gain can be attributed to an increase in irrigation (Bégué *et al*., 2018).

According to World Bank (2006) increasing irrigation has long been seen as the most direct strategy to alleviate the impact of drought and ensure food security. The report emphasizes without increased irrigation, the unpredictability of rains in Ethiopia is an overwhelming disincentive to investments in agricultural improvements. Awulachew *et al*. (2010) also explained that well-managed irrigation development is key in helping Ethiopia overcome major challenges of population pressure, soil and land degradation, high climate variability, and low agricultural productivity. Research in the Lake Tana Basin revealed that, on average, household incomes of those that practiced irrigation were 27% higher than those that did not (IWMI, 2015). Another study at Gubalafto District, North Wollo (Mengistie and Kidane, 2016) indicated that irrigation has a great impact on enhancing farmers' livelihoods through different dimensions, such as diversification of crops grown, as well as increased agricultural production, household income, employment opportunity and participation in community decisions.

2.2. Irrigated Area Mapping using Remote Sensed Data

For agronomic, environmental and economic reasons, the need for spatialized information about agricultural practices is expected to rapidly increase (Bégué *et al*., 2018). There is no clear idea of errors in the estimation of irrigated area of official reports (Droogers, 2002) and figures and data are not spatially distributed. Accurate mapping of the distribution of irrigated land using remote sensing data at a regional scale can facilitate an improved understanding of patterns of water use and food production (Chance *et al*., 2017). Yet, studies that have used remote sensing to map irrigated lands remain relatively rare (Ozdogan *et al*., 2010).

Hooda and Dye. (1995) suggested that if NDVI is correlated with climatic variables that are known to influence plant growth, particularly temperature and rainfall, the outlier pixels associated with irrigated vegetation. Thenkabail *et al*. (2006) used Unsupervised ISO-Class Clustering and Spectral Matching Technique on Mega-File of 159 Data Layer using AVHRR 10 km, SPOT one km, average precipitation 50 km, Forest cover one km and Elevation GTOPO 30 one km to map irrigated areas of the world. Mask areas of Precipitation less than 360 mm per year to identify arid and semiarid areas and deserts, precipitation greater than 2,400 mm per year to mask the rain-forest areas, temperature less than 280 °K per year for areas too cold for agriculture, and irrigation is not likely to be found, forest cover greater than 75% canopy cover, special forest SAR, elevation greater than 1,500 m and all other areas of the world used.

A methodology proposed by Ozdogan and Gutman (2008) involves four steps. (1) generate a potential irrigation index using surface moisture status and a map of cultivated areas. (2) identify temporal and spectral signatures that are associated with the presence of irrigation. (3) combine the potential irrigation index, remotely sensed indices, and learning samples within a decision tree supervised classification tool to make a binary irrigated/non-irrigated map and (4) apply a tree-based regression algorithm to derive the fraction of irrigated area within each pixel that has been identified as irrigated.

The ability to detect small and fragmented irrigated areas is directly related to the resolution of imagery because a single pixel in a coarser-resolution satellite data contains information from more than one land-use type, quantifying the area under each land-use type requires an understanding of sub-pixel composition (Velpuri *et al*., 2009). The study indicated the accuracy of estimation of irrigated areas for Landsat 30 m is 84%, MODIS (250 m: 79%; 500 m: 77%) and AVHHR (1 km: 63%).

Biggs *et al.* (2006) concluded mapping patchy and small irrigated areas remain challenging, but a comparison of multiple data sources improves confidence in the classification and highlights areas requiring more intensive fieldwork.

A review by Ozdogan *et al.* (2010) stated that remote sensing is valuable for inventories of irrigated land and for monitoring in developing countries, where funds are limited and little objective information is available. However, agricultural fields (especially irrigated fields) are highly dynamic because each field may be at a different stage of development, and thus subject to being confused with natural land cover classes. Times-series analysis, Supervised/unsupervised classification, masking recommended for regional irrigated area mapping. Bégué *et al.* (2018) explained among the data sources that need to be leveraged, expert knowledge on the local agricultural systems, in particular, the knowledge of crop types and crop calendars, plays an important role.

According to Chance *et al.* (2017) utilized the Google Earth Engine API platform for multitemporal algorithms to map irrigated areas at Snake river basin, USA. The study evaluated the performance of three algorithms namely Single-Date, Greenness-Duration and seasonal-maximum; and three spectral indices, NDVI, EVI, and NDMI. The seasonal-maximum algorithm yields an improvement in classification accuracy due to its ability to correctly classify non-irrigated lands in riparian and developed areas. As the frequency of precipitation events declines during the dry months, anomalies in plant greenness or water content can be attributed to irrigation practices and NDVI has been used for mapping irrigated areas.

Improvements in classification methods for the identification of irrigated areas are still necessary (Jin *et al.*, 2016). Object-based classifier technique is effective for cropland classification from time series data (Li *et al.*, 2015) because cropping systems are often diverse and complex, and the types of crops grown and the timing of their growth vary from region to region, the best choice of sensors to be used, the optimal number of images required, and the timing of image acquisitions are usually geographically specific.

2.3. GIS-based Land Suitability Analysis for Irrigation

Land suitability classification is the appraisal and grouping of specific areas of land in terms of 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), Multi-Criteria Evaluation (Malczewski, 2004) and Analytical Hierarchy Process (AHP) (Saaty, 2008) are the common approaches for land suitability analysis.

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 profile. 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 salinity/alkalinity status, drainage properties, and environmental factors such as slope.

Several studies have applied parametric evaluation approach for potential land suitability mapping for irrigation (Albaji *et al.*, 2010; Teka and Rompaey, 2010; Albaji *et al.*, 2015; Sultan, 2013; Ayalew, 2014; Bagherzadeh and Paymard, 2015). Albaji *et al.* (2010) have studied different irrigation methods Abbas Plain in the west of Iran. The study explained that soil properties such as cation exchange capacity, the percentage of basic saturation, organic matter, and pH were considered in terms of soil fertility. Fertility properties can be excluded from land evaluation for the purpose of irrigation (Sys *et al.*, 1991).

Teka and Rompaey (2010) compared land suitability for surface and drip irrigation methods using the parametric evaluation systems in Korir watershed, Northern Ethiopia. The study showed that by applying drip irrigation instead of surface irrigation methods, 62.77% can be improved from currently not suitable to marginally suitable and 6.19% and 22.58% from marginally suitable and moderately suitable respectively to highly suitable. Similarly (Ayalew, 2014) evaluates surface and sprinkler irrigation in Guang watershed at highlands of Ethiopia using soil pH in addition to texture, slope, depth, drainage and salinity properties. Soil salinity, drainage and pH were the dominant limiting factors for sprinkler irrigation and slope and soil drainage factors for surface irrigation method on the area.

Bagherzadeh and Paymard (2015) also compared different irrigation methods by Parametric and Fuzzy Approaches in Northeast Iran. They have developed a method that calculates capability index of each land unit by multiplying the geometrical mean value of the scores given to each land characteristic in the interaction of the square root values of scores. The study concluded the approach is better than classical approaches.

2.4. Irrigation Potential by Water Availability

According to Albaji *et al.* (2015), available water resources will not be able to meet various demands in the near future and inevitably result into the seeking of newer lands for irrigation in order to achieve sustainable global food security. A key question is whether there will be sufficient freshwater to satisfy the growing needs of agricultural and non-agricultural users (Alexandratos and Bruinsma, 2012). The truth is water has always been the main factor limiting crop production in much of the world where rainfall is insufficient to meet crop demand (Steduto *et al.*, 2012). Thus, assessment of irrigation potential should take into account water limitations.

Altchenko and Villholth (2015) applied a methodology which assumes groundwater as the sole source of irrigation water and hence gives an estimate of the area that could potentially be irrigated by groundwater disregarding any existing irrigation, whether from groundwater or surface water. Irrigation potential is calculated as a ratio of groundwater available to maximum irrigation water demand; where groundwater availability is calculated as an excess of groundwater recharge, considering other demands from humans and the environment. The necessary crop data related to the crop distribution across the continent, the crop calendar over the year, encompassing one or a maximum of two crops per year for any area collected to calculate annually monthly crop water demand.

Very few attempts have been made to estimate surface water irrigation potential in Ethiopia mostly referring master plan studies and official reports (Awulachew *et al*., 2007; Awulachew *et al*., 2010; FAO, 2016). Still, there is a scanty of detail study regarding water potentials and its developmental perspectives in the Ethiopian context as it lacks agreed on reports in common consensus (Haile and Kasa, 2015).

Worqlul *et al*. (2015) estimated the irrigable area was as the quotient of the Q90 (discharge exceeds 9 out of 10 years) and the crop water requirement during the growing season of the crop in Lake Tana basin. To find the irrigable area if all water was stored, they divided the average daily flow by the crop water requirements. The study recommended, to increase the irrigation in the potentially irrigable areas, water falling and flowing during the rainy monsoon phase needs to be stored for the dry phase. Similarly, Worqlul *et al*. (2017) studied the country level irrigation potential of the groundwater as the quotient of the potential average borehole yield and the total crop water requirement of the dominant crop in the area for the growing season.

3. MATERIALS AND METHODS

3.1. Description of the study area

The Abay/Upper Blue Nile River is the most important river basin in Ethiopia since it accounts 25 percent of the country's population and for over 40 percent of its agricultural production. The irrigation potential has been estimated at more than 523,000 hectares which is about 19.6% of 2,671,500 ha of the country's economic irrigation potential (Awulachew *et al*., 2007; FAO, 2016). It is well-known as the source of Nile.

The area is bounded by latitude 7° 42' 13" N – 12° 44' 03" N and longitude 34° 14' 43" E – 39° 48' 20"E. The originates from Lake Tana in Ethiopia at an elevation of 1780 m above sea level. It covers 173,686 km^2 catchment area upstream of the Ethiopian–Sudan border gauging station (Figure 3.1).

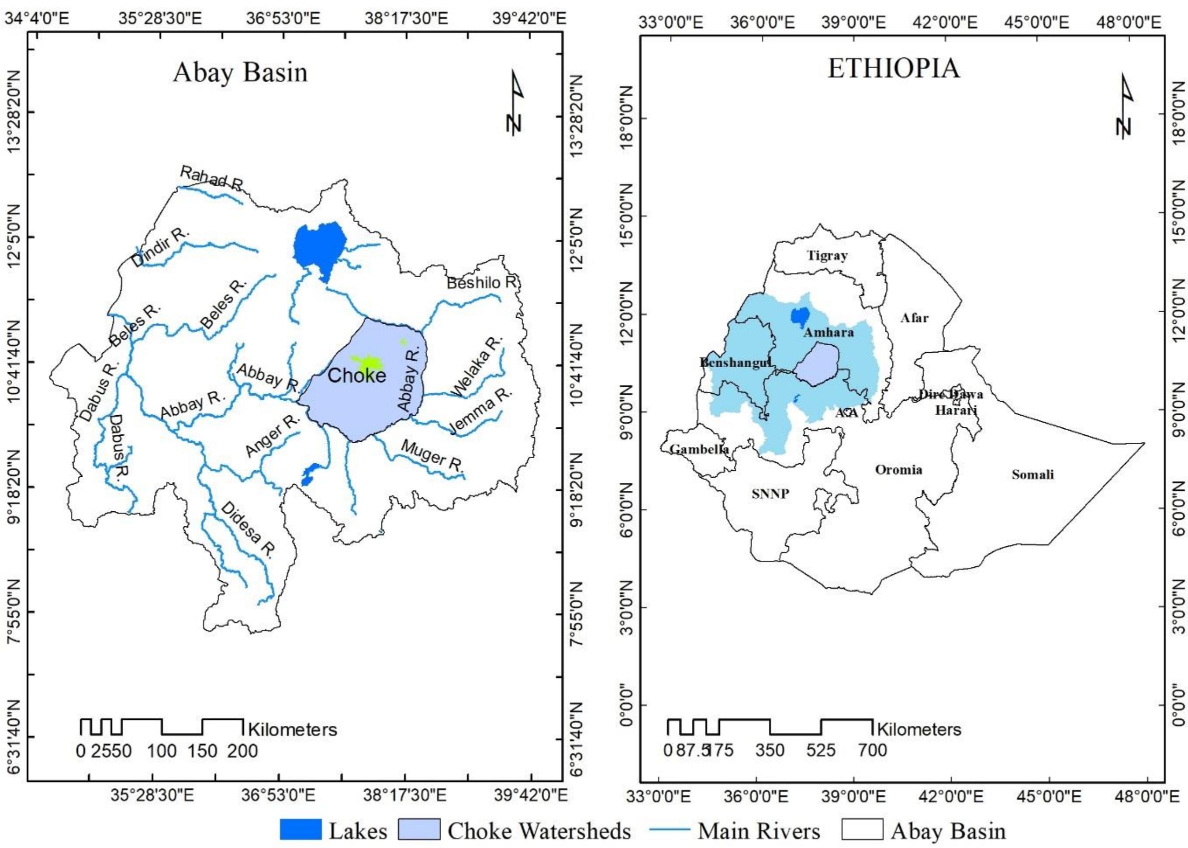


Figure 3.1: Location map of the study area

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. The topography of the basin includes flat plains (9.65%), undulating plains (32 %), rolling land (20.19%), hill to rolling (20.87 %), steep mountains (11.24 %) and very steep escarpment (4.42 %), respectively. The rest of the land is covered by inland water bodies Figure 3.2.

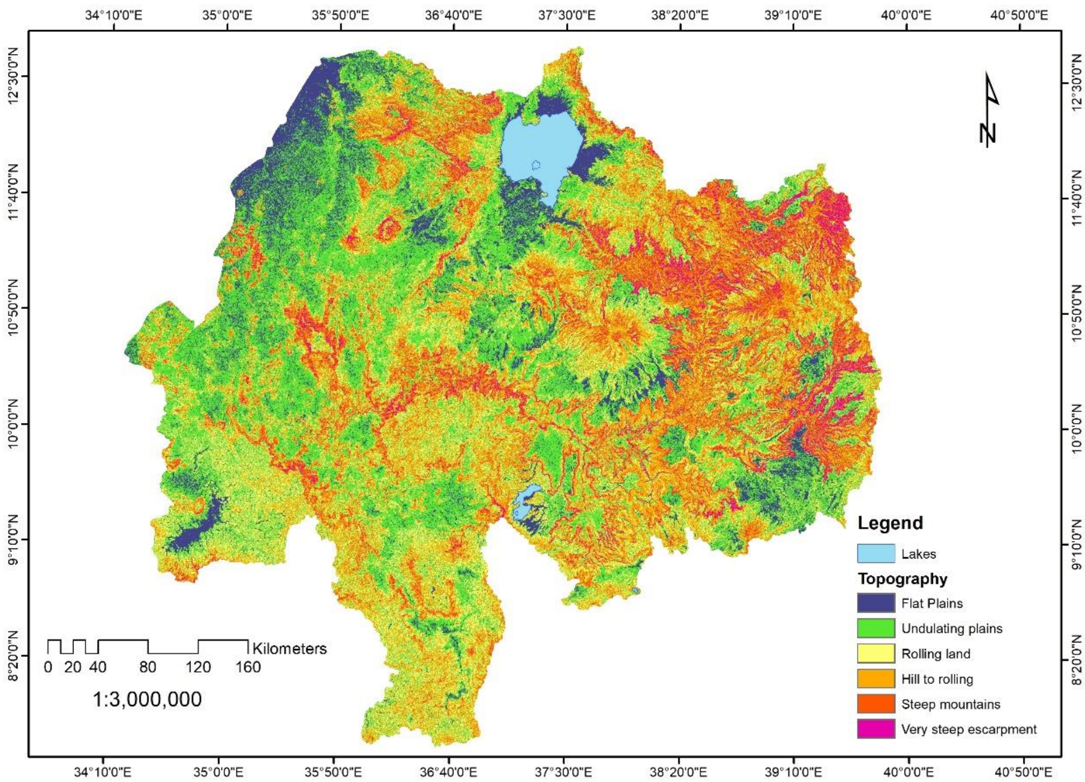


Figure 3.2: Topographic map of Abay Basin

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

3.1.2. Climate

The climate in the Abay/Upper Blue Nile basin varies from humid to semi-arid to arid; a variety of local climates, ranging from hot and arid along the Ethiopia-Sudan border to temperate at the highlands and even humid-cold at the mountain peaks in Ethiopia. The mean annual temperature ranges from 13ºC in southeastern parts to 26°C in the lower areas of the southwestern part near to the Ethiopia-Sudan border. Mean annual rainfall values range between 1148–1757 mm (Gebrekristos, 2015).

3.1.3. Soil

The dominant soil types of the basin according to (FAO,2007) are Eutric Nitosols (30.91%), Eutric Cambisols (25.62%), Humic Cambisols (14.45%), Cambic Arenosols (11.66%), Eutric Regosols(5.55%), Dystric Cambisols (4.03%), Chromic Vertisols (2.04%), Eutric Fluvisols (1.76%), Pellic Vertisols (1.58%) and Orthic Acrisols (0.61%). In terms of soil texture clay is dominant with 76.03% of the total area followed by clay loam 23.89% and sandy clay loam, loam, silty clay and silty clay loam (Figure 3.8).

3.1.2. Hydrology

The Abay/Upper Blue Nile river in Ethiopia emerges from Lake Tana as an outflow and is fed by major tributaries like Welaka, Jemma, Beshilo, Muger, Guder, Fincha, Dedissa and Dabus joining the main stem of the 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 North-western part of Lake Tana sub-basin and join in Sudan (Gebrekristos, 2015). The total mean annual flow from the river basin is estimated to be 54.8 billion m^3 (Awulachew *et al*., 2007).

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 (90 m). Irrigated area map of the basin has been mapped from eMODIS NDVI (250 m) from FEWSNET, MODIS Evapotranspiration (MOD16A2) (500 m) (Mu *et al*., 2011) and Sentinel 2A Level 1C (10m) and GFSAD30AFCE (30m) (Xiong *et al*., 2017).

3.2.1. MODIS Vegetation Index Data

Temporally Smoothed 10-day (dekadal) eMODIS AQUA NDVI at 250 m spatial resolution downloaded from FEWSNET depending on Irrigated Crop Calendar of Ethiopia (Appendix 4). The vegetation products generated from MODIS L1B Aqua surface reflectance, corrected for molecular scattering, ozone absorption, and aerosols using MODIS Science Team algorithms (Swets *et al*.,1999).

Data values range from 0 to 200, and values from 201 – 255 are invalid. The downloaded MODIS NDVI converted to actual NDVI value using Equ.1:

$$NDVI = (value - 100) / 100 \tag{1}$$

3.2.2. Sentinel 2MSI

The ESA Sentinel-2 MSI acquires multispectral, high-resolution optical observations over global terrestrial surfaces with a high revisit frequency of approximately 5 days using a bi-satellite system. It is important for dynamic land-cover mapping and updating. Sentinel-2 carries a MultiSpectral Instrument (MSI) with 13 spectral bands spanning from the VIsible Spectrum (VIS) and NIR to SWIR at different spatial resolutions on the ground ranging from 10 m to 60 m with a 290-km field of view.

With high time resolution and spectral resolution, Sentinel-2 exhibits the advantage of intensively and continuously monitoring the surface of the Earth. Sentinel-2 MSI imagery includes 20mresolution SWIR bands and 10mresolution green and NIR bands, thereby making Land Cover mapping at 10m resolution possible. The standard MSI scene is delivered as Level-1C (L1C) product with radiometric and geometric correction in UTM/WGS84 projection (Figure 3.4). About 38 tiles of Sentinel 2 images have been downloaded for the study.

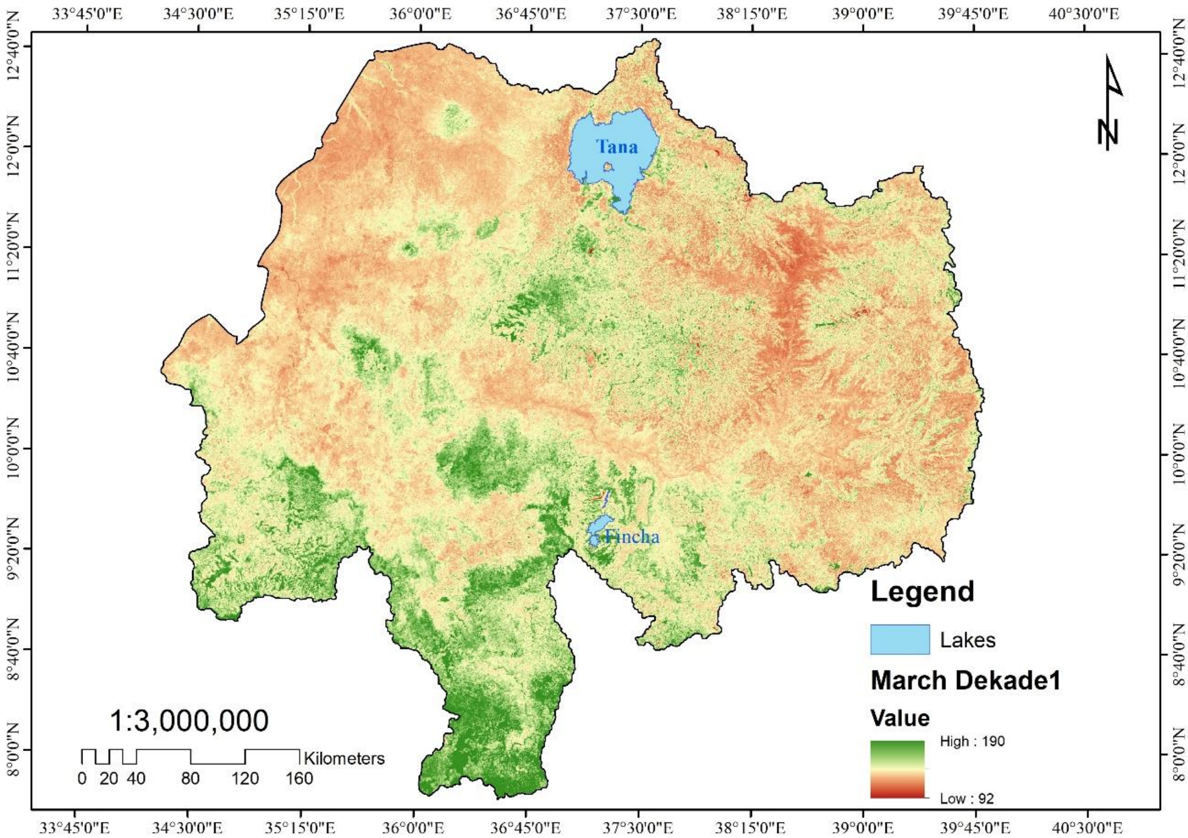


Figure 3.3: MODIS NDVI (March 2017 Dekade1)[1]

[1] One month is divided into three dekades (10-day composites)

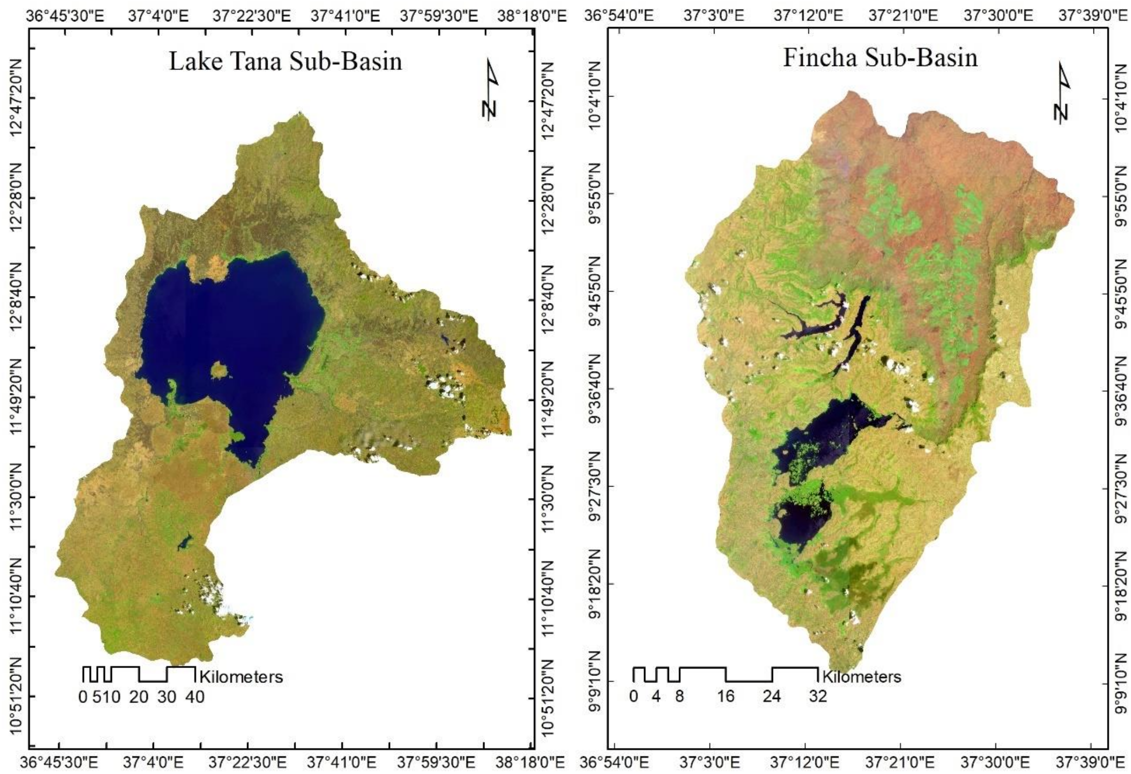


Figure 3.4: False Natural Color[2] Composite of Lake Tana and Fincha Sub-basins

3.2.3. SRTM DEM

The Shuttle Radar Topography Mission (SRTM) data available from the United States Geological Survey (USGS). Thirty-two (32) NASA Shuttle Radar Topography Mission (SRTM) at 3 arc-second (approximately 90 m) NASA JPL Version 3.0 tiles downloaded from earth explorer and mosaicked to get DEM of the study area.

3.2.4. Ground Truth Data

The first critical component for any remote sensing program is solid ground truth information. Without ground data to identify land cover categories, to train the classifier and validate the output image products, it is impossible to run a defensible program that provides reliable results. Google earth and Rivers shapefile data were used to extract ground truth data. Thus, 152 known irrigated and 250 known non-irrigated points have been collected combined from google earth and GPS data collection.

[2] False Natural color was created using SWIR-NIR-Blue bands of Sentinel 2 MSI to enhance irrigated fields

3.2.5. GFSAD30AFCE Product

The Global Food Security-support Analysis Data @ 30 m for the African Continent, Cropland Extent product (GFSAD30AFCE) (Xiong *et al*., 2017) is Cropland extent map at high spatial resolution (30 m) using the 10-day, 10 to 20 m, Sentinel-2 data in combination with 16-day, 30 m, Landsat-8 data on Google Earth Engine (GEE) distributed through the NASA's Land Processes Distributed Active Archive Center (LP DAAC). The GFSAD30AFCE data product uses two pixel-based supervised classifiers Random Forest (RF) and Support Vector Machine (SVM)‒and one object-oriented classifier Recursive Hierarchical Image Segmentation (RHSEG)‒to retrieve cropland extent (Figure 4.3).

3.2.6. MODIS Evapotranspiration

The MOD16 global evapotranspiration (ET)/latent heat flux (LE)/potential ET (PET)/potential LE (PLE) 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 ET algorithm is based on the Penman-Monteith equation. The product datasets are downloaded from NASA's Land Processes Distributed Active Archive Center (LP DAAC). Potential ET extracted using ArcGIS extract sub-dataset extraction tool and multiplied 0.1 to get the real ET/PET values. Special values are assigned to Water body, Barren or sparsely vegetated areas, Permanent wetland and Urban or Built-up areas as 32766, 32765, 32763 and 32762, respectively.

3.2.7. CHIRPS Precipitation

The climate hazards infrared precipitation with stations (CHIRPS) (Funk *et al*., 2015)) is a 30+ year quasi-global rainfall dataset. Spanning 50°S–50°N (and all longitudes), starting in 1981 to near-present. 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. Average of all available CHIRPS dataset used (Figure 3.5)

3.2.8. Soil Properties Map of Africa

Soil property maps of Africa at 250 m (Hengl *et al*., 2015) produced by ISRIC - World Soil Information, in collaboration with The Earth Institute, Columbia University, World Agroforestry Centre, and the International Center for Tropical Agriculture (CIAT) for the whole African continent at 250 m spatial resolution at two or six standard soil depths. The predictions of soil properties include organic carbon, pH, sand, silt and clay fractions, coarse fragments, bulk density, cation-exchange capacity, total nitrogen, exchangeable acidity, Aluminum content, and exchangeable bases (Ca, K, Mg, Na).

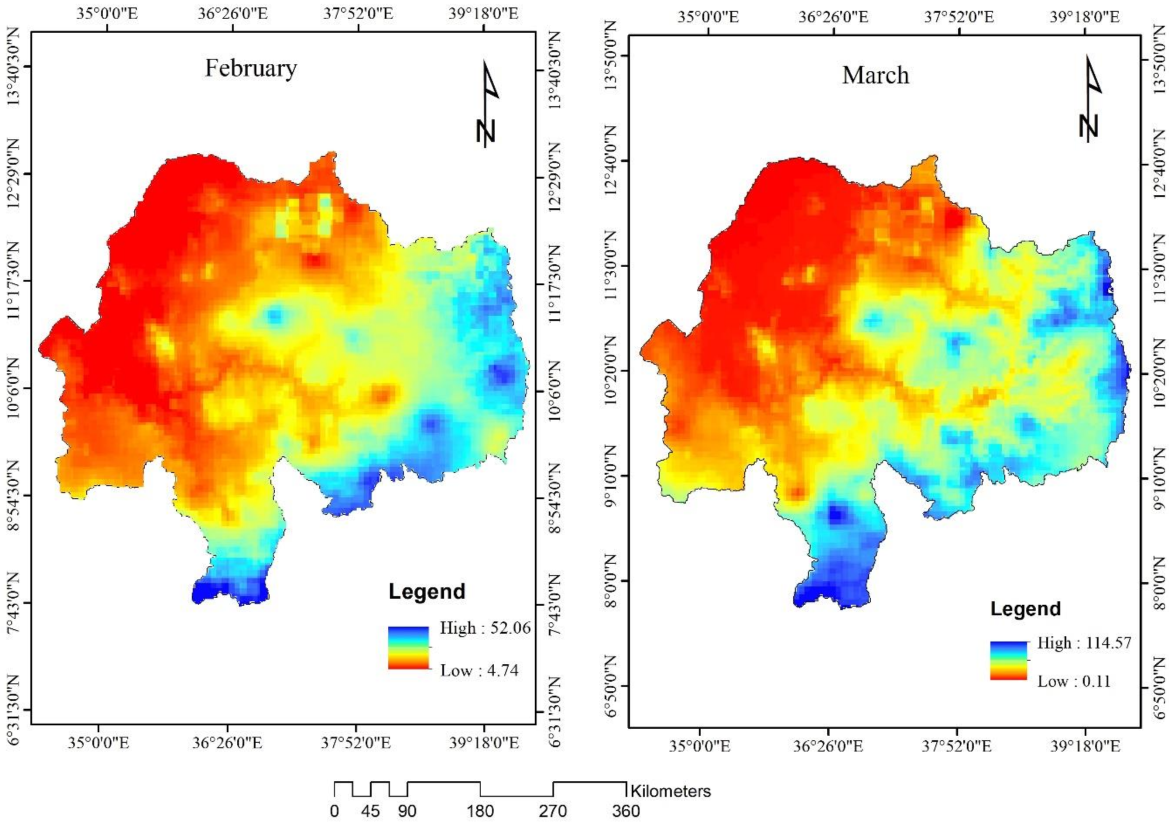


Figure 3.5: Average Rainfall in Blue Nile Basin (CHIRPS)

3.2.9. ISRIC-WISE Database

ISRIC-WISE derived soil property estimates on a 30 by 30 arcsec global grid (WISE30sec) (Batjes, 2015) dataset considers 20 soil properties that are commonly required for global agroecological zoning, land evaluation, crop growth simulation, modeling of soil gaseous emissions, and analyses of global environmental change. It presents 'best' estimates for: organic carbon content, total nitrogen, C/N ratio, pH(H2O), CECsoil, CECclay, effective CEC, total exchangeable bases (TEB), base saturation, aluminum saturation, calcium carbonate content, gypsum content, exchangeable sodium percentage (ESP), electrical conductivity, particle size distribution (content of sand, silt and clay), proportion of coarse fragments (> 2 mm), bulk density, available water capacity (-33 to -1500 kPa) and the dominant soil drainage class.

3.2.10. Discharge Data

Monthly river flow data from 1959 to 2007 (years differ according to installation dates (Table 3.3) of the ten rivers in Choke mountain watersheds (Azuari, Chemoga, Jedeb, Muga, Sede, Suha, Teme, Temcha, Tigder and Yeda) were obtained from Ministry of Water, Irrigation and Electricity (MoWIE). The data missed recordings were filled using an average of nearest records and mean values if the missing month is only one and more than one, respectively.

Table 3.1: Summary of data used for the study

No.	Data Type	Resolution	Acquisition Date
1.	Sentinel 2 MSI	10 m	Mid-February to Mid-March (2017)
2.	Vegetation Indices (MODIS Aqua 10-day Average)	250 m	September 2016 -May 2017
3.	GFSAD30AFCE	30 m	2015–2016
4.	SRTM DEM	30 m	February-2000
5.	CHIRPS precipitation	5 km	1983-2017
6.	Soil property grids (Africa)	250 m	Long-term average
7.	ISRIC WISE Database	1 km	Long-term average
8.	Discharge Data	----	Different among rivers

3.3. Methods

The methodology of the study was comprised of three different methodologies. First, object-based image analysis (OBIA) approach implemented to map irrigated areas using Sentinel 2 MSI. The second method applied parametric evaluation approach to map suitability of land for surface, sprinkler and drip irrigation methods. The third method was mainly hydrologic analysis i.e. rainfall, PET, kc and discharge to quantify the water resource potential for surface irrigation. The flow chart of the methods followed is shown Figure 3.6.

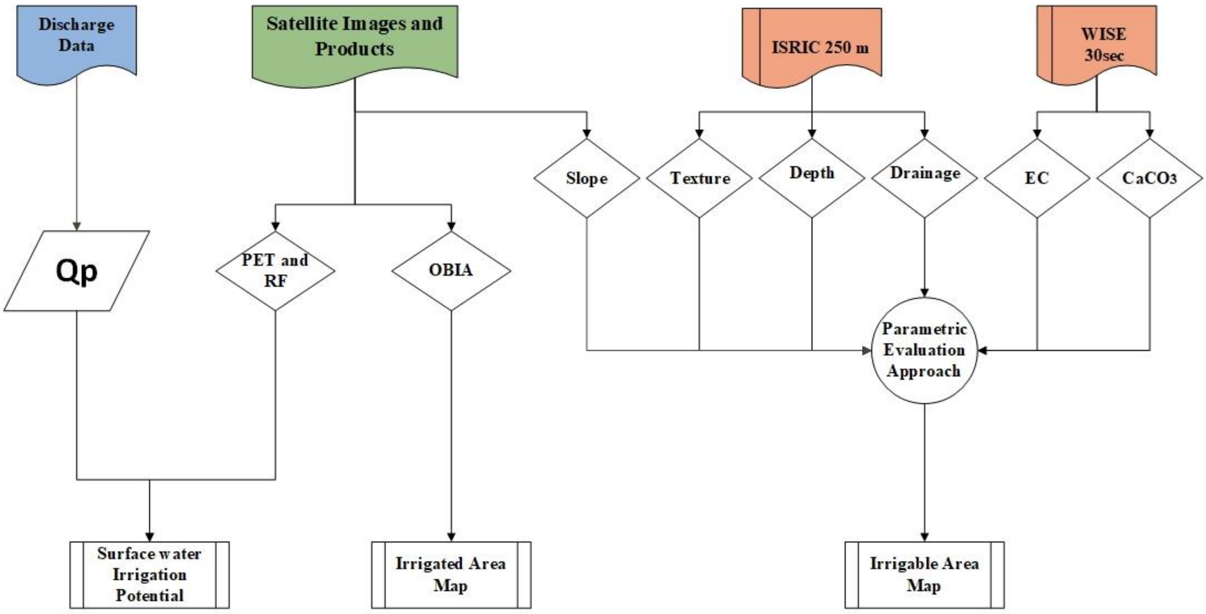


Figure 3.6: Flow Chart of the study methodology

3.3.1. Irrigated Area Mapping

Irrigated area mapped from Sentinel 2A MSI images with combination of eMODIS NDVI 10-day composite data using object-based image classification that comprised of segmentation (Multiresolution Segmentation) and computation of spectral, geometric, textural, conceptual and temporal attributes; object (semantic) classification; post-classification (verification, error elimination) and result validation using eCognition 9.0 software.

From a water resources point of view, it is essential to know the period when fields are really irrigated (Droogers, 2002). Therefore, satellite images and products used for mapping irrigated areas downloaded considering the irrigation calendar of Ethiopia. The peak period of irrigation where the irrigated area can be captured set to mid-February to mid-March.

3.3.1.1. Pre-processing of Images

Pre-processing used to correct for radiometric and geometric distortions of data – depending on the specific sensors and platforms used to acquire the data, the atmospheric conditions during data acquisition and the methods used in the classification process (GSARS, 2017). Sentinel 2 MSI data has been processed using Impact toolbox 3.9, and mosaicked and subset to the study area using ERDAS IMAGINE 2014.

3.3.1.2. Classification

Acceptable remote sensing techniques must distinguish between the various characteristic land covers (Turral, 2002). Thus, the classification approach developed based on the following considerations:

a. The temporal NDVI signal that has often been most related to irrigation.

Under ideal conditions, irrigation practiced when soil moisture deficit occurs, leading to a strong temporal mismatch between the greenness cycle of rain-fed crops and that of irrigated crops; because greenness associated with non-irrigated crops is often a direct result of rainfall while greenness associated with irrigated sites is generally independent of rainfall (Ozdogan and Gutman 2008).

b. The precise location of irrigated areas better established using finer spatial resolution data. The finer the spatial resolution of the sensor used, greater was the irrigated area derived, since, at finer spatial resolutions, fragmented areas are detected better (Velpuri *et al*., 2009).

c. Objected Based Image classification is the better method than Pixel Based Image Classification to map irrigated areas.

Methods that exploit the relationship between a group of pixels in an attempt to generate improved classification are promising when analyzing high-resolution data in fragmented environments (Ozdogan *et al*., 2010). Object-based Image classification is the best method to address these relationships.

Object based image analysis (OBIA) was applied in eCognition 9.0 software using Sentinel 2MSI images. Methods of image segmentation become more and more important in the field of remote sensing image analysis; best results have been calculated using eCognition multiresolution segmentation (Meinel and Neubert 2004). MRS provides a region-growing algorithm that merges individual pixels into image objects or regions based on the local homogeneity criteria (Baatz and Shápe, 2000).

The degree of local homogeneity to be used in the merging decision was set by Estimation of Scale Parameter (ESP 2) tool (Drăguţ *et al.*, 2014). Feature extraction involves the subsequent extraction of the various spectral, textual, morphic and contextual attributes associated with each objects created in the segmentation process (Blaschke, 2010) as indicated on Figure 3.7.

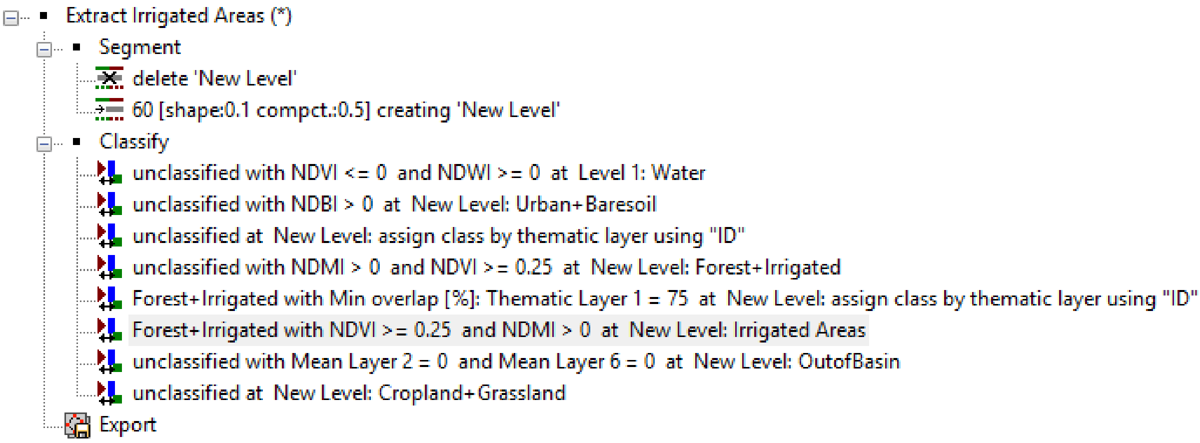


Figure 3.7: Ruleset developed for Object-based irrigated Area classification

Areas of altitude greater than 3700 m above sea level, slope greater than 30%, Wetlands, Urban or built up, Barren or Sparse vegetation, and Forest removed by the mask from the classification. Elevation above 3,700 m is classified as 'high wurch' (frosty-alpine) according to the agroecological zoning of Ethiopia and unsuitable for agricultural purposes (Yalew *et al.*, 2016). Using slope derived from SRTM DEM data at 90-m resolution; areas having slope more than 30% were identified and considered not feasible for irrigation (Sys *et al.*, 1991). High slope (>30%) and high elevation (>3700 m) areas were included in the non-irrigated area mask.

Areas with continuous NDVI values extracted as forest depending on threshold values set from 102 forest and 150 cropland points collected from known points to develop temporal NDVI curve. But, irrigated areas of sugar factories behave as forests. Thus, sugarcane plantation masked from the forest map and manually merged to the irrigated area map.

Table 3.2: Mask Features and sources

No.	Mask	Data Source
1.	Slope > 30%	SRTM DEM
2.	Elevation > 3700m	SRTM DEM
3.	Water Bodies	MOD16A2 (Dec 2016) and own classification (Sentinel 2MSI)
4.	Wet Lands	MOD16A2 (Dec 2016)
5.	Urban or Built-up	MOD16A2 (Dec 2016) and own classification (Sentinel 2MSI)
6.	Barren or Sparse Vegetation	MOD16A2 (Dec 2016)
7.	Forest	Own Computation (eMODIS NDVI and Sentinel 2MSI)
8.	Non-Crop Land Map	GFSAD30AFCE (2015–2016)

3.3.1.3. Accuracy Assessment

Accuracy assessment determines the probability that the class assigned to a pixel matches ground truth data at the same location. The accuracy assessment was performed using ground truth data, to understand the accuracies of the datasets used in this study. The software package performs segmentation and classification then it exports the results as polygons in the ESRI shapefile format. Thus, to do classification accuracy assessment the polygons converted to grids of irrigated areas. Then, grid values extracted using extract values to points. Frequency analysis done on the extracted values against truth values and pivot table developed for developing error matrix using MS-Excel 2016. The accuracy of the obtained object-based classification was evaluated using user's, producer's, overall accuracies and kappa coefficient:

$$Error\ of\ Omission = \frac{NIPI}{TNIP} \times 100 \tag{2}$$

$$Error\ of\ Comission = \frac{IPN}{TNP} \times 100 \tag{3}$$

$$User's\ Accuracy = \frac{CCP}{TRPc} \times 100 \tag{4}$$

$$Producer's\ Accuracy = \frac{CCPc}{TRPc} \times 100 \tag{5}$$

$$Overall\ Accuracy = \frac{SCCP}{TRP} \times 100 \tag{6}$$

Where:

NIPI is Non-Irrigated Ground-truth points classified as Irrigated Area; TNIP is Total Number of Non-Irrigated Ground-truth points; IPN is Irrigated Ground-truth points falling on Non-Irrigated Area; TIP is Total Number of Points in a class; CCP is Correctly Classified points in a class; TRPc is Total Reference Points in a class; CCPc is Correctly Classified points in a class; SCC is Sum of Correctly Classified points and TRP is Total Reference Points.

$$Kappa = \frac{N\sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r}(x_i + * x_{+i})}{N^2 - \sum_{i=1}^{r}(x_i + * x_{+i})} \tag{7}$$

Where; N is the total number of reference points, X_{ii} is number correctly classified points, x_i is a row total in error pivot table, x_{+i} is a column total in error pivot table.

The final irrigated map also compared with IWMI data and official reports of Abay Basin Authority.

3.3.2. Land Suitability Analysis for Irrigation

Among the different land suitability assessment methods, this work is interested in the parametric evaluation approach. The method consists in the numerical rating of the different level of land characteristics on a numerical scale from 0 to 100. The rating thematic layer of Soil texture (T), soil depth (D), Calcium carbonate/$CaCo_3$/ (C), Salinity/Alkalinity (S), Drainage (E) and slope (F) the capability index for irrigation (C_i) calculated using rating tables adapted from the tables that prepared by (Sys *et al*, 1991).

$$C_i = T \times \frac{D}{100} \times \frac{C}{100} \times \frac{S}{100} \times \frac{E}{100} \times \frac{F}{100} \quad (8)$$

To get the capability index(Ci), the following GIS operations have been done:

i. In order to obtain the average soil properties for ISRIC data provided with sections six (6) sections, weighting factors of 2,1.5, 1, 0.75, 0.50 and 0.25 used for each section, respectively from top to bottom.
ii. Texture classification using SAGA GIS 2.3.2 soil texture classification tool that is developed based on the USDA texture triangle from soil separates (clay, silt, and sand) average values.
iii. 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.
iv. Extract $CaCO_3$ and EC using Lookup tool in ArcGIS 10.4 to get individual data set of each.
v. Convert $CaCO_3$ provided in g/kg to percent (1percent =.10g/kg)
vi. Combine datasets using Combinatorial And too to combine the cell values in accordance with the requirement of rating table (Texture with Coarse Fragment, EC with Texture, and Drainage with Texture)
vii. Prepare a slope map of the basin from SRTM DEM
viii. Fill the values according to rating tables (Appendix 1: Rating Tables for Parametric Evaluation) using a query of attributes for the respective irrigation system.
ix. Export Each column of rating values by Lookup as new raster.
x. Finally, Multiply thematic layers created according to the model above.

For irrigation, soil is a cultivation space in which during the vegetative period is lacking specific amount of water and which has to be introduced by artificial means. Thus, soil and land properties that resulted maximum usage of added water; and preservation of soil structure especially if there is a risk of soil salinization have been considered for the study. These are:

a. Soil Texture: 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. It determines the rate at which water should be applied, how much should be applied and how often irrigation should occur.

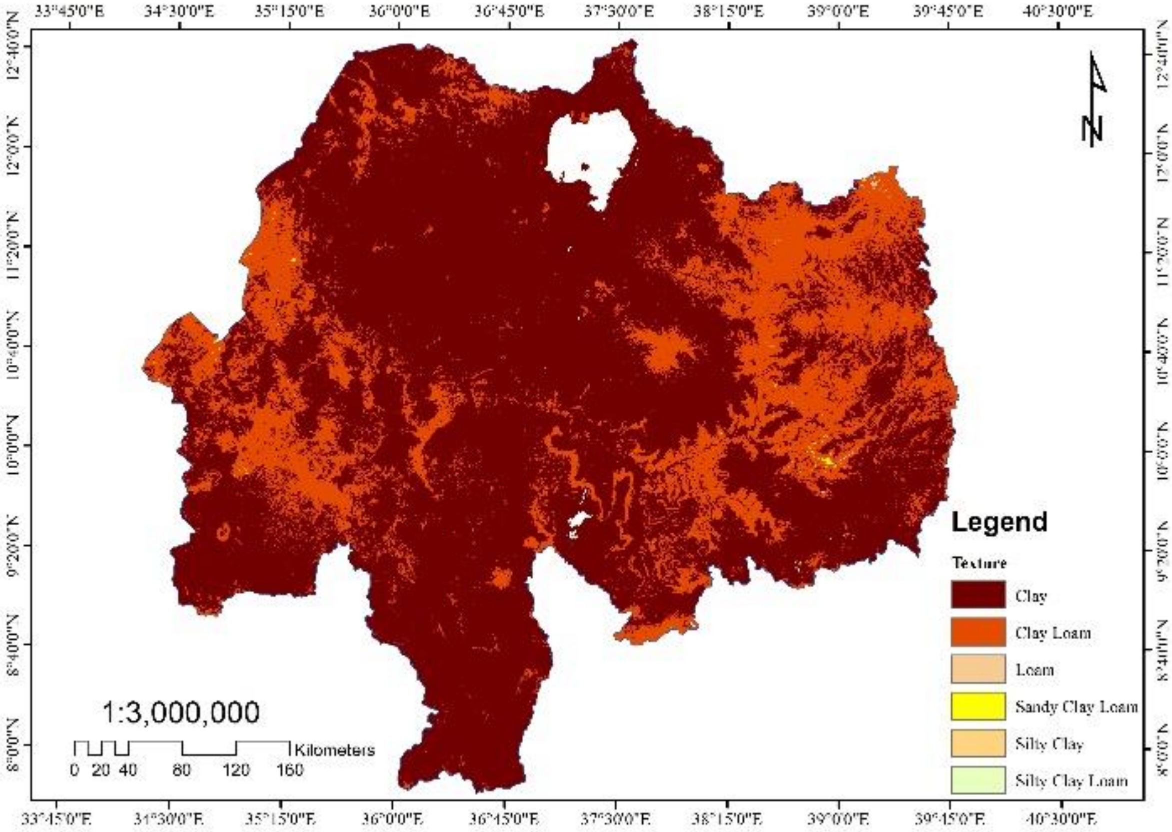


Figure 3.8: Soil Texture Map of Abay Basin

b. 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.

c. Calcium Carbonate: The presence of free lime in the soil affect the structural arrangement of the soil mass, and the soil reaction and the physico-chemical constitution of the solum. The calcium carbonate status influences thus at the same time the soil-water relationship of the soil and its available nutrient supply for plant growth. Moderate CaC03 content has a favorable effect on soil suitability for irrigation.

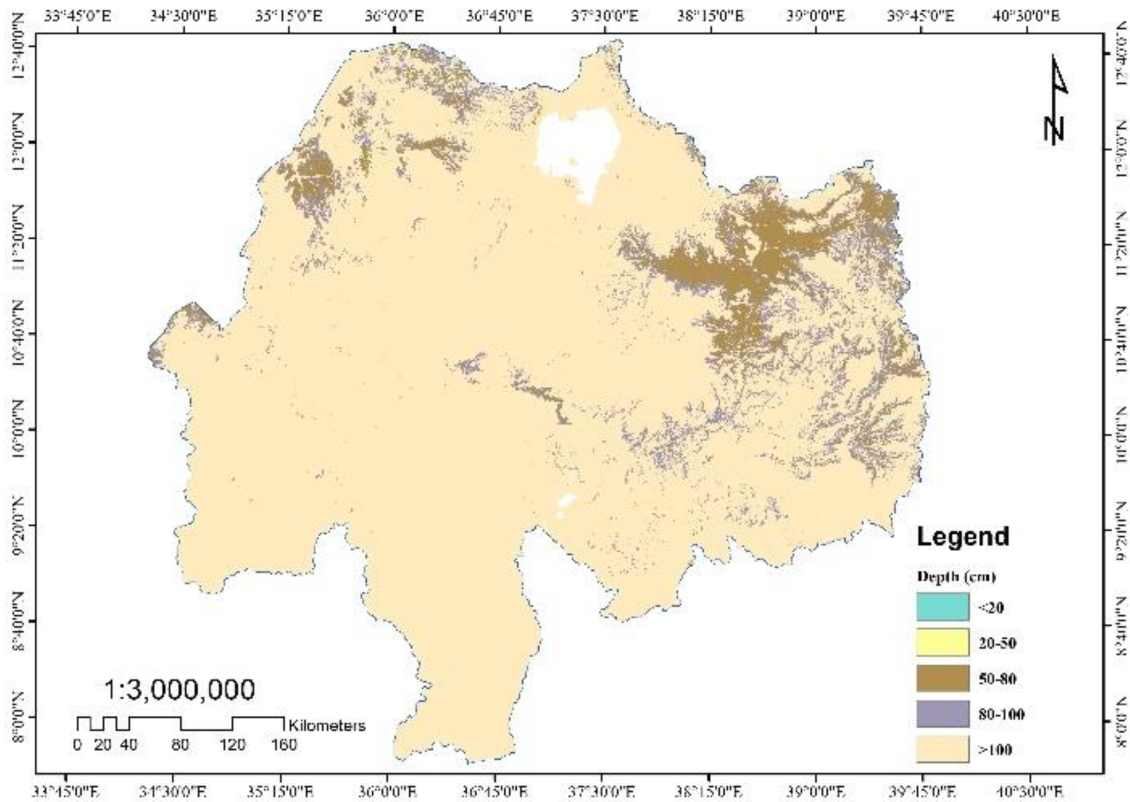


Figure 3.9: Soil Depth map of Abay Basin

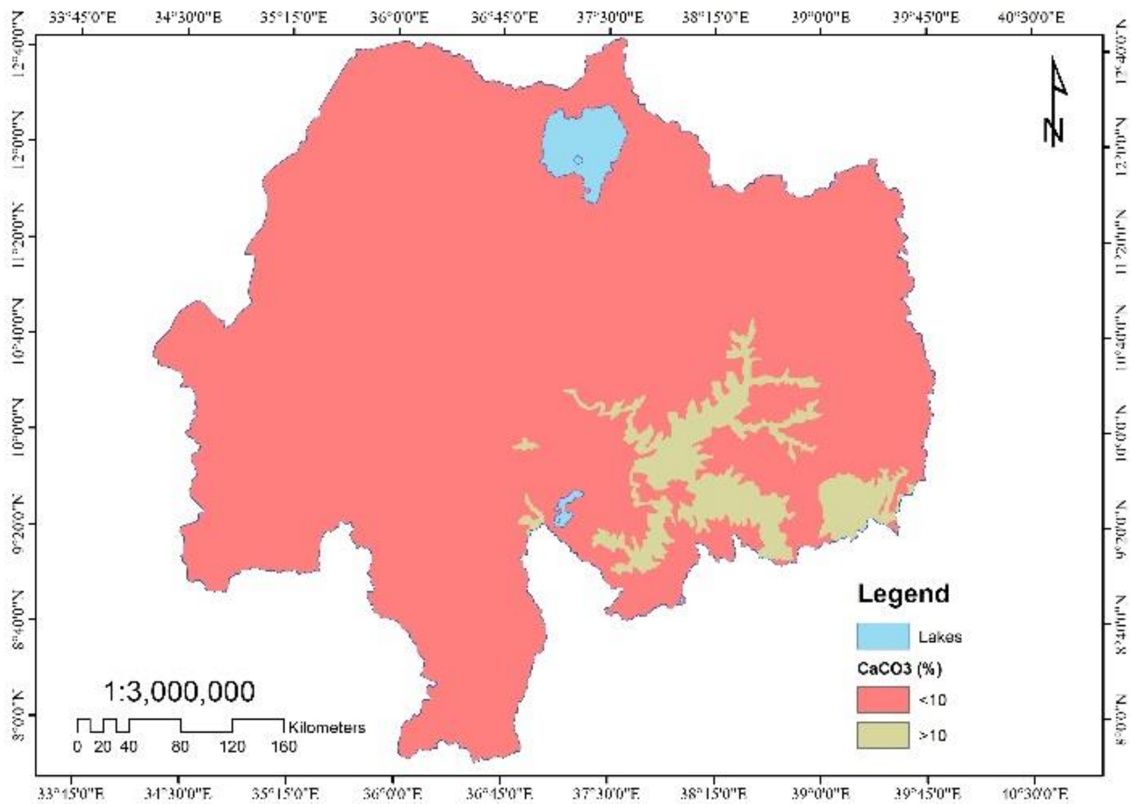


Figure 3.10: Calcium Carbonate map of Abay Basin

d. Electrical Conductivity: Electrical conductivity (EC) is the most common measure of soil salinity and is indicative of the ability of an aqueous solution to carry an electric current. The higher conductivity indicates excessive clay, which may limit production and suitability of the land.

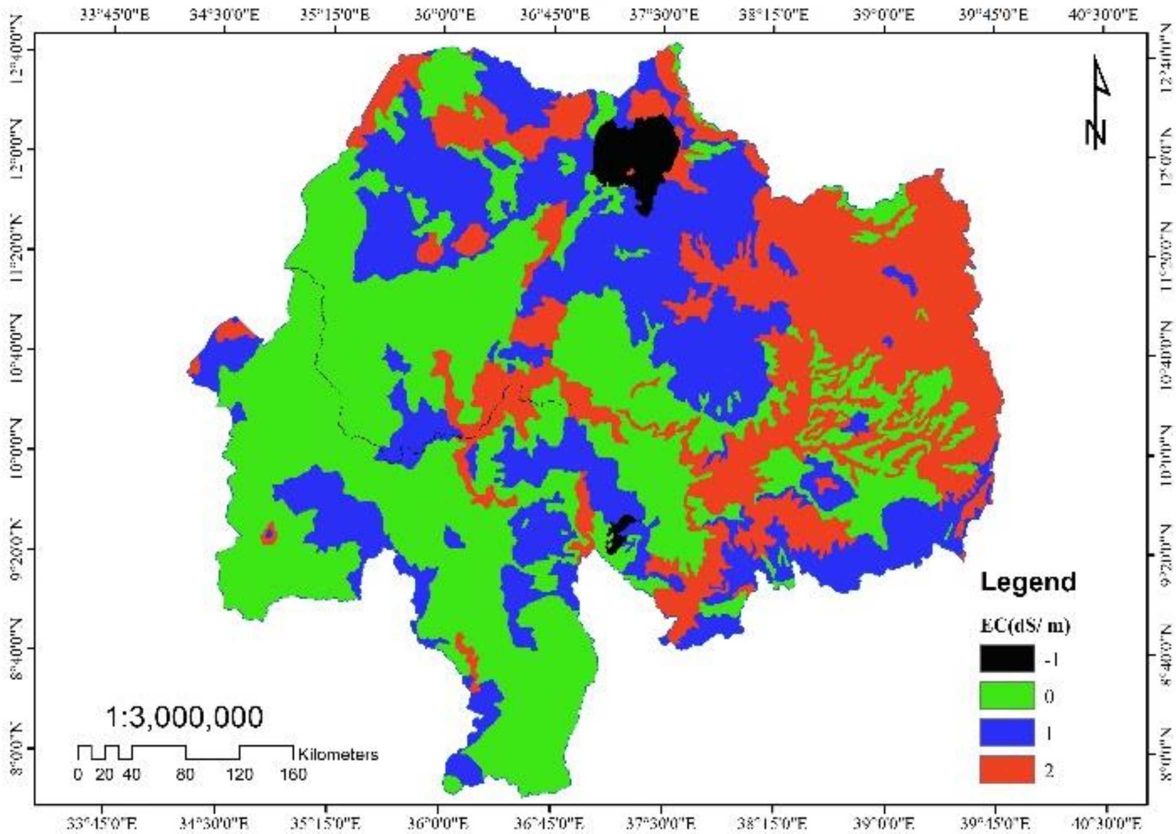


Figure 3.11: Electrical Conductivity map of Abay Basin

d. Soil Drainage: Imperfect or poor drainage is an evident limiting factor. 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.

e. Slope: Slope is important to soil formation and management because of its influence on runoff, soil drainage, erosion, the use of machinery and choice of crops. Gravity (surface) irrigation can be used only on simple slopes. Greater slopes could be irrigated only with sprinkler or drip systems. To accommodate gravity or sprinkler irrigation systems, land smoothing can be used to modify the slope in a field.

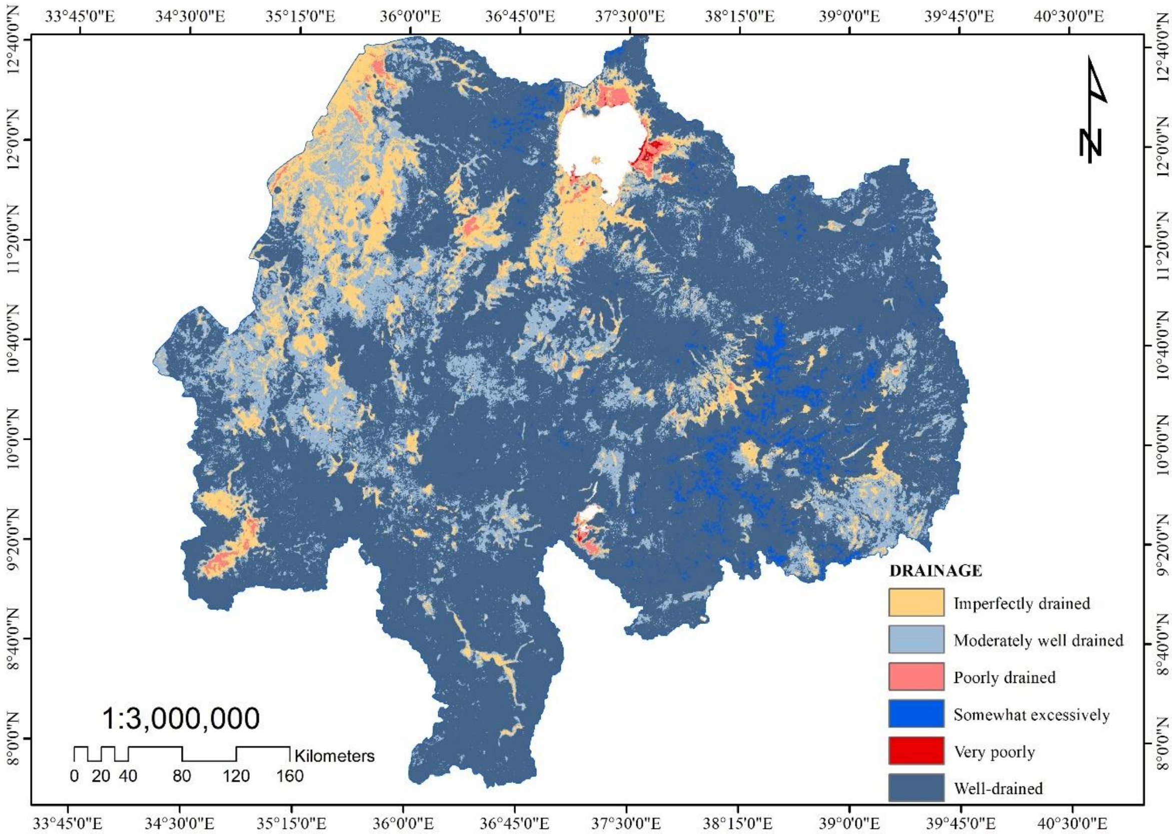


Figure 3.12: Soil Drainage map of Abay Basin

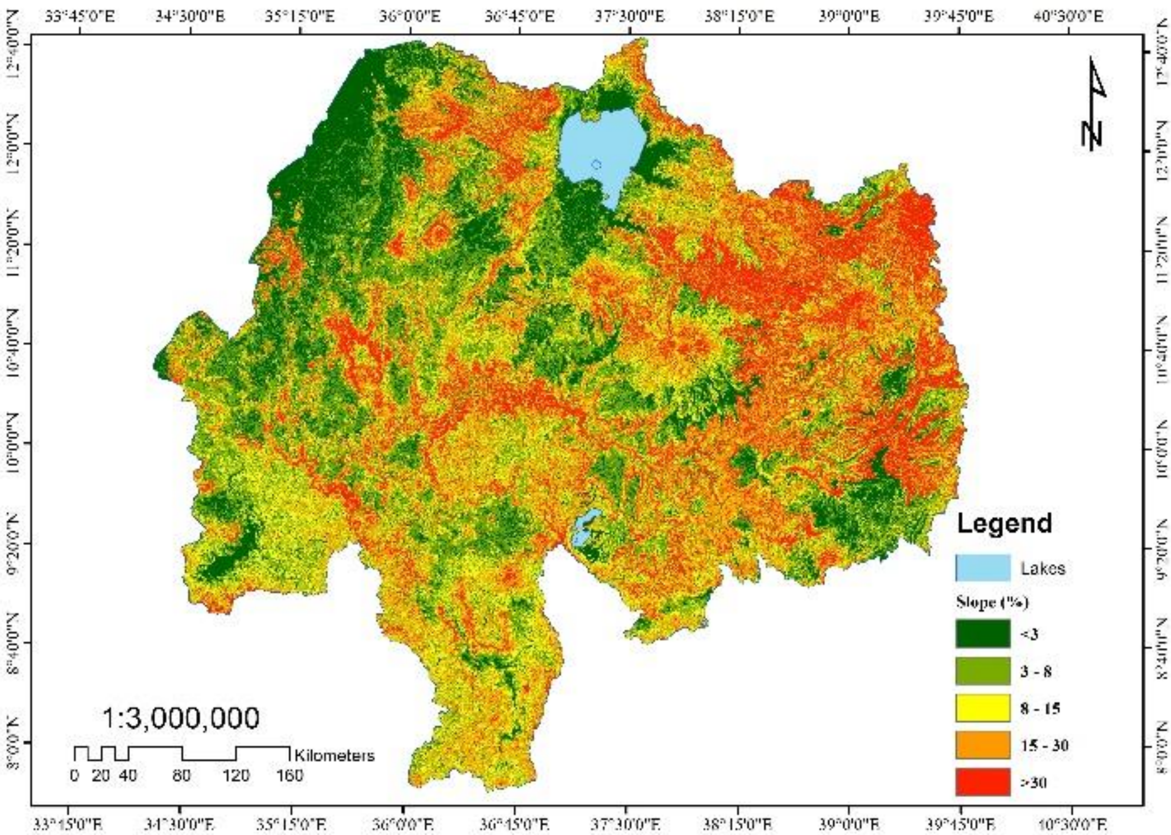


Figure 3.13: Slope Map of Abay Basin

3.3.3. 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 potential evapotranspiration (ETo) and the crop coefficient (Kc) (Allen *et al*., 1998).

$$CWR(mm) = K_c \times ETo \tag{9}$$

$$NIR(mm) = CWR - P_{eff} \tag{10}$$

Where, CWR is crop water requirement for the growing period, Kc is crop coefficient for crop, ETo is Potential evapotranspiration, P_{eff} is effective rainfall.

Effective rainfall was calculated according to FAO/AGLW formula (Smith, 1992):

$$Peff = 0.6 * P - 10 \quad \text{for Pmonth} <= 70 \text{ mm} \tag{11}$$

$$Peff = 0.8 * P - 24 \text{ for Pmonth} > 70 \text{ mm} \tag{12}$$

P is precipitation (mm)

The result of the rainfall deficit analysis indicated that rainfall in the wet season June through September is well above crop evapotranspiration (Worqlul *et al*., 2015). Therefore, MOD16 data downloaded for dry season specifically for the irrigation season (December to March).

MODIS evapotranspiration (MOD16A2) data used from data from 2000-2016 from NASA LPDAAC. The data distributed in Hierarchical Data Format (HDF), thus a model developed to extract the PET data using ArcMap model builder with iterator. Here, Extract PET from datasets included in HDF, scaled with scale factor, extract values by removing water bodies, urban, barren land and wetlands.

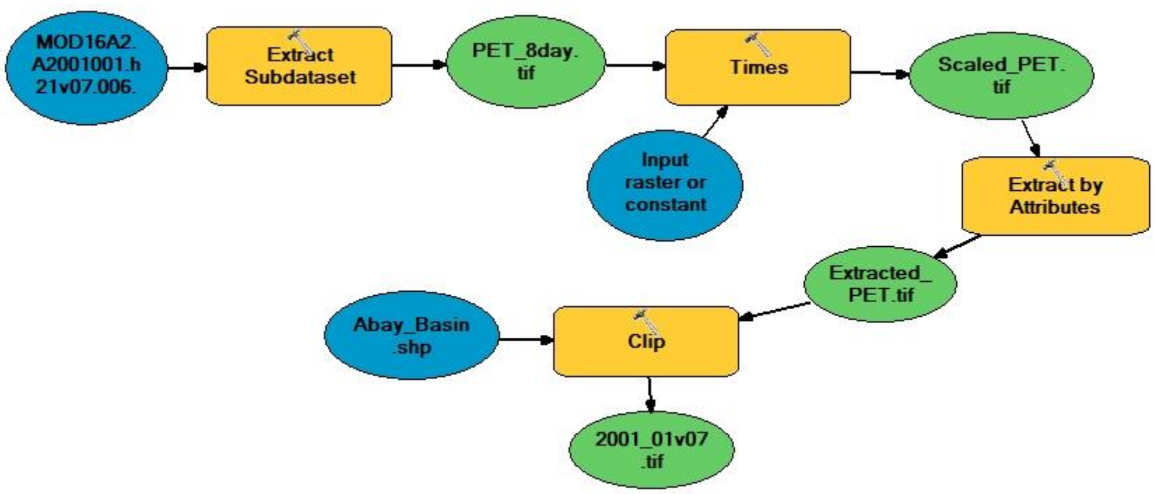


Figure 3.14: Model for MODIS PET extraction

3.3.4. Water Resources Potential

Prior to irrigation development, the irrigation potential of the rivers has to be assessed because assessing the suitability of land is critical to the development of productive and economically viable irrigation schemes (FAO, 1997). This depends on the correct prediction of hydrologic events. Information on the past records helps to derive statistical parameters based on which the future occurrences are predicted. Laws of probability help to arrive at the desired objective.

In addition to limited years of data, all the stations have some missing data for different periods of time. Because of this missing data, the following methods were followed to fill these gaps. For short missing gap length (one up to two months) the mean value of data in available years was simply taken; For longer missing gap length (more than two months) the long-term average of the station used.

Information on low-flow 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 discharge data obtained from the Ethiopian Ministry of Water, Irrigation and Electricity (MoWIE) determined by cumulative frequency analysis with probability distribution fitting software (CumFreq**)** (Oosterbaan, 1994). At these dependable river flows irrigation potential estimated.

Table 3.3: General information about Rivers studied

Station No.	**River**	**Site**	**Location**		**Installation Date**	**Drainage Area (km^2)**
			Latitude	**Longitude**		
112018	Azuari	Nr. Motta	392925.35	1212836.59	28-2-80	209
113008	Chemoga	Nr. Debre Markos	360932.54	1138857.46	27-11-59	364
113011	Jedeb	Nr. Amanuel	343458.59	1149991.14	28-11-59	305
112017	Muga	Nr. Dejen	406889.42	1124330.34	26-2-80	2800
112037	Sede	Nr. Motta	379837.05	1219517.26	26-6-87	209
112031	Suha	Nr. Bichena	410246.60	1151965.93	15-2-85	359
112030	Teme	Nr. Motta	388353.57	1152029.52	17-4-84	156
113014	Temcha	Nr. Dembecha	335862.50	1164404.82	1-12-59	406
112019	Tigder	Nr. Gundewoin	392893.08	1202883.94	27-2-80	-----
112038	Yeda	Nr. Amber	370768.76	1133290.40	12-4-88	125

3.3.5. Irrigation potential by Water Availability

Efficiencies in irrigation water application and water requirements for special applications, such as land preparation and leaching, are assumed to be 60%, 75%, and 90% for surface, sprinkler and drip irrigation respectively (Brouwer et a., 1989). The irrigation potential of the 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 area for the growing season.

That is;

$$Area = \frac{Q(80)}{IR} * E_{ff} \tag{13}$$

Where

Q (80) is Runoff at gauge location at 80% exceedance probability (Million m^3)

IR is irrigation requirement, and

E_{ff} is irrigation efficiency

4. RESULTS AND DISCUSSION

In this section results obtained on object-based irrigated area mapping, parametric 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. Irrigated area statistics

The first step in the irrigation mapping algorithm for Abay basin was identifying possible areas that cannot be irrigated. These areas are land with Slope greater than 30%, Elevation above 3700 m, Water Bodies, Wet Lands, Urban or Built-up areas, Barren or Sparse Vegetation, and Forest identified according to the method described in 3.3.1. Irrigated **Area Mapping** section. These areas cover about 4,688,847.39 ha or 27 % of total area of the basin.

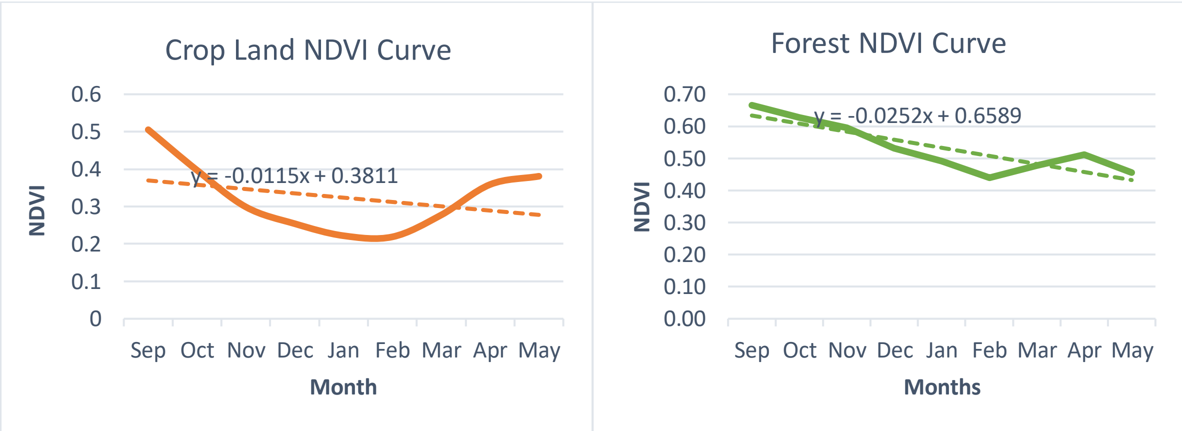


Figure 4.1: Temporal NDVI curve of Crop Land and Forest

As indicated above on the Figure 4.1 above NDVI values of forests is greater than 0.45 throughout the dry season while croplands have NDVI values nearly less than forest minimum in the dry season. This clear difference between cropland and forests enable the researcher to mask the forest land from other lands in the classification process.

The result showed that, permanent vegetation or forest cover was low for the basin as a whole (5.65%). Didessa,Dabus and Anger sub-basins 78.76 % of the total forest in the basin having 532,982.08 ha 227,211.22 ha and 129,069.50 ha, respectively. The rest 13 sub-basins make 21.24 % having 239,832.20 ha. Areas with slope graeter than 30%, elevation greater than 3700m, water bodies, wetlands, builtup and barren lands collectively make 20.37% of total area of the basin Table 4.1.

Table 4.1: Mask Areas with Area Coverage

No.	Mask		Area (ha)	Area (%)
1.	Slope > 30%		3,132,950	18.04
2.	Elevation > 3700m		29,735	0.17
3.	Water Bodies		320,786	1.85
4.	Wet Lands		8,460	0.05
5.	Urban or Built-up		8,815	0.05
6.	Barren or Sparse Vegetation		36,835	0.21
7.	Forest		1,129,095	5.65
		Sub-total	4,666,676	26.02
8.	Cropland		8,422,231	42.15

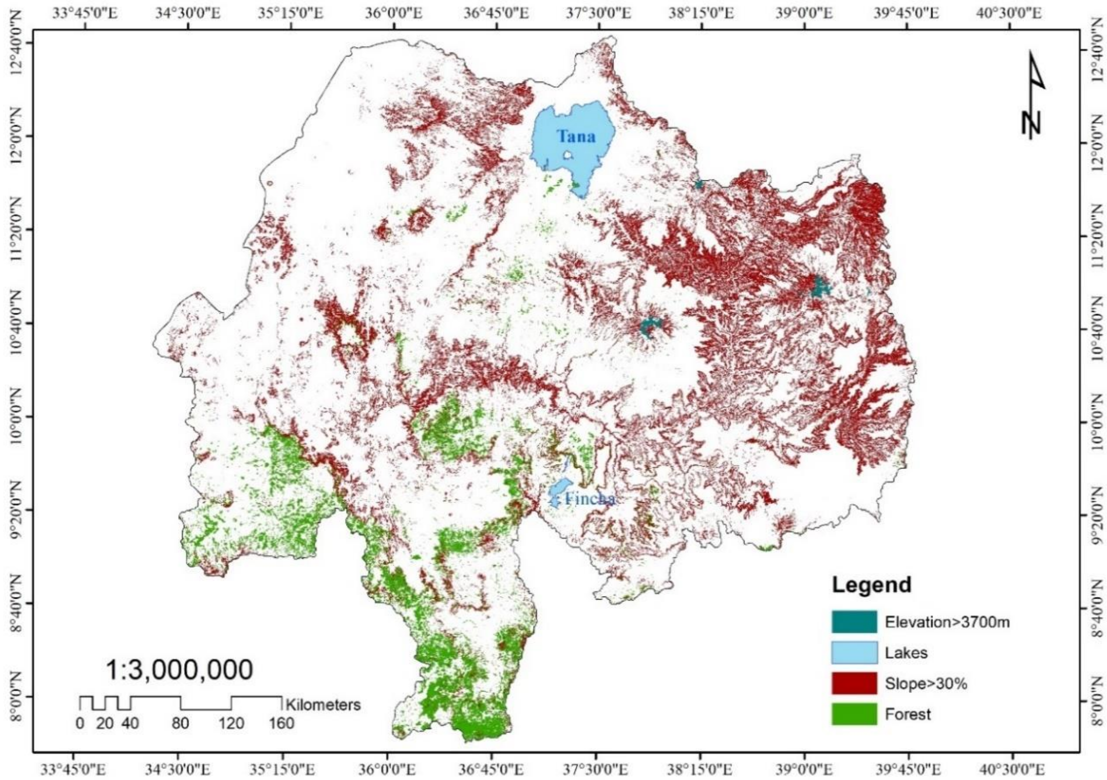


Figure 4.2: Map of Mask (non-irrigable) Areas in Abay Basin

Cropland (Figure 4.3) dominated the highland part of the basin covering 42.15% of the total area of the basin. The highland agriculture (greater than 1500 m altitude) takes the lionshare, i.e. 92.39% of total cropland or 7,781,468.63 ha. Jemma, Welaka and South Gojjam are sub-basins that have highest coverage of cropland of the basin. They take 15.31%, 12.94%, 12.92% of total area of cropland in Abay basin.

As shown on the figure majority of the land cannot be irrigated because of limitations of slope, elevation and current land use and landcover covering 20.37% of the basin area or 4,666,676 ha. These areas were excluded from classification in the object-based image analysis (OBIA). The rest 4,279,693 ha of land covered grass lands and shrublands.

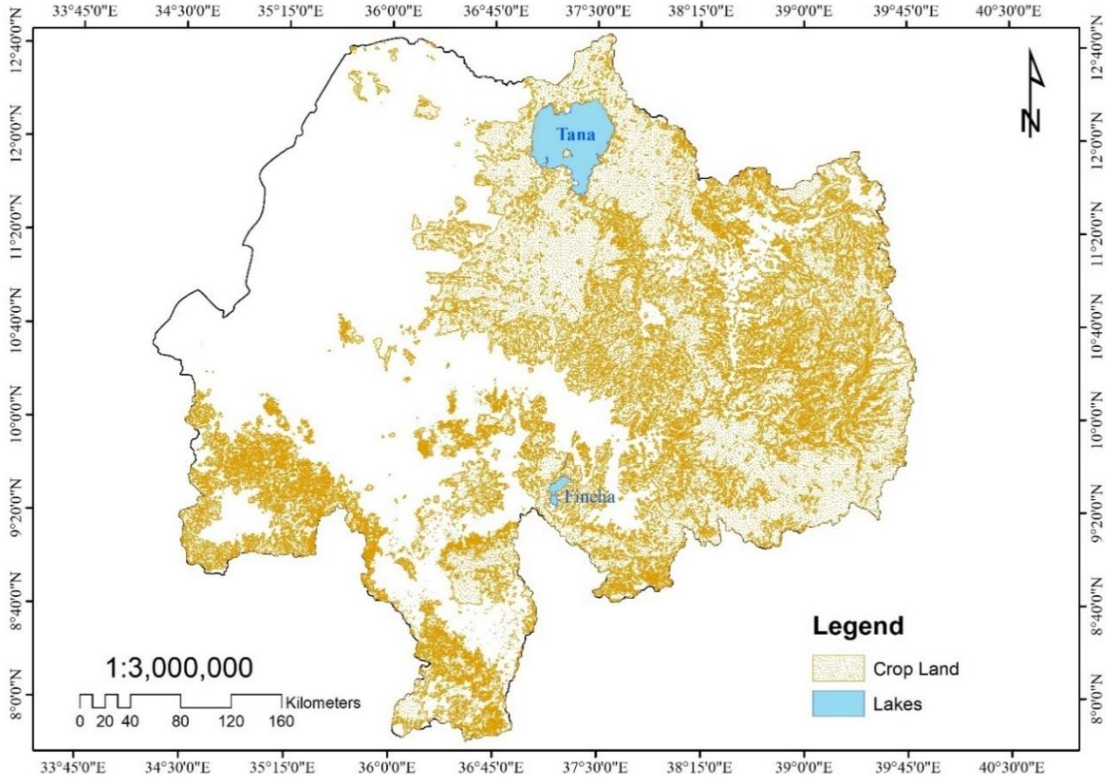
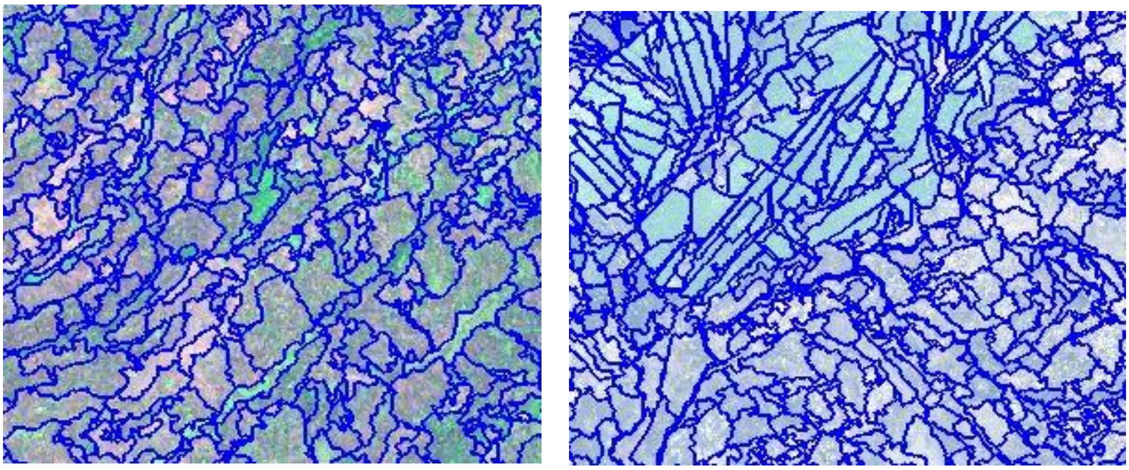


Figure 4.3: Crop land map of Abay Basin

The second step was the implementation of an algorithm that prepared as ruleset to each sub-basin because running the ruleset takes over 37 hours and failed when used to the whole basin at a time. The rule set was designed to delete the previous classification first, classify according to the given parameters, and export the classification to ESRI shapefile format (Figure 3.7). When multiresolution segmentation algorithm executed Image Objects or expressions representing an image object as a set of pixels created. Each object represents a definite space within a scene and objects can provide information about this space. These image objects used for classification of irrigated areas (Figure 4.4) using threshold values collected using ground truth points.



(a) Jedeb Watershed, East Gojjam(Maize) (b) Beles Sugar Project (Sugarcane)

Figure 4.4: Segmentation of Different Irrigation Schemes

The image objects delineated by applying multi-resolution segmentation algorithm were further classified using assign class algorithm to identify irrigated areas. The algorithm assigns all objects of the domain to the class specified by the class parameter as shown in Figure 3.7.

The classification considers different indices; that is, unclassified objects with NDVI values less than zero and NDWI values greater than zero classified as water. Objects with NDBI values greater than zero are bare lands and urban areas; NDMI values greater than zero and NDVI values greater than 0.25 are areas of forests and irrigated lands. These areas that overlap 75% with areas classified as forest from eMODIS NDVI are forests from Sentinel 2MSI. The rest areas that NDMI values greater than zero and NDVI values greater than 0.25 are irrigated lands. The NDVI value is determined by samples taken from objects created on irrigated fields.

(a) (b)

Figure 4.5: Potato (a) and Maize (b) Irrigation at Yeda Plain (East Gojjam)

Objects that have Layer values with zero (Green and NIR considered) are areas out of basin because eCognition segments out of basin area. The rest land that is not previously classified are grasslands and non-irrigated croplands. At the end, wetlands and non-crop lands masked manually by erasing tool in ArcMap environment using data prepared from MOD16A2 and GFSAD30AFCE. Major irrigated areas were identified in the north-eastern highlands of the basin mainly plain areas of Gojjam, while Abay valley and the western part of the basin are less irrigated as shown in Figure 4.7.

The irrigation mapping procedure was capable of identifying both the location and intensity of majority of irrigated lands like Beles Sugar project sugarcane plantation (Figure 4.6). Ancillary data and information from sources other than remote sensing used to improve classification accuracy (GSARS, 2017). Therefore, secondary data from zonal Agriculture and Water resources offices used for qualitative accuracy assessment.

Finally, 18,446 irrigation fields identified with mean area of 16.84 ha and Standard Deviation 22.47 ha. The fields size ranges from 0.50 ha to 307 ha. The total irrigated area estimated is 310,706.92 ha for the year 2016/2017 (Figure 4.7) from which only 32,160.77 ha or 10.35% is irrigated at the lowlands of the basin. Tana (55,921.59 ha), South Gojjam (53,849.47 ha) and Didessa (37,813.23 ha) are sub-basins with most irrigated areas; Fincha (13.13%), Didessa (6.74%), Belles (6.24%) and Tana (5.22 %) are sub-basins that have high percentage of irrigation from total crop land whereas Dinder (325.39 ha), Rahad (1,539.30 ha) and Wonbera (2,280.67 ha) are least irrigated; and Welaka (0.64%), Jemma (0.99%) and Rahad (1.41%) have the least percentage of irrigation from total crop land (Table 4.3)

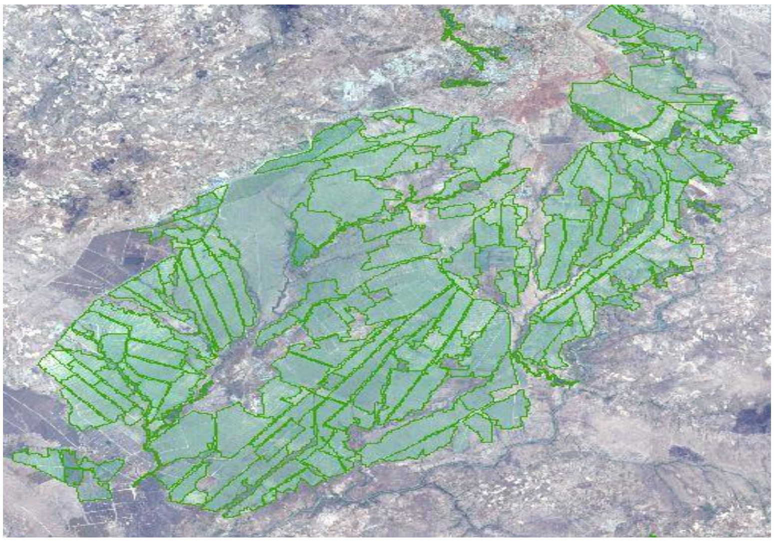


Figure 4.6: Irrigation Classification at Beles Sugar Plantation

Table 4.2: Irrigated area as a percentage of crop land

Sub-Basin	Irrigated Area (ha)	Crop Land (ha)	Irrigated Area (%)
Anger	4,542.65	220,120.18	2.06
Belles	15,999.18	256,358.85	6.24
Beshilo	20,789.77	656,790.49	3.17
Dabus	20,127.89	460,996.16	4.37
Didessa	37,813.23	561,118.42	6.74
Dinder	325.39	17,330.21	1.88
Fincha	25,790.75	196,358.60	13.13
Guder	13,487.15	371,731.39	3.63
Jemma	12,618.15	1,268,200.65	0.99
Muger	24,895.65	634,119.92	3.93
North Gojam	17,931.15	945,706.75	1.90
Rahad	1,539.30	109,527.93	1.41
South Gojam	53,849.47	1,069,766.74	5.03
Tana	55,921.59	1,071,634.15	5.22
Welaka	2,794.93	433,802.66	0.64
Wonbera	2,280.67	90,749.79	2.51
Total	310,706.92	8,364,312.89	3.69

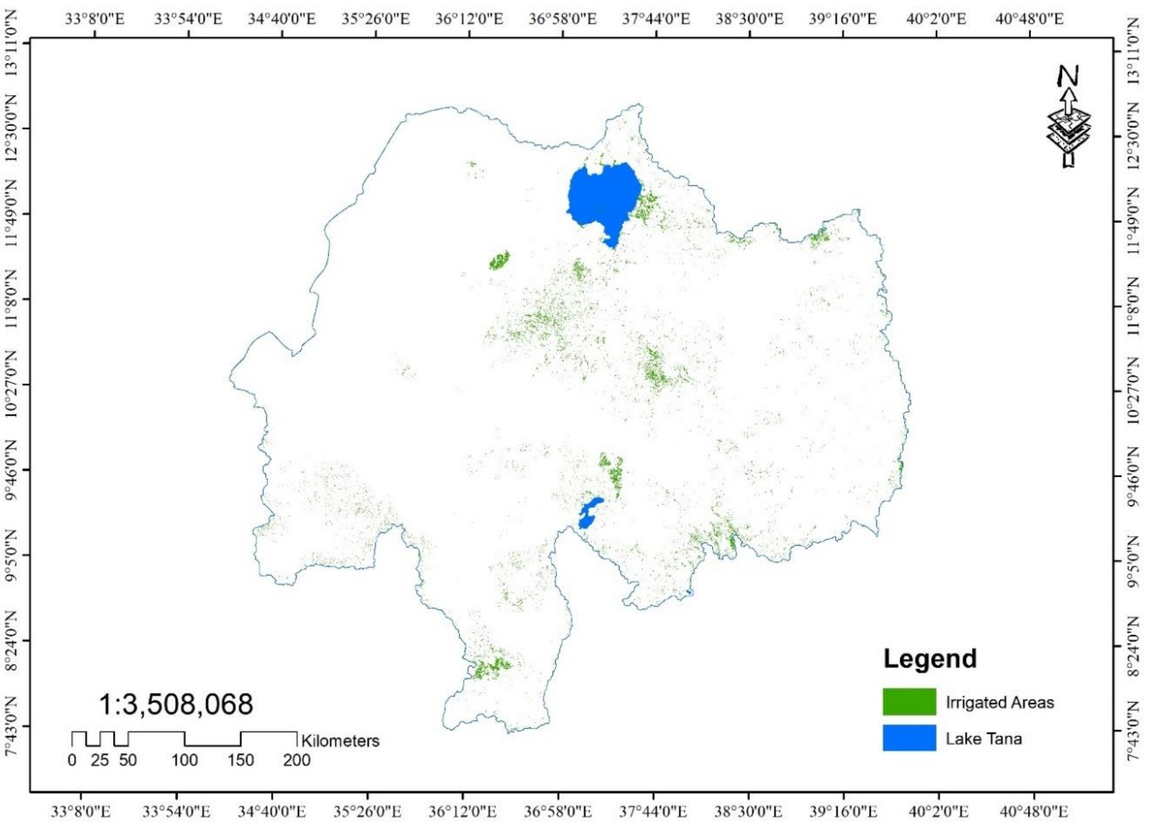


Figure 4.7: Irrigated area map of Abay Basin

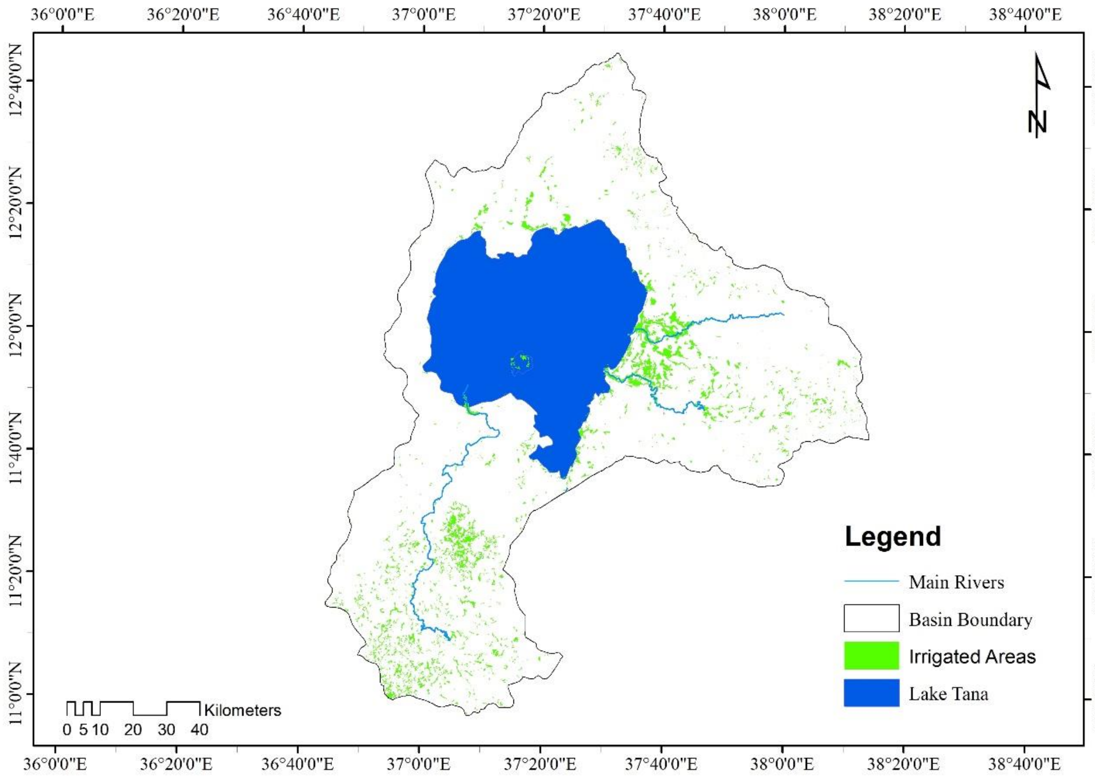


Figure 4.8: Irrigated Area Map of Tana Sub-basin

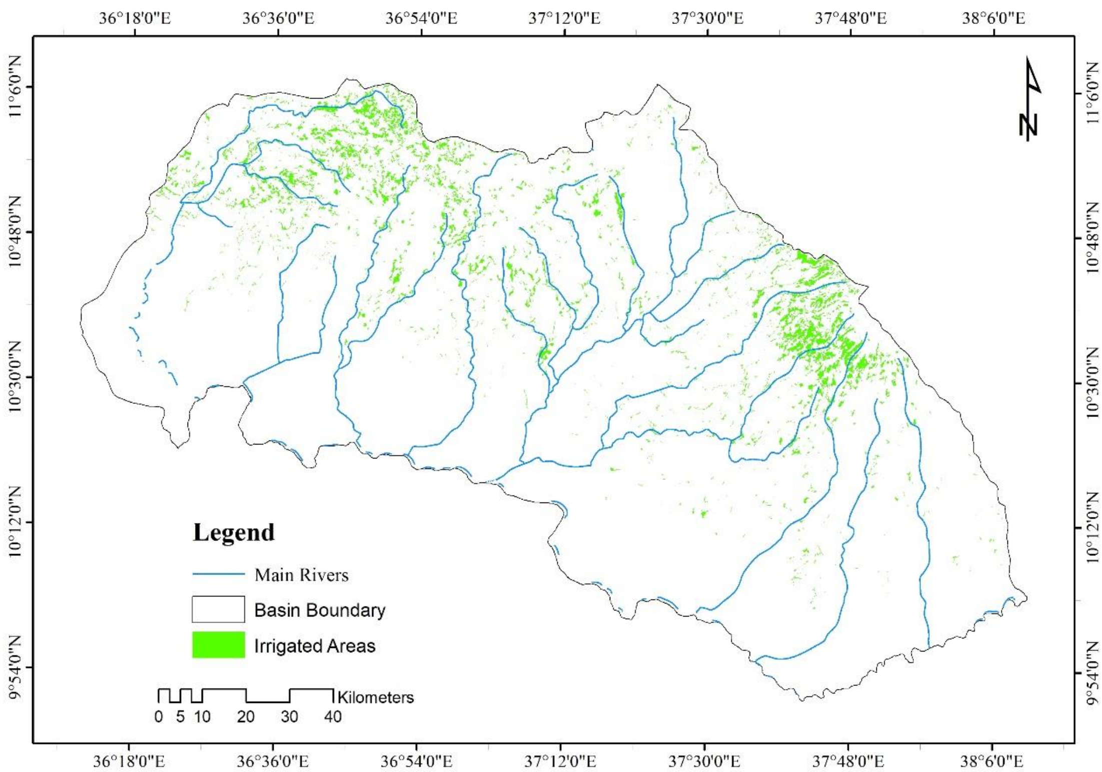


Figure 4.9: Irrigated Area Map South Gojjam Sub-basin

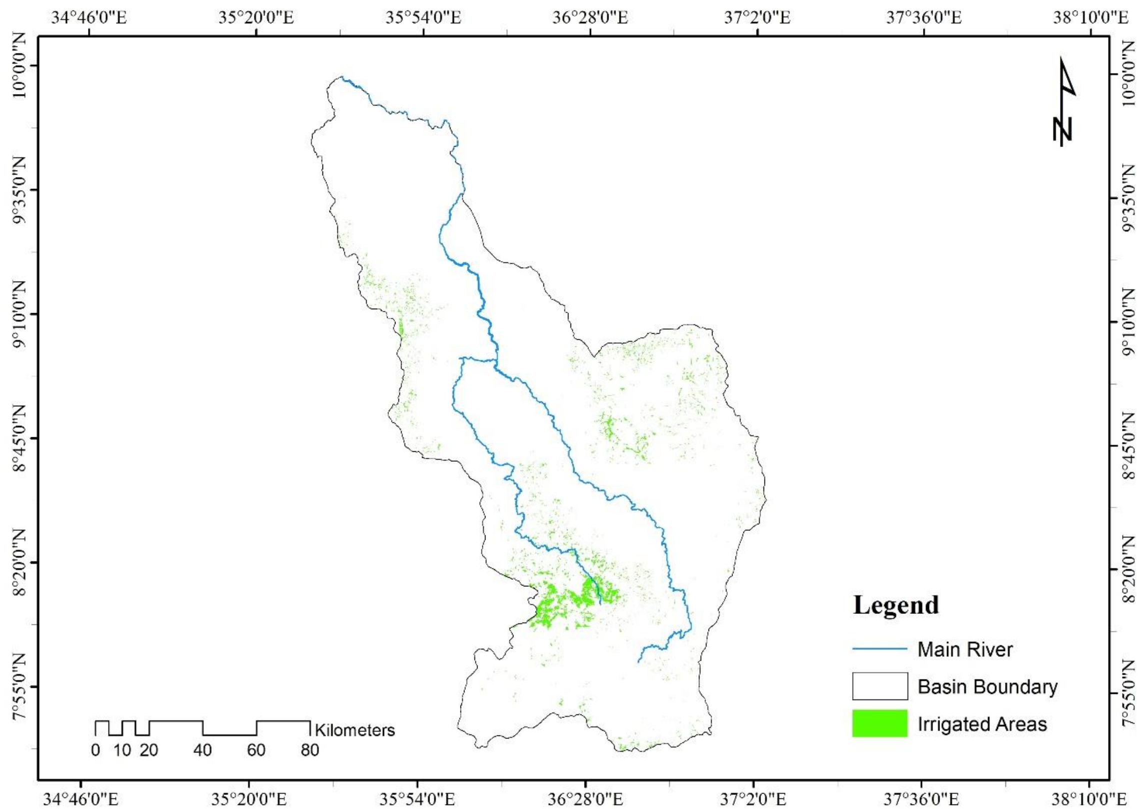


Figure 4.10: Irrigated Area Map Didessa Sub-basin

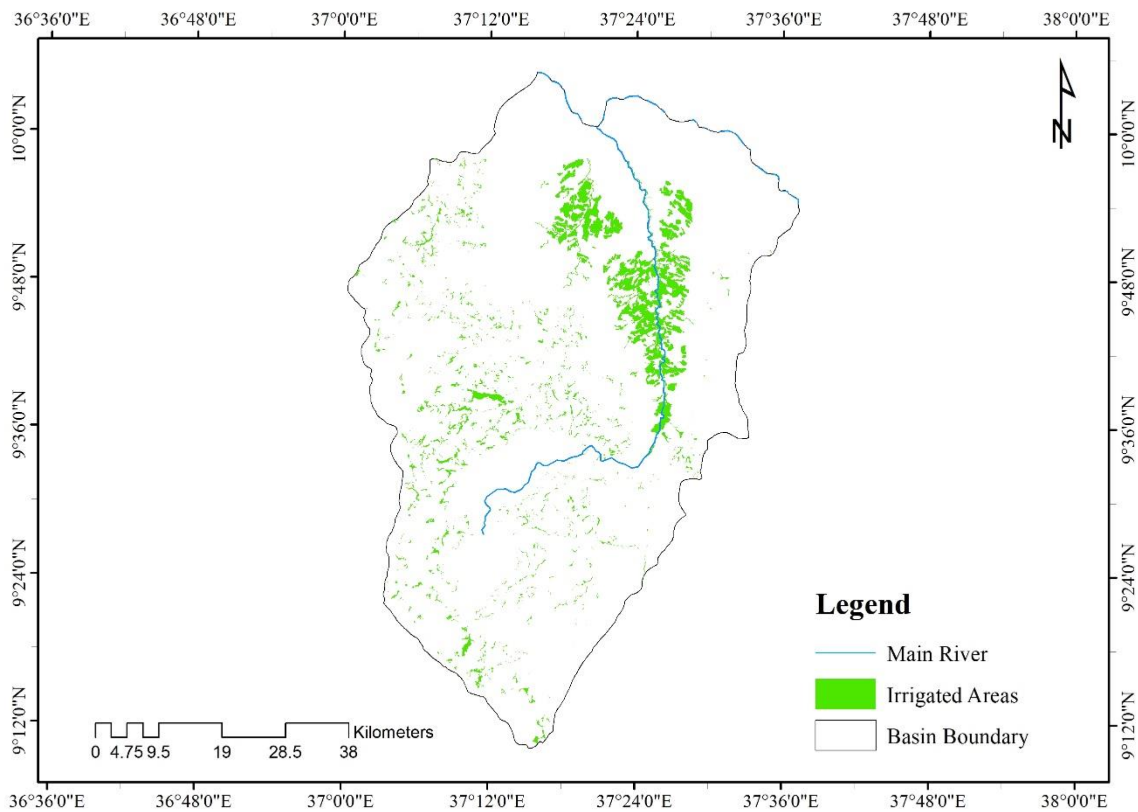


Figure 4.11: Irrigated Area Map Fincha Sub-basin

4.1.1. Accuracy assessment

The accuracy assessment showed that overall accuracy of 91.04%, with a producer's accuracy of 88.82% (or omission error of 11.18%), and user's accuracy of 87.66% (commission error of 11.34%) for the irrigated areas. The kappa coefficient calculated is about 0.854.

Table 4.3: Error matrix for irrigated area mapping

	Non-Irrigated	Irrigated	**Total**	User Accuracy
Non-Irrigated	231	17	248	93.15
Irrigated	19	135	154	87.66
Total	**250**	**152**	**402**	
Producer Accuracy	92.4	88.82		
Overall	91.04			
Kappa	0.854			

The study tried to compare the final classified map of irrigated areas with official irrigation area statistics and IWMI 2010 irrigation map (Table 4.4).

Table 4.4: Schemes at Abay basin and their status

Location	**Volume (Mm^3)**	**Irrigated area (ha)**	**Status**
Finchaa	477	20145	Implemented
Koga	83.1	7004	Implemented
Beles	1692	80000	Semi operational
Didessa	2200	80000	Under construction
Rija	10	3492.59	Implemented
Rib Dam	234	17200	Under construction
Megech Robit /gravity	185	16700	Under construction
Megech Guramba	No Dam	6500	Feasibility study
Megech Jajer	No Dam	6500	Feasibility study
Megech Serba pump	No Dam	10000	Under construction
Gumara	307	13800	Feasibility study
Jemma	173	7800	Feasibility study
Gilgel Abbay1&2	563	11500	Feasibility study
Angar	22	18000	Detail design
Negesso		21315	Detail design
Birr		14000	Feasibility study
Upper Guder		6282	Reconnaissance
Dabus	69.4	9661	Under construction
Gelagu	98.2	9860	Reconnaissance
Rahad		45135	Reconnaissance
Nekemt	71.5	11220	Reconnaissance

Source: Abay Basin Authority (2018)

As indicated above (Table 4.4) the official data did not clearly indicate how much area is currently covered from the schemes developed. It indicates only where large-scale irrigation projects are available such that it is only used as indicator where irrigated areas available in the basin. Thus, the statistical comparison mainly done with IWMI 2010 map of irrigated areas.

As indicated in Table 4.4 IWMI 2010 irrigated area map over-estimated the irrigated extent of the basin, that is about 47 % of country's total irrigated area reported in 2015. According to (FAO, 2016) the total area irrigated in the country is less than 5% with an area of 1,958,340 ha having areas equipped for full-control irrigation 658,340 ha, equipped for spate irrigation 200,00 ha (is not practiced in Blue Nile river basin) and small temporary water managed 1,100,000 ha. Similarly, the percentage of irrigation is nearly 3 % (IWMI, 2018) for sub-saharan Africa. The economic irrigation potential of Abay basin indicated in river master plan studies (Awulachew *et al*., 2007) is about 815,581 ha.

Table 4.5: Comparison of classification result with IWMI 2010 map

Sub-Basin	This Study (ha)	IWMI 2010 (ha)	Irrigated Area (%) [3]	Remark
Anger	4,542.65	33,200.89	15.08	
Belles	15,999.18	2,706.59	1.06	Before Sugarcane plantation
Beshilo	20,789.77	85,435.04	13.01	
Dabus	20,127.89	11,573.02	2.51	
Didessa	37,813.23	94,911.23	16.91	Agroforests as irrigated
Dinder	325.39	118.22	0.68	
Fincha	25,790.75	30,593.85	15.58	(23,000 ha currently) [4]
Guder	13,487.15	59,451.74	15.99	
Jemma	12,618.15	84,800.39	6.69	
Muger	24,895.65	35,876.37	5.66	
North Gojam	17,931.15	72,692.27	7.69	
Rahad	1,539.30	105.77	0.10	
South Gojam	53,849.47	179,431.63	16.77	
Tana	55,921.59	105,712.71	9.86	
Welaka	2,794.93	98,768.90	22.77	
Wonbera	2,280.67	26,281.96	28.96	
Total	310,706.92	921,660.58	11.02	

[3] Assuming crop land extent of the basin did not change much from 2010 to 2015
[4] Yalemneh Menji (Irrigation engineer at the Project)

These differences resulted from the methodology and data used in the two studies. The main source of uncertainty is resolution of MODIS products used. The in the MODIS-derived maps the 250-m (6.25 hectares) pixel mapping unit where 100% of the pixel area is considered irrigated but the average field size cultivated in Ethiopia 0.15 ha with total household landholding size of 1.77 hectares (CSA and World Bank, 2013).

The selection of threshold values to differentiate irrigated areas from non-irrigated area is another source for discrepancies. Irrigation in Ethiopia is dominated by traditional small-scale irrigation practices. The potential misclassification error in forest, pasture, built-up and wetland land cover types also introduce additional uncertainties in the non-irrigated area mask used by the method.

The IWMI 2010 did not consider factors that affect irrigation practices. About 140,000 ha of land classified as irrigated on areas that do not have a capability for irrigation. The classification exaggerates the area even by including dams built and turbid water bodies as irrigated land (for example, 360 ha on koga irrigation project dam and 965 ha on Fincha Lake).

4.2. Potential Area for Irrigation

In this study, an attempt has been made to analyze and compare three irrigation systems by taking into account various soil and land characteristics based on the parametric evaluation system of Sys *et al*., (1991). The results obtained showed that sprinkler and drip irrigation methods are more suitable than surface irrigation method.

The result showed that, 639,554.05 ha of the land was found suitable for surface irrigation, 3,037,849.43 ha for sprinkler irrigation, and 5,506,189.33 ha for drip irrigation. The values of land capability indices for surface irrigation at the study area ranged from 27.20 to 90; for sprinkler irrigation 30.60 to 90 and for drip irrigation 29.75 to 90. The geographic distribution of capability classes for irrigation at the study area revealed that the potential areas extensively found on plain areas of Gojjam, Northern Shewa and lowlands of the basin.

The main limiting factor was physical limitation of high slope and clay dominated soil texture. Mean slope of the basin is 15.43% with standard deviation of 15.77 that is slightly suitable for irrigation especially for surface and sprinkler irrigation methods. Generally, the topography of the basin dominated by Undulating plains to very steep escarpment, only 9.65 % of the basin Flat (or <2% slope). The soil texture map of the basin was classified into clay, clay loam, loam, sandy clay loam, silty clay, silty clay loam. Nearly 76% of the area is under the clay soil texture and the rest area 24% of the area is covered by silty clay texture. A very small percentage of clay loam, loam and silty clay loam soil textures also found in the study area.

Table 4.6: Mean Rating Values for different factors

Factor	Mean Surface Rating	Mean Sprinkler Rating	Mean Drip Rating
Texture	87.05	87.05	87.07
Depth	98.25	98.85	99.44
Drainage	92.77	95.11	97.50
EC	100	100	100
Slope	68.48	73.23	77.32
carbonate	95	95	93.33

Areal distribution of different Biophysical characteristics used for irrigation suitability analysis with their classes and percentage of each class from the total area of the basin are summarized in the following tables.

Table 4.7: Classes of Factors and their area

Tex*	Area (10^3 ha)	Area (%)	Depth (m)	Area (10^3 ha)	Area (%)	CaCO3 (%)	Area (10^3 ha)	Area (%)
C**	14,971.12	76.0302	<20	0.13	0.001	<0.3	18,383.53	91.85
CL	0.08	0.0004	20–50	19.74	0.100	0.3-10	351.46	1.76
L	0.03	0.0002	50–80	1,032.87	5.245	>10	1,279.47	6.39
SCL	11.68	0.0593	80–100	1,296.86	6.586			
SiC	4,703.23	23.8852	>100	17,341.43	88.068			
iCL	4.88	0.0248						

* Tex: Textural Classes.

** C: Clay CL: Clay Loam L: Loam SiCL: Silty Clay Loam SCL: Sandy Clay Loam SiC: Silty Clay

Drainage	Area (10^3 ha)	Area (%)	Slope (%)	Area (10^3 ha)	Area (%)
Very poorly drained	13,612.5	0.07	0–1	4882.46	2.85
Poorly drained	158,750	0.81	1–3	14971.53	8.73
Imperfectly drained	1,900,800	9.65	3–5	18764.73	10.94
Moderately well drained	3,694,162.5	18.76	5–8	23616.44	13.77
Well Drained	13,603,400	69.08	8–16	39638.29	23.11
Somewhat excessively	320,331.25	1.63	16–30	34873.28	20.34
			>30	34740.36	20.26

Table 4.8: Texture and Slope statistics in Sub-basins

Sub-Basin	Limiting Factors	
	Texture (%)	Mean Slope (%)
Anger	C (91.36), CL (8.64)	13.36
Belles	C (88.17), SCL (0.002), CL (11.83)	11.99
Beshilo	C (30.99), SiC (0.001), SCL (0.04), CL (68.66), L (0.31)	29.81
Dabus	C (64.52), SCL (0.07), CL (35.41)	9.86
Didessa	C (91.70), CL (8.30)	14.28
Dinder	C (84.56), SCL (0.10), CL (15.34)	8.37
Fincha	C (87.76), CL (12.24)	12.78
Guder	C (73.06), SCL (0.02), CL (26.90), L (0.03)	17.83
Jemma	C (67.15), SiCL (0.0004), SCL (0.38), CL (32.45), L (0.02)	20.21
Muger	C (69.55), SiC (0.001), SCL (0.002), CL (30.45)	17.80
North Gojam	C (74.41), SCL (0.02), CL (25.58), L (0.002)	21.72
Rahad	C (81.78), CL (18.22)	15.01
South Gojam	C (90.21), SCL (0.03), CL (9.76)	14.46
Tana	C (96.93), SiC (0.005), SiCL (0.002), CL (3.06)	7.91
Welaka	C (37.91), SCL (0.18), CL (61.89), L (0.02)	23.02
Wonbera	C (79.27), CL (20.73)	16.79

** C: Clay CL: Clay Loam L: Loam SiCL: Silty Clay Loam SCL: Sandy Clay Loam Si: Silty SiC: Silty Clay

The comparison between surface and pressurized systems shows a big difference in the suitability of the different irrigation methods. Additional land of 20,116.16 ha is almost suitable, 861,012.73 ha is Slightly suitable, 1,450,896.95 ha is suitable and 66,269.54 ha is excellent applying sprinkler instead of surface irrigation methods. Drip irrigation could also increase additional land additional land of 14,091.65 ha almost suitable, 4,676,669.50 is Suitable and 208,840.83 ha Excellent; while Slightly suitable area decreases by 32,966.7 ha in the basin. Therefore, Pressurized irrigation systems (sprinkler and drip irrigation systems) are good irrigation methods to apply.

4.2.1. Surface Irrigation

As shown in Tables Table 4.9 and Table 4.10 for surface irrigation the basin area classified as Unsuitable (96.74%), Almost suitable (0.20%), Slightly suitable (1.96%), Suitable (1.06%) and Excellent (0.04%). Total area of land estimated by the analysis that can be developed by surface irrigation is about 639,554 ha. Tana Sub-basin has the highest percentage 10.45 % of its total area followed by Rahad and Fincha sub basins having 7.94% and 7.30%, respectively. Welaka, Beshilo, and Guder are sub-basins with the lowest percentage of surface irrigation potential having 0.60 %, 0.43 % and 0.89 % of their area, respectively.

Table 4.9: Surface Irrigation Suitability of Abay Basin

No.	Class Definition	Area (ha)	Area (%)
1	Unsuitable	18,984,063.74	96.74
2	Almost suitable	39,146.34	0.20
3	Slightly suitable	384,559.83	1.96
4	Suitable	207,444.60	1.06
5	Excellent	8,403.28	0.04

Large areas of suitable Plain lands are available in the lowlands of Rahad, Dinder and Dabus. As shown in Table 4.10 Dinder has 102,650 ha of land suitable followed by Tana, Dabus and Rahad having 85,093 ha, 82,611 ha and 65,468 ha of land suitable for surface irrigation. From the highland part of the basin suitable areas found in Gojjam and North Shewa.

The analysis of the suitability irrigation maps for surface irrigation indicates that the most limiting factor is slope. sub-basins with less slope have more suitable area for surface irrigation. Lake Tana sub-basin leads in the percentage of suitability from its total land with 7.91% mean slope and the topography dominated by flat and undulating plains (Figure 3.2).

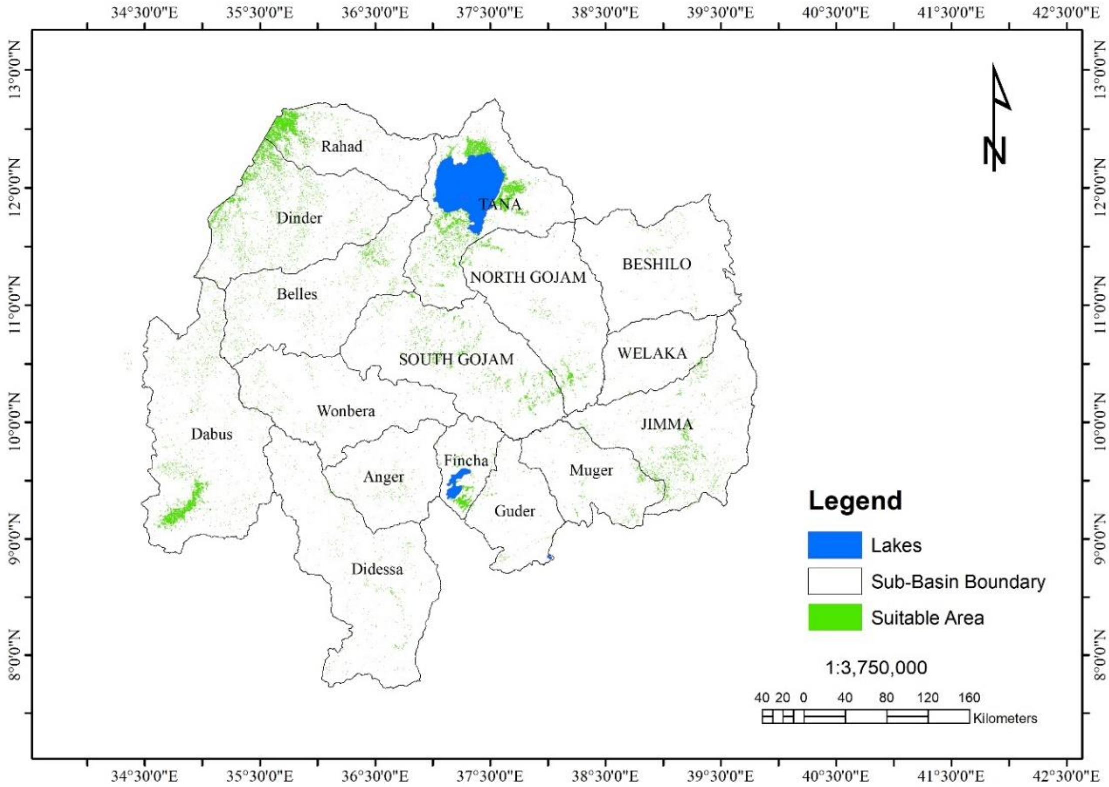


Figure 4.12: Surface Irrigation Suitability Map

Table 4.10: Sub-basin Summary (Surface Irrigation Suitability)

Sub-Basin	Area (1000 ha)						
	Excellent	Suitable	Slightly suitable	Almost suitable	Suitable Total	Unsuitable	Total
Anger	0.078	7.550	1.913	---	9.541	776.463	786.004
Belles	0.181	11.894	22.495	---	34.57	1384.860	1419.430
Beshilo	0.879	3.956	0.802	---	5.637	1293.846	1299.483
Dabus	3.284	28.856	50.471	0.078	82.611	1977.666	2060.354
Didessa	0.052	13.419	5.197	---	18.668	1899.968	1918.636
Dinder	0.750	31.131	70.769	---	102.65	1384.498	1487.147
Fincha	0.052	9.696	17.893	0.905	27.641	362.349	390.895
Guder	0.698	4.783	0.646	---	6.127	686.121	692.249
Jemma	1.319	19.392	30.536	0.026	51.247	1499.352	1550.624
Muger	0.078	9.722	6.154	---	15.954	789.339	805.293
North Gojam	---	6.438	20.013	---	26.451	1412.087	1438.538
Rahad	0.129	15.669	49.670	---	65.468	758.829	824.297
South Gojam	0.052	27.770	24.072	---	51.894	1623.849	1675.743
Tana	---	6.774	78.319	38.086	85.093	1056.124	1179.303
Welaka	0.362	1.758	1.707	0.052	3.827	637.744	641.623
Wonbera	0.259	7.007	2.818	---	10.084	1285.417	1295.501

4.2.2. Sprinkler Irrigation

The basin area Unsuitable (84.52%), Almost suitable (0.30%), Slightly suitable (6.35%), Suitable (8.45%), and Excellent (0.38%) (Table 4.11). An additional area of 20,116.16 ha almost suitable, 861,012.73 ha Slightly suitable 1,450,896.95 ha Suitable and 66,269.54 ha Excellent in the basin if sprinkler irrigation applied rather than surface irrigation.

Table 4.11: Sprinkler Irrigation Suitability of Abay Basin

No.	Class Definition	Area (ha)	Area (%)
1	Unsuitable	16,585,768.38	84.52
2	Almost suitable	59,262.50	0.30
3	Slightly suitable	1,245,572.56	6.35
4	Suitable	1,658,341.55	8.45
5	Excellent	74,672.82	0.38

Tana Sub-basin has the highest percentage 10.45 % of total potential area of the basin followed by Rahad and Fincha sub basins having 7.94% and 7.30%, respectively. Welaka Sub-basin has the lowest percentage 0.60 % of its total area followed by Beshilo and Guder sub basins having 0.43 % and 0.89 %, respectively.

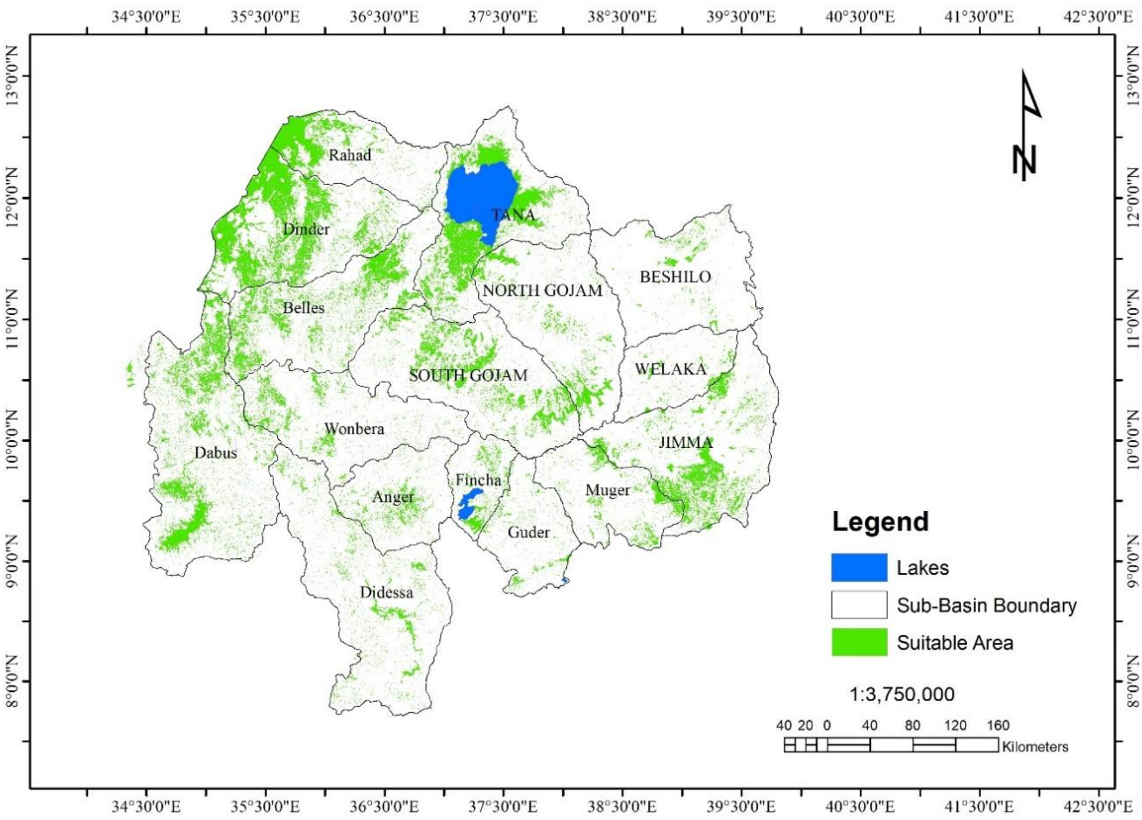


Figure 4.13: Sprinkler Irrigation suitability Map of Abay Basin

The highland area covers about 61.69 %. The highland dominates in Almost suitable (99.38 %) and Slightly suitable (78.09 %) classes; whereas the lowland of the basin makes 56.80 % and 53.12 % of suitable and excellent suitability classes that makes 53.55% of the land found in the lowlands from the total suitable area of the basin.

Table 4.12: Sprinkler Irrigation Suitability of Abay Basin

Sub-Basin	Area (1000 ha)						
	Excellent	Suitable	Slightly suitable	Almost suitable	Suitable Total	Unsuitable	Total
Anger	0.078	7.550	1.913	---	9.541	776.463	786.004
Belles	0.181	11.894	22.495	---	34.57	1384.860	1419.430
Beshilo	0.879	3.956	0.802	---	5.637	1293.846	1299.483
Dabus	3.284	28.856	50.471	0.078	82.689	1977.666	2060.354
Didessa	0.052	13.419	5.197	---	18.668	1899.968	1918.636
Dinder	0.750	31.131	70.769	---	102.65	1384.498	1487.147
Fincha	0.0517	9.6961	17.8925	0.9050	28.5453	362.3493	390.8946
Guder	0.698	4.783	0.646	---	6.127	686.121	692.249
Jemma	1.319	19.392	30.536	0.026	51.273	1499.352	1550.624
Muger	0.078	9.722	6.154	---	15.954	789.339	805.293
North Gojam	0.000	6.438	20.013	---	26.451	1412.087	1438.538
Rahad	0.129	15.669	49.670	---	65.468	758.829	824.297
South Gojam	0.052	27.770	24.072	---	51.894	1623.849	1675.743
Tana	---	6.774	78.319	38.086	123.179	1056.124	1179.303
Welaka	0.362	1.758	1.707	0.052	3.879	637.744	641.623
Wonbera	0.259	7.007	2.818	---	10.084	1285.417	1295.501

4.2.3. Drip Irrigation

For drip irrigation the basin area is Unsuitable (71.94%), Almost suitable (0.27%), Slightly suitable (1.79%), Suitable (24.89%) and Excellent (1.11%). Dinder Sub-basin has the highest percentage 59.12% of its total area followed by Tana and Belles sub basins having 45.56% and 41.78%, respectively. Beshilo Sub-basin has the lowest percentage 6.92% of its total area followed by Welaka and Guder sub basins having 10.11% and 13.36%, respectively.

Table 4.13: Drip Irrigation Suitability with Percentage of Basin Area

No.	Class Definition	Area (ha)	Area (%)
1.	Unsuitable	14,111,429.81	71.89
2.	Almost suitable	12,798.84	0.27
3.	Slightly suitable	155,499.42	0.79
4.	Suitable	4,913,874.63	25.03
5.	Excellent	439,478.48	2.24

Considering the altitude of the area, the highland area covers about 61.69%. The highland dominates in Almost suitable (99.39%), Slightly suitable (62.22%) and excellent (68.44 %) suitability classes; whereas the lowland of the basin makes 58.90% of suitable class. Generally, 56% of the suitable land found in the lowlands of the basin.

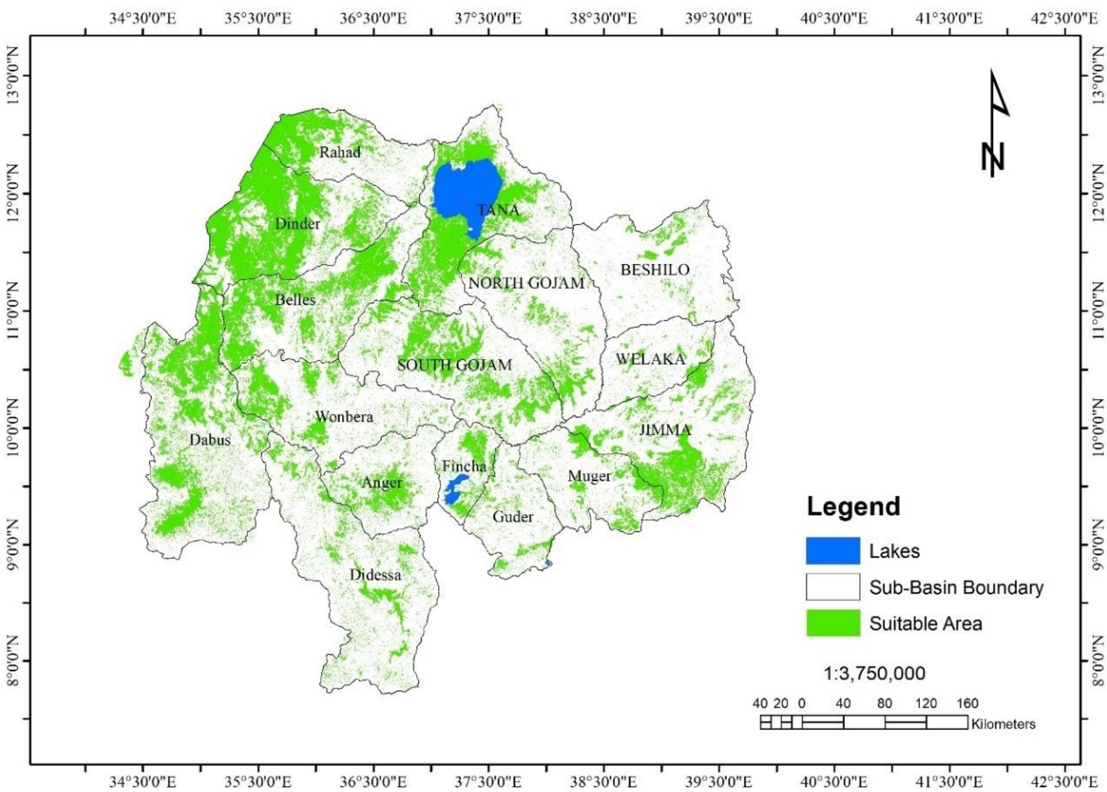


Figure 4.14: Drip Irrigation Suitability Map of Abay Basin

Table 4.14: Drip Irrigation Suitability of Abay Basin

Sub-Basin	Area (1000 ha)						
	Excellent	Suitable	Slightly suitable	Almost suitable	Total Suitable	Unsuitable	Total
Anger	2.068	176.908	0.595	--	179.571	606.432	786.004
Belles	13.600	569.018	10.394	--	593.012	826.417	1419.430
Beshilo	18.099	71.803	0.000	--	89.902	1209.581	1299.483
Dabus	70.200	652.870	22.340	0.078	745.488	1314.867	2060.354
Didessa	1.758	290.986	2.275	0.000	295.019	1623.617	1918.636
Dinder	29.088	837.846	12.308	0.000	879.242	607.906	1487.147
Fincha	0.750	105.752	13.704	1.164	121.37	269.525	390.895
Guder	11.920	73.406	6.904	0.233	92.463	599.787	692.249
Jemma	36.406	265.828	133.677	0.155	436.066	1114.559	1550.624
Muger	0.595	112.009	47.007	0.362	159.973	645.320	805.293
North Gojam	1.655	217.735	5.895	0.026	225.311	1213.226	1438.538
Rahad	4.551	270.999	14.273	0.026	289.849	534.448	824.297
South Gojam	0.905	457.216	18.332	0.052	476.505	1199.238	1675.743
Tana	1.345	424.508	60.374	51.118	537.345	641.959	1179.303
Welaka	13.032	49.903	1.913	0.026	64.874	576.749	641.623
Wonbera	5.947	271.284	0.103	--	277.334	1018.167	1295.501

Using Drip irrigation 4,866,635.28 ha and 2,468,340 ha additional land can be developed when compared with surface and sprinkler irrigation systems. The additional area is 14,091.65 ha almost suitable, 4,676,669.50 ha Suitable and 208,840.83 ha Excellent; while Slightly suitable area decreases by 32,966.7 ha. Similarly, an additional area of 3,225,772.55 ha is Suitable and 142,571.29 ha is Excellent; while almost suitable and slightly suitable area decreases by 6,024.51 ha and 893,979.43 ha respectively when compared with sprinkler irrigation.

The reality of how much pressurized irrigation methods increases the potential illustrated on Lake Tana Sub-basin by Figure 4.15. The suitability analysis result gives a potential land that can be utilized by surface irrigation is 85,093 ha, while 123,179 ha can be irrigated by sprinkler and 537,345 ha by drip irrigation. Thus, more than 38,000 ha of land is additional area suitable for irrigation using sprinkler irrigation method. At the same time greater than 400,000 ha can be developed using drip technology. This is supposed to be greater than the current area irrigated in the whole basin.

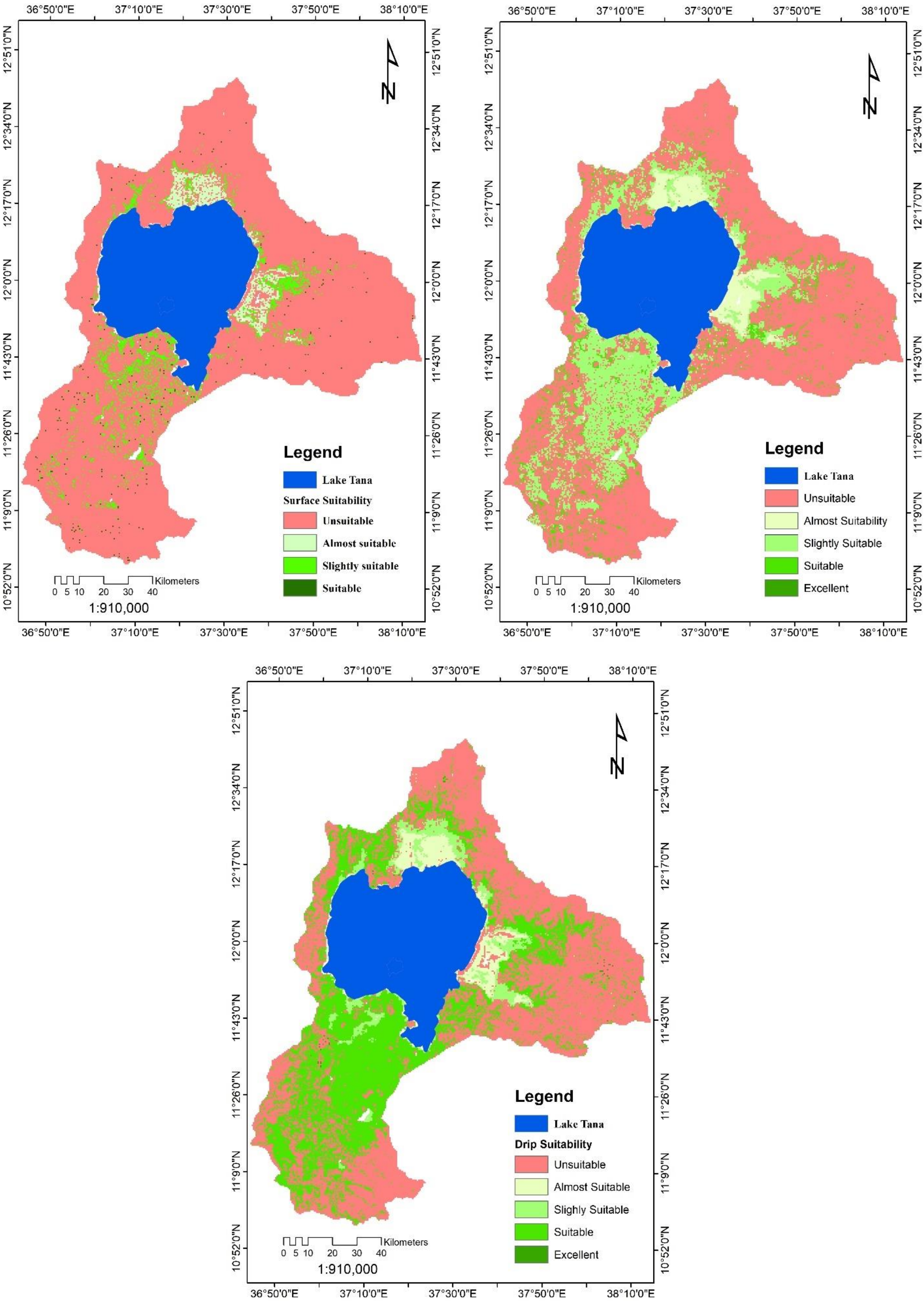


Figure 4.15: A Suitability Map of Lake Tana Sub-basin (Comparison)

4.3. Surface Water Resource Irrigation Potential

Potential irrigable area of each 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 Choke Mountain watersheds.

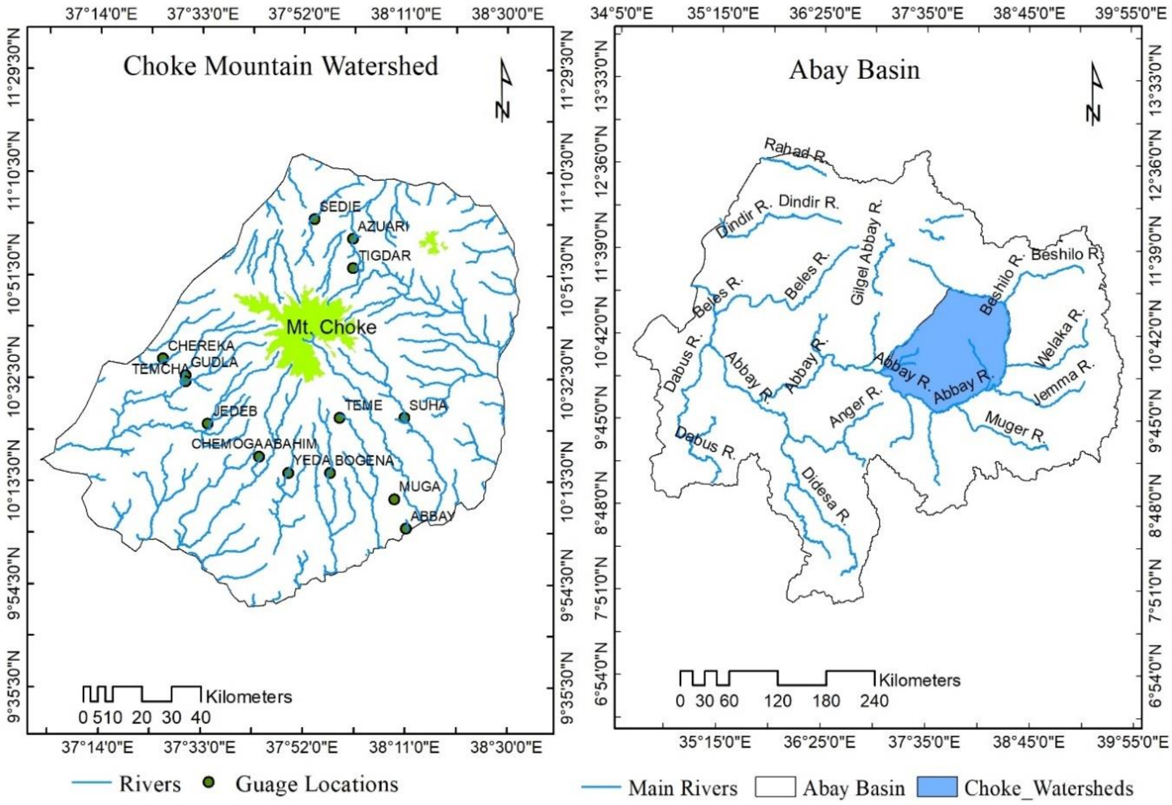


Figure 4.16: Location Map of Choke Mountain Watersheds

4.3.1. Runoff Analysis

The minimum flow for Azuarie, Chemoga, Gudla, Jedeb, Muga, Sede, Suha, Teme, Temcha, Tigder and Yeda Rivers at 80% exceedance probability calculated by Cumfreq software. Missing values filled using an average of adjacent year records. 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 available for irrigation in a sustainable basis and avoid crop failure because of water scarcity.

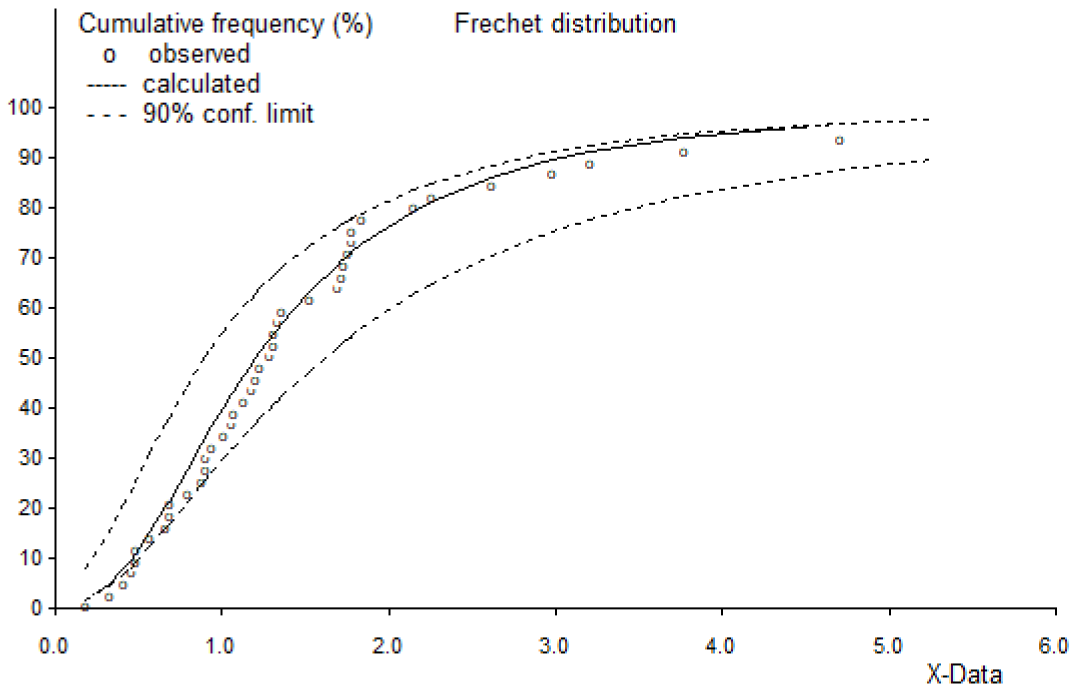


Figure 4.17: Cumulative Curve of Temcha at February

Table 4.15: River flows at 80% exceedance probability

River Name	80% Exceedance Probability (Million m^3)											
	J	F	M	A	M	J	J	A	S	O	N	D
Azuarie	0.491	0.437	0.574	0.444	0.606	1.629	21.033	27.444	9.158	2.929	1.310	0.842
Chemoga	0.423	0.265	0.308	0.292	0.498	1.165	22.627	57.004	20.972	3.794	1.378	0.758
Gudla	0.786	0.434	0.470	0.338	0.681	4.801	58.767	84.114	43.880	9.875	3.112	1.530
Jedeb	1.199	0.694	0.862	0.688	1.246	3.682	36.819	63.777	41.030	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
Sede	0.362	0.207	0.167	0.129	0.277	0.783	13.817	27.336	2.696	3.817	1.244	0.577
Suha	0.298	0.103	0.111	0.097	0.180	0.444	14.005	25.654	5.574	1.433	0.500	0.376
Teme	0.251	0.132	0.115	0.147	0.332	1.005	15.793	16.490	8.856	1.159	0.425	0.293
Temecha	1.355	0.656	0.826	0.491	1.643	5.370	55.854	108.441	45.732	17.172	4.956	2.042
Tigder	0.152	0.090	0.129	0.126	0.278	0.491	7.207	10.992	3.472	0.693	0.257	0.190
Yeda	0.350	0.251	0.166	0.144	0.193	0.120	0.727	4.360	5.063	0.989	0.540	0.659

4.3.2. Irrigation Potential

To calculate the crop water requirement a potential evapotranspiration should be multiplied with Kc of crops grown with irrigation. The crop coefficients for the initial, mid and late seasons and growing period were extracted from the FAO – 66 (Steduto *et al*., 2012). Thus, the weighted mean of Kc values calculated.

Table 4.16: Kc Values for major irrigated crops

Crop	Initial	Development	Mid-season	Late	Total
Maize	25 (0.30)	40 (0.85)	40 (1.2)	35 (0.5)	135
Onion	20(0.7)	45(0.7)	20(1.0)	10(1.0)	95
Potato	25 (0.5)	30 (0.5)	35 (1.15)	30 (0.5)	120
Cabbage	40(0.7)	60(0.7)	50(1.05)	15(0.95)	165

Maize Kc = (25 (0.30) + 40 (0.85) + 40 (1.2) + 35 (0.5))/135

= (7.5 + 34 + 48 + 17.5)/135

= 0.79

Onion kc = 20(0.7) + 45(0.7) + 20(1.0) +10(1.0)/95

= (14 + 31.5 + 20 + 10)/95

= 0.79

Potato Kc = ((25 (0.5) + 30 (0.5) + 35 (1.15) + 30 (0.5))/120

= (12.5 + 15 + 40.25 + 15)/120

= 0.70

Cabbage kc = (40(0.7) + 60(0.7) + 50(1.05) + 15(0.95))/165

= (28 + 42 + 52.5 + 14.25)/165

=0.83

Thus, Kc average of the major crops is **0.78**.

The net irrigation requirement (NIR) is the difference between crop water requirement (CWR) and effective rainfall (P_{eff}). The results gave an indication of the areas that could be irrigated with the available stream flow at the gauge location. About 2100 ha of land can be irrigated at the gauge location of these rivers without further development on the downstream part of these rivers (Table 4.17).

Table 4.17: Irrigable Area by surface water

River	PET (mm)	CWR (mm)	Peff (mm)	IR (mm)	Q (80) (Million m^3)	Irrigable Area (ha)		
						Surface	Sprinkler	Drip
Azuarie	909.47	709.39	13.96	695.43	2.344	202.24	252.79	303.35
Chemoga	940.38	733.50	12.83	720.67	1.754	146.03	182.54	219.05
Gudla	884.34	689.79	6.22	683.57	3.220	471.06	353.29	423.95
Jedeb	880.30	686.63	18.21	668.42	4.797	430.60	538.25	645.90
Muga	925.56	721.94	4.04	717.90	2.159	180.44	225.55	270.66
Sede	899.59	701.68	8.92	692.76	1.313	113.72	142.15	170.58
Suha	910.82	710.44	13.55	696.89	0.888	76.45	95.57	114.68
Teme	916.34	714.75	15.59	699.16	0.791	67.88	84.85	101.82
Temcha	915.47	714.07	16.60	697.47	4.879	419.72	524.65	629.58
Tigder	908.95	708.98	15.34	693.64	0.561	48.53	60.66	72.79
Yeda	962.95	751.10	10.48	740.62	1.426	115.52	144.41	173.29

If sprinkler and drip technology introduced to the area, there could be additional area of 520.94 ha and 1041.88 ha with the available water resource respectively.

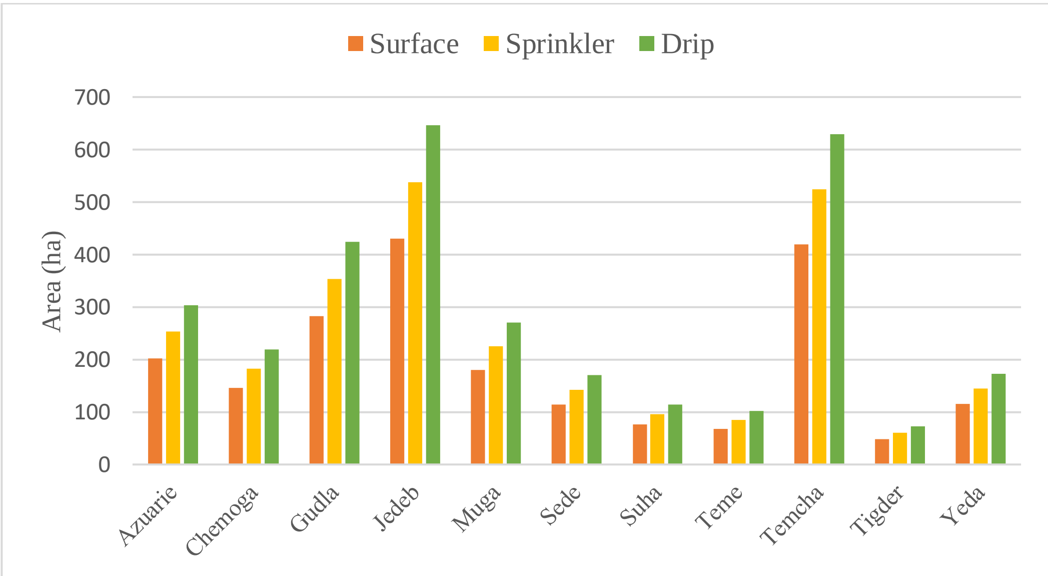


Figure 4.18*:* Irrigation Potential of main rivers in Choke mountain watersheds

As indicated above, Jedeb and Gudla rivers have the highest water resource potential for irrigation. Because of suitability of slope to convey water from the river to irrigation farm Temcha river don't have irrigated areas.

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

From the results obtained and discussed in the preceding section, the following conclusion are made:

Multiresolution segmentation approach combined with assign class algorithm using different indices is capable of identifying both the location and intensity of heterogeneous and patchy irrigated areas, including minor irrigation areas that dominate Ethiopia's agricultural landscape. The overall accuracy of the 91.04% indicated that the method applied is robust

Comparing irrigated areas using remote sensing data with official statistics is difficult because data is not available in a basin wise approach. Sources of differences include; approaches in collecting irrigated area statistics in official statistics, non-clarity in the irrigated areas in its use, under-development, and potential for development in official statistics i.e. only large scale irrigated areas monitored, errors of the remote sensing approach especially the resolution of MODIS to identify non-agricultural lands. Studies that use low resolution images overestimated irrigated areas. It included areas that couldn't be irrigated like turbid waterbodies, areas with high slope and urban or built up areas.

The result shows that 639,554.05 ha of the land was found suitable for surface irrigation, 3,037,849.43 ha for sprinkler irrigation, and 5,506,189.33 ha for drip irrigation. The main limiting factor was physical limitation of high slope and clay dominated soil texture. The potential land and irrigated area found mostly highland part of basin, and Tana sub-basin have been found the most suitable and most utilized one. The study shows the potential is underutilized, only half of the surface irrigation potential have been irrigated so far with 310,707 ha.

The hydrologic analysis done to surface water irrigation potential estimated about 2100 ha of land can be irrigated by surface irrigation at the gauge location of rivers in Choke mountain watersheds without further development on the downstream part of these rivers. More than 500 ha and 1000 ha additional land can be irrigated using sprinkler and drip irrigation. 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, irrigated area information and water resources potential for large areas with short period of time and limited budget.

5.2. Recommendation

It was difficult to estimate irrigated areas due to the high fragmentation of arable land, smallholder management and dispersed irrigation times and concentrated at high altitude areas of the basin. Based on the results of this study the following points are recommended for further consideration:

- When using optical imagery, frequent cloud cover in tropical areas negatively impacts these methods, so methods based on the use of RADAR data are preferred in these areas.
- Low resolution imagery either underestimate or overestimate extent of features; using time series high resolution imagery is recommended when masking out non-agricultural features.
- Both remote sensing and national statistical approaches require further refinement to estimate more accurately. Web based analysis of time series of high resolution imagery like Google Earth Engine may be exploited to refine remote sensing estimate.
- Because of the insufficiency of water resources sprinkle and drip irrigation methods are highly recommended for a sustainable use of this natural resource; hence, the changing of current irrigation methods from surface to pressurized for better performance.
- The concept of land suitability requires analysis for the services delivered by the land that is valued by society thus further research should be done to improve the results.

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APPENDICES

Appendix 1: Rating Tables for Parametric Evaluation

Table 7.1: Rating of Soil Texture (Original)

Tex*	Rating for surface irrigation					Rating for sprinkler irrigation					Rating for drip irrigation				
	Fine gravel (%)			Coarse gravel (%)		Fine gravel (%)			Coarse gravel (%)		Fine gravel (%)			Coarse gravel (%)	
	<15	15–40	40–75	15–40	40–75	<15	15–40	40–75	15–40	40–75	<15	15–40	40–75	15–40	40–75
CL**	100	90	80	80	50	100	90	80	80	50	100	90	80	80	50
SiCL	100	90	80	80	50	100	90	80	80	50	100	90	80	80	50
SCL	95	85	75	75	45	95	85	75	75	45	95	85	75	75	45
L	90	80	70	70	45	90	80	70	70	45	90	80	70	70	45
SiL	90	80	70	70	45	90	80	70	70	45	90	80	70	70	45
Si	90	80	70	70	45	90	80	70	70	45	90	80	70	70	45
SiC	85	95	80	80	40	85	95	80	80	40	85	95	80	80	40
C	85	95	80	80	40	85	95	80	80	40	85	95	80	80	40
SC	80	90	75	75	35	95	90	80	75	35	95	90	85	80	35
SL	75	65	60	60	35	90	75	70	70	35	95	85	80	75	35
LS	55	50	45	45	25	70	65	50	55	30	85	75	55	60	35
S	30	25	25	25	25	50	45	40	30	30	70	65	50	35	35

* Tex: Textural Classes.

** CL: Clay Loam SiCL: Silty Clay Loam SCL: Sandy Clay Loam L: Loam SiL: Silty Loam Si: Silty SiC: Silty Clay C: Clay SC: Sandy Clay SL: Sandy Loam LS: Loamy Sand S: Sandy.

Due to lack of separate data availability of fine gravel and coarse gravel data, the average value is used using Coarse fragment data downloaded from ISRIC.

Table 7.2: Rating of soil Texture (Adapted)

Tex*	Surface Irrigation			Sprinkler Irrigation			Drip Irrigation		
	Coarse Fragment (%)			Coarse Fragment (%)			Coarse Fragment (%)		
	<15	15 – 40	40 – 90	<15	15 – 40	40 –90	<15	15– 40	40 –90
CL**	100	85	65	100	85	65	100	85	65
SiCL	100	85	65	100	85	65	100	85	65
SCL	95	80	60	95	80	60	95	80	60
L	90	75	57.5	90	75	57.5	90	75	57.5
SiC	85	87.5	60	85	87.5	60	85	87.5	60
C	85	87.5	60	85	87.5	60	85	87.5	60

Table 7.3: Rating of Soil Depth for Irrigation

Soil depth (cm)	surface irrigation	sprinkler irrigation	drip irrigation
<20	25	30	35
20–50	60	65	70
50–80	80	85	90
80–100	90	95	100
>100	100	100	100

Table 7.4: Rating of CaCo3 for irrigation

$CaCo_3$ (%)	surface irrigation	sprinkler irrigation	drip irrigation
<0.3	90	90	90
0.3–10	95	95	95
10–25	100	100	95
25–50	90	90	80
>50	80	80	70

Table 7.5: Rating of slope for irrigation

Slope Classes (%)	surface irrigation		sprinkler irrigation		drip irrigation	
	Non-terraced	Terraced	Non-terraced	Terraced	Non-terraced	Terraced
0–1	100	100	100	100	100	100
1–3	95	95	100	100	100	100
3–5	90	95	95	100	100	100
5–8	80	90	85	95	90	100
8–16	70	80	75	85	80	90
16–30	50	65	55	70	60	75
>30	30	45	35	50	40	55

Table 7.6: Rating of salinity for irrigation

EC ($ds.m^{-1}$)	surface irrigation		sprinkler irrigation		drip irrigation	
	*C, SiC, SiCL, S, SC	Other Textures	*C, SiC, SiCL, S, SC	Other Textures	*C, SiC, SiCL, S, SC	Other Textures
<4	100	100	100	100	100	100
4–8	90	95	95	95	95	95
8–16	80	50	85	50	85	50
16–30	70	30	75	35	75	35
>30	60	20	65	25	65	25

* C: Clay SiC: Silty Clay SiCL: Silty Clay Loam S: Sand SC: Sandy Clay.

Table 7.7: Rating of Drainage Classes for Irrigation

Drainage classes	surface irrigation		sprinkler irrigation		drip irrigation	
	C, SiC, SiCL, S, SC textures	Other textures	C, SiC, SiCL, S, SC textures	Other textures	C, SiC, SiCL, S, SC textures	Other textures
Well drained	100	100	100	100	100	100
Moderately drained	80	90	90	95	100	100
Imperfectly drained	70	80	75	85	80	90
Poorly drained	60	65	65	70	70	80
Very poorly drained	40	65	45	65	50	65
Drainage status not known	70	80	70	80	70	80

* C: Clay SiC: Silty Clay SiCL: Silty Clay Loam S: Sand SC: Sandy Clay.

Table 7.8: Suitability classes for the irrigation capability indices

Capability index	Class	Definition
>80	I	Excellent
60–80	II	Suitable
45–59	III	Slightly suitable
30–44	IV	Almost suitable
<30	V	Unsuitable

Appendix 2: USDA Soil Texture Triangle

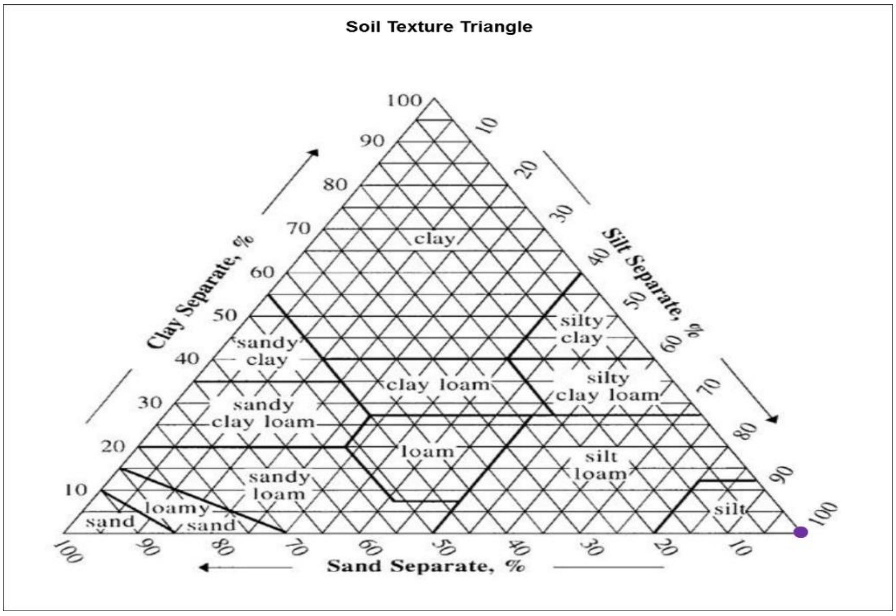

Figure. 7.0.1: USDA Soil Texture Triangle

Table 7.9: USDA soil texture classification

<table>
<tr><th></th><th>Basics</th><th>Texture</th></tr>
<tr><td>1</td><td>((silt + 1.5*clay) < 15)</td><td>SAND</td></tr>
<tr><td>2</td><td>((silt + 1.5*clay >= 15) && (silt + 2*clay < 30))</td><td>LOAMY SAND</td></tr>
<tr><td>3</td><td>((clay >= 7 && clay < 20) && (sand > 52) && ((silt + 2*clay) >= 30) || (clay < 7 && silt < 50 && (silt+2*clay)>=30))</td><td>SANDY LOAM</td></tr>
<tr><td>4</td><td>((clay >= 7 && clay < 27) && (silt >= 28 && silt < 50) && (sand <= 52))</td><td>LOAM</td></tr>
<tr><td>5</td><td>((silt >= 50 && (clay >= 12 && clay < 27)) || ((silt >= 50 && silt < 80) && clay < 12))</td><td>SILT LOAM</td></tr>
<tr><td>6</td><td>(silt >= 80 && clay < 12)</td><td>SILT</td></tr>
<tr><td>7</td><td>((clay >= 20 && clay < 35) && (silt < 28) && (sand > 45))</td><td>SANDY CLAY LOAM</td></tr>
<tr><td>8</td><td>((clay >= 27 && clay < 40) && (sand > 20 && sand <= 45))</td><td>CLAY LOAM</td></tr>
<tr><td>9</td><td>((clay >= 27 && clay < 40) && (sand <= 20))</td><td>SILTY CLAY LOAM</td></tr>
<tr><td>10</td><td>(clay >= 35 && sand > 45)</td><td>SANDY CLAY</td></tr>
<tr><td>11</td><td>(clay >= 40 && silt >= 40)</td><td>SILTY CLAY</td></tr>
<tr><td>12</td><td>(clay >= 40 && sand <= 45 && silt < 40)</td><td>CLAY</td></tr>
</table>

Appendix 3: *SAGA-GIS* Soil Texture Classification Interpretation

Derived soil texture classes with USDA scheme from sand, silt and clay contents.

Output Number	**Texture**
1	Clay
2	Silty Clay
3	Silty Clay Loam
4	Sandy Clay
5	Sandy Clay Loam
6	Clay Loam
7	Silt
8	Silt Loam
9	Loam
10	Sand
11	Loamy Sand
12	Sandy Loam

Appendix 4: Irrigated crop calendar of Ethiopia

Table 7.10: Irrigated Crop Calendar of Ethiopia

Irrigated crops	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Wheat												
Maize												
Barley												
Vegetables												
Bananas												
Citrus												
Fruits												
Groundnuts												
Potatoes and other tubers												
Pulses												
Sugarcane												
Cotton												

Source: Irrigated crop calendar by (FAO, 2012).

Appendix 5: Summary of Hydrometric Discharge Data (Million m^3)

Station Name: Azuarie **Nr. /@Motta**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1982	1.150	0.745	0.897	0.598	1.440	0.695	12.010	40.810	12.840	11.010	1.890	1.420
1983	0.920	0.756	0.687	0.531	0.868	1.060	10.530	72.820	14.700	9.860	2.220	1.210
1984	0.871	0.637	0.662	0.508	1.310	17.590	35.310	23.930	15.450	2.230	1.590	1.210
1985	0.919	0.609	0.416	0.487	1.170	1.560	25.620	55.040	21.740	4.320	1.200	0.940
1986	0.718	0.528	0.492	0.575	0.331	5.490	34.250	24.500	16.260	4.830	1.230	0.901
1987	0.667	0.499	0.932	0.609	3.410	3.300	11.980	24.300	6.010	1.310	1.400	1.100
1988	1.000	1.110	0.690	0.610	0.703	1.940	35.430	73.350	17.600	12.290	2.220	1.130
1989	0.963	0.937	1.320	0.676	1.380	1.300	30.700	26.240	10.325	12.890	1.090	0.791
1990	0.750	0.615	0.830	0.778	0.632	2.590	22.510	21.110	3.050	2.270	1.720	1.720
1991	1.710	1.290	1.540	1.860	2.530	3.030	24.090	56.695	23.120	7.690	1.420	0.648
1992	0.598	0.570	0.780	1.360	2.100	5.940	60.340	92.280	11.700	32.620	9.250	1.800
1993	0.964	0.661	0.989	2.560	4.852	13.932	60.823	40.185	14.929	6.522	2.525	15.289
1994	0.737	0.567	0.658	0.559	3.287	10.091	57.553	103.876	8.925	2.050	1.612	1.020
1995	0.643	0.349	0.487	0.476	2.501	2.472	76.867	46.696	11.448	3.915	1.403	1.252
1996	1.100	0.638	0.844	2.178	4.619	8.446	54.496	65.191	22.186	8.925	3.044	1.925
1997	1.153	0.515	0.848	3.341	2.881	11.302	67.447	35.948	13.993	10.865	14.210	4.405
1998	3.078	1.653	1.177	0.411	0.454	2.824	39.847	78.015	12.345	49.305	3.514	0.824
1999	41.899	0.521	0.133	0.206	0.623	2.489	51.546	76.476	16.414	28.659	3.282	1.419
2000	0.853	0.340	0.095	1.551	1.165	2.409	32.876	69.554	13.583	10.698	2.553	2.113
2001	3.194	0.400	0.412	1.362	0.710	4.104	49.260	72.996	9.842	21.345	1.824	2.113
2002	3.194	0.460	0.730	1.173	0.254	5.799	55.340	68.222	14.582	9.472	3.154	1.137

Station Name: Chemoga **Nr. /@ Debre Markos**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1960	1.038	0.731	1.104	1.156	1.814	4.615	53.450	89.660	36.390	5.580	1.730	1.450
1961	0.630	0.530	0.590	3.140	2.440	3.450	69.460	94.840	49.350	33.220	4.330	2.700
1962	1.460	0.820	1.660	1.290	1.470	1.450	25.300	83.500	54.350	19.240	1.980	1.350
1963	1.200	0.860	0.740	1.240	2.110	1.960	36.700	95.880	73.190	5.480	2.390	9.250
1964	3.050	2.230	1.620	1.310	1.580	5.030	77.930	96.080	69.920	29.180	2.510	2.980
1965	1.492	1.121	0.792	1.493	0.746	0.781	23.668	85.713	19.242	9.644	2.264	5.600
1966	1.810	1.510	1.160	0.973	0.814	1.610	20.320	77.500	59.800	3.300	1.730	1.140
1967	0.729	0.518	0.818	0.572	1.560	0.757	39.490	81.660	44.710	26.030	4.790	2.140
1968	1.251	1.016	0.846	0.973	0.977	7.230	41.020	69.330	45.150	12.640	2.129	1.277
1969	1.526	3.068	13.500	3.313	4.938	3.402	41.860	85.320	41.000	3.949	1.510	0.985
1970	0.795	0.593	0.924	0.922	0.472	0.895	32.107	97.628	29.993	9.036	1.758	1.048
1971	0.910	0.541	0.573	0.476	0.985	5.703	47.040	85.550	25.400	8.420	3.878	1.530
1972	1.261	0.745	0.788	0.928	1.414	0.998	18.710	51.320	17.100	3.366	1.615	0.896
1973	0.537	0.312	0.258	0.328	1.083	1.658	28.140	50.030	26.850	7.908	1.840	0.886
1974	0.720	0.418	0.935	0.494	1.143	2.622	27.642	53.172	18.270	4.616	1.816	0.969
1975	0.627	1.101	0.490	0.304	0.392	6.461	35.060	70.860	46.340	8.630	1.957	1.393
1976	1.648	1.218	1.729	1.297	2.593	6.560	53.700	63.810	19.680	5.020	8.010	2.215
1977	1.130	0.933	1.860	0.677	1.470	15.030	8.190	78.910	49.570	20.400	10.580	1.810
1978	0.933	0.366	0.797	0.467	0.826	1.566	26.580	67.030	54.040	36.810	2.607	1.620
1979	0.391	1.001	0.767	0.919	0.887	3.066	45.995	69.865	42.790	5.600	1.366	0.727
1980	0.459	0.615	0.530	1.152	0.948	4.565	65.410	72.700	39.360	6.499	1.631	0.675
1981	0.389	0.084	1.090	1.020	0.967	0.500	31.490	59.350	32.900	7.200	1.910	0.947
1982	4.050	1.060	1.060	0.664	1.034	1.110	16.510	54.230	17.370	14.880	4.240	2.530
1983	0.877	0.812	0.320	0.307	1.100	1.500	9.100	84.830	52.680	16.070	8.260	2.100
1984	1.160	0.459	0.425	0.127	1.020	14.080	57.830	54.290	33.760	3.550	1.330	0.896
1985	0.394	0.154	0.091	0.813	0.399	2.330	39.160	71.350	32.580	5.510	1.300	0.758
1986	0.166	0.120	0.378	0.488	0.029	4.050	34.730	52.680	34.530	3.340	0.500	0.339
1987	0.615	0.228	3.120	1.600	7.450	11.210	30.620	81.950	18.480	6.630	1.630	12.750
1988	0.709	0.825	0.337	0.103	0.184	1.190	21.070	128.800	50.740	18.140	1.089	0.808
1989	0.474	0.695	0.533	2.710	0.766	1.194	47.950	73.390	24.340	5.070	0.547	1.600
1990	1.055	0.453	0.136	0.398	1.911	1.518	43.700	64.520	31.750	10.120	1.462	1.201
1991	0.446	0.510	0.823	3.672	3.055	15.220	101.200	134.900	38.180	1.490	1.488	2.024
1992	0.777	1.681	1.930	1.317	1.046	1.390	21.960	60.240	61.010	9.884	4.849	1.777
1993	1.302	1.123	1.004	4.786	11.630	23.950	57.040	105.100	77.980	16.510	4.003	1.529
1994	0.634	0.326	0.078	0.266	0.917	1.256	20.736	53.951	2.097	0.964	0.113	0.000
1995	0.000	0.000	0.000	0.014	0.182	0.025	11.978	28.061	10.149	0.375	0.000	0.180
1996	2.512	1.078	0.819	5.600	10.526	14.894	46.559	59.164	28.560	4.958	2.244	1.357
1997	0.806	0.125	0.139	0.465	0.634	3.792	32.596	56.678	19.566	10.610	7.513	2.564
1998	1.406	0.485	0.534	0.082	2.405	3.607	39.363	46.233	34.902	36.128	3.213	0.768
1999	0.557	0.140	0.026	0.021	0.127	2.799	41.393	78.764	32.366	36.097	2.597	0.962
2000	0.451	0.129	0.265	0.248	0.629	4.590	50.213	84.230	24.294	30.682	10.361	1.797
2001	0.652	0.441	0.601	0.407	1.132	6.381	59.033	89.696	16.222	4.442	1.242	0.760
2002	1.605	0.274	1.300	1.169	0.194	2.455	33.652	58.356	12.369	8.564	1.025	0.257

Station Name: Gudla Nr. /@Dembecha

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1960	2.930	1.360	0.990	0.610	1.990	2.450	74.370	83.240	54.710	12.030	3.020	1.590
1961	0.780	0.660	0.640	0.940	0.510	1.380	83.700	100.255	87.210	34.120	5.540	5.260
1962	1.330	0.490	0.680	0.390	1.010	14.710	90.780	117.270	89.320	25.300	4.260	2.220
1963	1.240	0.600	0.510	0.850	3.670	9.140	116.510	140.430	72.090	19.070	18.700	25.360
1964	3.460	1.540	0.780	0.780	3.460	25.120	154.900	130.600	80.400	51.600	7.440	4.730
1965	1.660	1.110	0.900	0.980	0.620	3.010	34.270	86.120	36.790	26.170	9.100	6.890
1966	2.320	1.500	1.240	0.861	1.050	8.360	54.900	103.200	36.900	7.040	3.910	2.050
1967	1.180	0.740	1.190	0.820	1.530	4.030	75.910	107.180	70.360	29.150	6.230	3.440
1968	1.390	0.960	0.780	0.760	1.640	16.440	75.460	89.380	48.090	25.280	3.940	2.380
1969	1.950	1.390	2.750	2.210	2.380	4.090	59.800	140.300	44.580	6.880	4.480	1.760
1970	0.920	0.580	0.640	0.680	0.670	3.090	57.300	114.100	56.150	25.170	5.150	2.020
1971	1.190	0.660	0.650	0.460	1.410	10.700	63.820	82.970	50.430	12.490	5.520	2.040
1972	1.390	0.760	0.590	0.570	0.650	2.860	39.410	54.160	38.060	8.600	11.450	2.740
1973	1.180	0.575	0.455	0.372	2.520	15.900	69.280	105.060	56.950	28.520	5.960	2.220
1974	1.110	0.627	0.755	0.363	3.278	14.830	76.700	93.400	46.720	12.500	3.410	1.390
1975	0.810	0.920	0.557	0.433	0.440	13.800	84.800	132.900	77.770	12.420	4.340	2.300
1976	0.910	0.702	0.639	0.318	2.410	12.084	70.340	88.200	76.740	11.110	8.420	2.860
1977	0.946	0.610	0.773	0.390	2.930	16.450	114.490	99.320	62.560	54.900	12.590	3.790
1978	1.705	0.754	0.770	0.586	1.377	9.940	64.720	78.600	52.420	24.820	5.910	3.740
1979	1.720	0.750	0.665	0.452	1.708	27.100	60.810	84.980	71.980	12.320	4.080	1.880
1980	0.860	0.780	0.589	0.776	0.956	3.530	84.890	101.300	49.460	14.680	4.070	2.000
1981	0.892	0.518	0.526	0.453	2.680	8.090	76.810	92.880	55.840	13.190	3.980	1.270
1982	0.900	0.490	0.520	0.360	1.010	1.620	40.940	92.140	87.670	40.580	4.580	2.200
1983	0.920	0.640	0.680	0.420	0.740	2.570	36.660	86.980	39.680	11.860	5.700	2.200
1984	0.920	0.460	0.400	0.310	0.850	17.480	20.000	105.920	56.880	8.900	2.680	2.240
1985	0.910	0.470	0.440	0.620	0.920	5.240	96.080	126.840	83.200	12.940	2.830	1.600
1986	0.696	0.340	0.532	0.547	0.494	14.160	113.900	69.520	52.870	16.520	2.920	1.400
1987	0.918	0.410	0.728	0.460	12.000	51.350	101.200	108.600	48.250	12.130	4.010	2.640
1988	1.140	0.584	0.391	0.266	0.517	11.560	172.900	147.000	46.220	23.540	5.340	1.610
1989	0.577	0.250	0.463	0.558	2.430	7.595	71.310	94.990	47.610	13.550	3.170	3.080
1990	1.520	0.716	0.492	0.428	0.628	3.630	117.905	69.940	45.730	10.660	1.700	0.732
1991	0.395	0.174	0.217	0.247	0.657	46.690	164.500	143.500	80.450	17.810	3.430	1.380
1992	0.539	0.310	0.672	10.120	3.000	46.870	123.900	159.300	106.200	52.010	2.630	1.980
1993	1.039	0.727	0.620	3.885	9.404	32.170	134.000	105.000	98.394	32.540	6.191	2.082
1994	0.885	0.423	0.678	0.223	11.603	74.650	114.026	105.000	90.588	10.992	5.092	1.583
1995	0.392	0.118	0.429	2.172	13.430	34.250	94.052	112.040	75.566	7.490	2.449	1.422
1996	1.766	0.270	4.276	4.121	15.258	54.377	162.720	115.150	35.245	12.162	3.399	1.622
1997	1.469	0.775	1.693	2.264	9.213	48.973	147.161	104.348	53.155	54.213	26.093	5.412
1998	1.788	0.525	1.445	0.407	3.169	43.568	131.601	166.822	86.639	64.105	6.875	1.905
1999	1.704	0.735	0.395	0.326	2.614	25.597	85.921	86.349	54.995	62.602	6.744	2.614
2000	1.430	0.548	0.324	1.689	2.100	46.520	92.794	75.207	62.643	58.978	11.796	3.307
2001	1.437	0.789	1.692	0.567	2.207	25.325	81.979	98.191	34.196	13.663	5.224	2.537
2002	2.238	0.624	0.719	0.640	0.495	30.758	119.376	108.408	47.883	7.585	3.172	3.721
2003	1.274	0.466	1.528	0.403	0.166	25.740	111.193	112.928	61.618	23.539	5.989	3.051

Station Name: Jedeb **Nr. /@Amanuel**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1960	3.780	3.570	3.400	2.080	2.520	4.200	50.710	78.450	41.830	14.690	3.710	2.550
1961	1.390	1.150	1.000	2.380	1.380	3.290	93.890	129.460	78.300	47.600	7.060	4.770
1962	2.520	1.460	1.700	0.960	1.660	3.500	44.860	89.970	59.890	28.910	4.040	2.420
1963	1.670	1.220	1.140	1.450	3.420	6.280	43.890	97.930	73.660	11.050	5.620	12.810
1964	4.620	5.140	2.000	2.170	2.010	13.190	68.840	90.410	60.520	36.380	5.700	4.970
1965	2.570	1.700	1.400	1.470	1.200	1.490	26.210	93.940	48.680	21.490	9.320	15.950
1966	1.330	1.100	1.110	1.140	0.796	2.770	21.500	74.300	54.200	7.910	3.620	2.140
1967	1.560	1.160	1.800	1.240	1.960	2.369	53.220	69.400	62.270	42.580	6.900	3.390
1968	2.120	1.690	1.570	1.400	1.640	9.530	45.740	74.770	51.190	24.700	4.900	2.970
1969	3.230	2.820	1.610	4.360	4.440	5.630	49.500	84.910	39.120	8.080	3.380	2.160
1970	1.580	1.120	1.500	1.490	1.150	2.520	40.640	105.090	70.450	32.810	11.990	18.290
1971	5.900	3.900	3.980	2.800	4.710	23.760	88.630	96.290	52.660	27.030	17.580	7.100
1972	2.940	1.440	0.960	1.320	1.820	3.890	35.870	67.930	52.830	11.680	10.150	3.410
1973	2.050	0.787	0.419	0.682	2.223	8.256	41.770	72.070	60.050	19.540	6.220	3.180
1974	1.396	0.696	1.269	0.905	6.086	10.040	63.020	104.310	45.900	18.700	4.810	1.730
1975	1.183	1.460	1.042	0.536	0.552	5.572	29.370	148.280	82.750	17.240	5.650	3.690
1976	2.520	1.460	2.020	0.993	5.638	14.520	69.860	104.770	47.880	9.550	13.600	3.860
1977	2.100	1.710	1.060	0.769	2.900	12.390	68.790	104.780	70.220	37.620	19.650	7.540
1978	2.670	1.060	1.172	0.881	1.920	8.742	75.920	110.760	92.890	43.910	12.125	4.885
1979	1.916	1.580	1.866	0.682	2.271	7.891	70.890	91.440	67.340	14.060	4.600	2.230
1980	1.162	1.398	1.091	1.793	2.621	7.040	65.860	72.120	54.080	27.790	6.200	4.000
1981	2.020	0.840	1.140	0.890	2.010	3.210	38.420	122.290	101.100	34.650	5.680	1.850
1982	3.360	1.620	1.230	0.549	3.130	2.330	52.550	74.920	82.640	34.890	9.920	4.680
1983	2.630	1.387	0.727	0.350	6.690	4.460	19.860	119.920	92.640	26.280	8.400	2.370
1984	1.900	0.956	0.725	0.561	1.590	16.490	57.570	69.400	42.440	6.540	3.180	2.190
1985	1.048	0.650	0.357	0.535	1.560	5.270	46.570	70.625	45.920	13.210	4.070	2.390
1986	1.070	0.744	0.803	0.453	0.596	10.530	46.380	71.850	79.540	12.200	3.030	1.800
1987	1.040	0.762	2.160	1.210	7.380	23.110	53.000	76.050	24.500	18.470	4.300	2.270
1988	1.110	0.712	1.882	1.835	4.212	14.035	52.030	62.430	27.225	12.332	2.468	3.720
1989	1.625	0.661	1.603	2.459	1.044	4.960	42.388	48.809	29.950	6.194	0.636	6.864
1990	0.395	1.163	0.623	1.151	0.982	3.645	50.994	57.786	56.841	11.539	3.691	1.748
1991	1.311	0.570	1.390	5.257	2.342	11.746	68.209	119.718	85.449	12.213	3.388	2.458
1992	1.267	0.277	0.019	0.362	3.348	8.091	41.834	78.980	59.566	35.009	15.387	19.798
1993	2.733	1.880	1.226	4.975	13.654	27.796	84.814	131.490	136.304	73.298	26.758	20.245
1994	5.079	3.062	2.432	1.998	7.578	20.657	57.558	93.477	53.821	10.073	4.182	2.492
1995	2.303	1.991	2.298	4.199	9.160	8.799	54.360	45.265	39.087	12.958	6.497	4.421
1996	2.303	0.919	2.164	5.082	8.886	8.799	51.162	51.800	42.148	19.745	7.378	7.411
1997	6.469	5.028	5.040	6.638	8.612	11.033	39.887	49.830	28.850	16.099	18.113	13.760
1998	2.894	2.019	1.339	1.120	1.672	2.187	24.305	61.297	64.303	57.890	8.711	5.466
1999	5.029	3.316	2.537	2.211	3.028	7.956	34.442	51.625	28.838	22.221	6.158	3.115
2000	1.367	0.714	1.547	1.800	3.427	8.799	51.633	85.474	59.697	13.900	4.029	5.455
2001	1.078	0.446	1.547	1.800	3.427	8.799	51.633	85.474	59.697	5.579	1.899	5.455
2002	0.789	0.177	0.610	0.447	0.122	8.799	51.633	85.474	59.697	23.022	7.493	0.550

Station Name: Muga **Nr. /@Dejen**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1980	1.010	1.048	0.748	1.450	3.215	3.910	55.550	51.850	19.200	12.230	2.020	1.170
1981	0.887	0.510	0.940	0.930	1.920	0.989	37.330	57.870	40.390	8.390	1.500	1.130
1982	0.846	0.543	2.114	1.050	3.020	1.010	12.040	50.300	21.340	22.130	2.540	1.800
1983	0.805	0.575	0.603	0.395	0.668	2.120	44.450	76.020	27.800	5.960	2.580	1.110
1984	0.623	0.360	0.331	0.232	1.620	18.340	36.080	35.500	32.400	2.350	1.060	1.000
1985	0.564	0.334	0.350	1.020	2.690	1.400	27.710	50.520	31.300	4.970	1.100	0.873
1986	0.602	0.388	0.688	0.876	0.460	14.430	39.240	58.840	34.570	6.230	0.970	0.705
1987	0.424	0.290	2.730	1.890	10.460	12.770	15.880	52.130	6.050	2.370	0.899	1.380
1988	0.661	0.872	0.231	0.302	6.095	1.090	58.940	118.500	40.180	24.770	2.450	0.493
1989	0.546	0.795	4.550	4.350	1.730	4.360	39.675	56.970	22.590	3.050	0.472	10.100
1990	1.440	2.300	1.740	1.310	1.550	0.581	20.410	44.490	24.490	4.130	0.715	0.526
1991	0.391	0.218	0.504	0.201	0.348	1.110	57.410	80.590	24.690	2.550	1.370	0.895
1992	0.715	0.752	0.515	1.980	2.680	1.120	15.910	57.190	29.780	12.830	1.940	1.250
1993	1.106	0.376	0.266	6.046	8.584	7.642	58.810	40.710	34.120	14.880	1.993	0.576
1994	0.612	0.425	0.548	0.406	1.471	3.818	89.615	123.037	39.157	4.145	1.955	1.273
1995	1.216	0.485	0.565	1.297	2.271	1.790	30.532	69.220	25.515	3.848	2.565	1.655
1996	3.817	1.196	1.275	1.742	13.581	5.758	39.750	69.220	25.515	3.552	2.565	1.655
1997	0.968	0.511	1.192	2.187	2.207	9.726	48.969	59.471	6.954	22.051	7.966	2.757
1998	1.152	2.854	0.884	1.335	5.218	6.220	49.361	113.828	32.063	58.854	3.958	1.829
1999	1.337	5.196	0.577	0.483	0.699	1.921	49.753	87.349	15.061	43.352	2.390	1.159
2000	1.146	2.885	1.133	0.859	1.170	3.483	51.741	79.251	20.111	17.439	13.068	1.724
2001	0.956	0.573	1.690	1.235	1.642	14.345	119.258	105.005	22.659	5.121	1.887	1.359
2002	1.401	0.625	3.184	2.759	0.653	2.284	32.403	54.208	10.908	2.136	1.038	1.651

Station Name: Sede Nr. /@ Motta

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	0.645	0.386	0.348	0.489	1.040	2.719	8.610	14.650	6.420	3.650	1.940	1.250
1988	0.976	0.699	0.679	0.512	1.040	0.774	28.320	36.930	23.240	13.720	2.840	1.710
1989	0.758	0.513	0.438	0.465	0.788	0.629	18.590	29.800	14.550	5.710	2.000	2.170
1990	0.414	0.350	0.238	0.198	0.188	1.072	20.553	113.623	92.146	4.918	0.524	0.328
1991	0.273	0.192	0.216	0.196	0.252	1.302	68.532	64.266	63.263	13.153	3.070	3.824
1992	0.952	0.661	0.589	0.663	2.266	1.531	5.901	49.421	34.379	21.388	5.616	1.272
1993	0.554	0.297	0.299	1.967	3.014	6.899	41.966	34.765	8.780	5.198	1.996	0.485
1994	0.327	0.224	0.219	0.185	1.164	2.627	96.146	162.217	49.564	2.110	0.754	0.433
1995	0.239	0.229	0.220	0.123	1.163	0.756	30.272	54.416	17.487	3.577	0.879	0.628
1996	0.530	0.299	0.568	0.602	3.153	8.318	94.939	160.912	26.083	7.973	1.941	0.769
1997	0.481	0.253	0.320	0.281	0.450	7.582	90.243	58.227	23.751	14.047	5.226	1.036
1998	0.501	0.200	0.127	0.058	0.665	1.359	19.248	38.413	15.539	23.409	2.987	1.005
1999	0.470	0.167	0.074	0.073	0.185	1.109	20.128	37.347	13.077	20.657	3.404	1.239
2000	0.736	0.325	0.196	1.025	0.467	0.529	25.354	32.838	10.229	20.719	5.968	1.677
2001	1.820	0.996	0.684	0.500	0.664	4.545	133.276	210.397	30.906	22.529	4.055	1.325
2002	0.564	0.826	0.312	0.428	0.137	1.751	38.789	45.524	26.124	9.256	5.621	0.658

Station Name: Suha Nr. /@ Bichena

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1985	0.461	0.340	0.038	0.302	1.050	0.539	15.570	18.970	9.470	2.820	0.934	0.687
1986	0.466	0.414	0.392	0.298	0.253	2.980	32.450	58.970	22.470	5.330	1.160	5.860
1987	0.587	0.220	1.760	0.656	3.580	5.090	6.230	41.720	3.990	1.440	0.678	0.526
1988	0.432	0.825	0.167	0.054	0.024	0.393	34.750	48.350	26.330	9.660	1.370	0.416
1989	0.240	0.169	1.630	3.060	1.800	0.854	18.840	31.530	12.000	2.150	0.629	2.600
1990	0.615	0.757	0.369	0.237	0.429	0.237	15.390	20.510	4.400	2.580	0.373	0.305
1991	0.233	0.028	0.180	0.094	0.164	0.489	24.360	60.170	8.200	1.680	0.523	1.013
1992	0.364	1.476	0.334	0.287	0.418	0.267	7.850	47.570	23.780	3.468	0.768	1.013
1993	0.300	0.234	0.062	2.991	1.098	13.629	35.750	22.520	17.612	5.255	1.013	0.361
1994	0.237	0.143	0.554	0.095	0.675	3.465	39.793	44.875	19.909	2.599	0.870	0.509
1995	0.608	0.174	0.554	0.817	2.440	0.616	20.860	34.985	14.533	1.747	0.664	0.611
1996	0.979	0.204	0.535	1.538	3.307	6.937	25.337	36.031	9.253	1.728	1.555	0.672
1997	0.517	0.228	0.275	0.516	0.921	4.224	29.815	32.312	4.321	12.661	3.504	0.935
1998	0.427	0.356	0.495	0.137	3.455	6.704	34.798	46.033	19.913	20.240	1.997	0.777
1999	0.686	0.146	0.062	0.048	0.180	1.644	22.400	32.055	8.170	22.038	1.614	0.727
2000	0.344	0.089	0.070	0.115	0.546	0.750	23.194	32.911	9.313	8.117	3.597	0.890
2001	0.379	0.261	1.829	0.361	0.618	5.341	42.201	43.512	14.410	1.583	0.583	0.289
2002	0.423	0.061	0.663	0.799	0.061	0.853	13.713	24.155	4.420	0.635	0.167	0.041

Station Name: Teme Nr. /@Motta

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1985	0.358	0.355	0.208	0.245	1.120	1.740	12.460	21.760	6.680	2.220	0.779	0.532
1986	0.339	0.177	0.135	0.207	0.089	3.770	20.050	14.980	11.320	2.820	0.389	0.152
1987	0.168	0.154	0.179	0.363	2.660	6.470	10.560	17.020	3.390	1.790	1.610	0.527
1988	0.340	0.279	0.000	0.004	0.094	0.656	32.120	34.660	6.640	6.680	0.861	0.224
1989	0.056	0.026	0.688	0.546	0.698	0.832	17.370	22.680	8.570	1.540	0.280	1.600
1990	0.571	0.490	0.179	0.268	0.358	1.126	45.077	210.912	13.107	0.825	0.459	0.272
1991	0.067	0.222	0.649	0.428	0.781	0.908	75.081	68.931	11.728	0.316	0.179	0.119
1992	0.900	0.208	0.227	1.060	1.858	3.686	10.426	47.572	6.689	7.263	1.990	0.839
1993	0.950	0.531	0.661	2.741	2.343	3.502	37.688	11.616	13.049	4.006	1.609	0.691
1994	0.511	0.620	0.730	0.623	5.070	5.212	43.138	57.700	10.979	0.916	0.641	0.515
1995	0.304	0.176	0.321	0.240	1.638	0.942	67.923	17.207	5.591	2.675	1.183	0.719
1996	0.762	0.313	0.365	1.108	3.774	7.513	36.563	34.626	13.151	4.435	1.726	0.924
1997	0.648	0.220	0.868	1.506	1.357	7.509	27.428	15.159	6.819	8.541	5.864	1.660
1998	1.079	0.345	0.619	0.157	0.952	6.465	24.865	36.800	10.333	29.828	3.837	0.826
1999	0.670	0.198	0.072	0.065	0.548	1.386	25.403	33.597	8.826	11.098	1.741	0.651
2000	0.473	0.094	0.118	1.198	0.918	2.090	26.773	27.570	6.145	8.830	4.060	1.275
2001	0.676	0.315	0.328	0.363	0.531	6.576	37.934	54.964	8.509	3.116	1.402	0.548
2002	0.489	0.163	0.430	0.332	0.159	3.442	15.333	27.544	7.164	1.052	0.396	0.442

Station Name: Temecha Nr. /@ Dembecha

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1960	7.210	3.770	3.280	1.620	4.820	4.230	113.293	184.957	94.690	26.500	4.910	3.660
1961	1.980	1.730	1.910	4.030	1.770	4.160	118.380	188.010	130.230	62.100	19.510	14.320
1962	2.250	0.880	2.520	1.270	5.600	15.870	75.740	116.920	82.160	39.980	8.320	5.070
1963	2.970	1.720	1.710	4.060	8.220	9.420	82.580	153.700	83.170	21.840	12.910	21.990
1964	7.280	5.270	3.250	2.780	3.380	19.640	121.800	129.900	72.080	50.620	11.300	7.140
1965	3.690	2.248	2.024	2.664	1.478	3.128	29.200	102.930	62.470	29.910	14.060	13.500
1966	5.140	4.710	3.880	3.170	3.360	7.610	42.000	102.000	69.100	14.900	8.020	5.380
1967	1.277	0.790	2.149	1.016	2.465	4.380	82.460	109.140	82.570	49.060	13.450	6.651
1968	2.557	1.747	1.390	1.506	2.397	16.070	81.340	133.180	83.410	37.980	5.806	3.802
1969	3.829	3.198	6.309	4.105	6.064	7.094	72.830	160.810	63.190	15.220	6.153	2.245
1970	1.209	0.678	0.953	0.888	1.041	4.203	99.370	187.292	116.231	56.884	10.520	3.805
1971	2.174	1.068	1.049	0.711	3.641	31.477	107.600	137.400	79.380	33.110	15.290	5.560
1972	2.530	1.330	0.950	1.130	1.340	4.110	55.280	124.200	70.380	12.380	13.960	4.010
1973	2.890	1.059	0.555	0.453	4.270	23.120	70.460	188.240	102.670	29.200	4.510	1.960
1974	1.540	1.203	1.512	0.536	3.939	17.830	108.120	322.200	74.820	27.150	4.550	2.810
1975	1.660	1.690	1.029	0.834	1.016	15.218	123.500	544.200	338.900	58.900	6.160	3.350
1976	2.180	1.520	1.227	0.457	1.615	40.160	157.050	322.460	184.260	24.060	15.440	0.715
1977	1.980	1.230	1.200	0.568	1.770	18.640	265.690	196.860	215.970	116.580	32.720	6.700
1978	2.081	1.133	0.933	0.728	1.198	13.690	116.340	213.290	85.970	52.958	7.903	4.032
1979	2.484	1.283	1.012	0.638	5.516	9.937	65.470	165.850	141.100	19.411	5.048	2.570
1980	1.670	1.310	1.300	2.050	3.390	6.930	114.470	202.210	144.330	16.960	5.160	3.290
1981	2.120	1.010	0.789	0.535	4.230	6.460	98.600	115.640	102.270	18.330	5.670	2.450
1982	1.944	0.900	0.952	0.360	2.938	4.080	52.033	153.395	86.601	49.760	8.072	3.135
1983	2.950	1.840	1.600	0.667	1.900	5.140	108.857	233.970	83.350	23.230	12.520	4.890
1984	2.350	2.980	0.810	0.379	1.930	2.600	165.680	190.630	170.450	9.120	4.000	2.970
1985	0.670	0.184	0.055	0.125	1.820	4.980	193.940	140.990	160.250	25.400	5.770	3.240
1986	1.190	0.319	0.433	0.455	6.920	21.100	312.760	120.550	12.460	38.040	6.530	4.040
1987	1.130	0.480	1.380	0.778	10.690	109.370	333.190	442.640	187.110	22.890	7.220	6.000
1988	1.100	0.450	0.187	0.035	0.058	14.700	419.300	564.200	11.800	67.330	7.970	3.020
1989	1.240	0.664	1.540	2.200	5.220	8.638	153.900	259.300	203.500	40.180	9.010	7.840
1990	2.069	1.309	1.055	0.672	1.458	2.576	30.477	69.053	49.819	19.575	3.734	1.539
1991	0.789	0.483	1.135	0.295	3.627	12.170	72.837	74.107	55.126	10.906	3.957	2.618
1992	2.560	0.902	1.214	1.367	2.846	21.764	54.130	93.495	60.432	20.519	15.156	7.727
1993	4.331	2.153	1.571	1.367	4.508	27.314	76.470	185.031	57.945	30.132	8.038	2.329
1994	2.644	1.364	0.506	0.538	5.521	37.172	64.712	185.031	55.457	9.841	6.309	2.297
1995	0.956	0.574	1.616	1.367	3.584	16.092	52.954	185.031	47.633	11.192	4.626	2.672
1996	1.733	1.171	1.616	1.367	3.584	17.855	50.843	185.031	42.846	20.195	15.570	6.964
1997	2.509	1.769	2.826	3.994	7.920	19.618	48.732	67.430	38.059	29.197	26.513	11.256
1998	5.531	2.611	4.270	1.552	5.978	24.928	76.574	79.343	53.206	52.188	6.042	2.164
1999	3.048	1.777	1.616	1.367	3.584	16.933	62.743	70.553	38.234	43.835	4.969	0.666
2000	1.646	0.943	1.616	1.367	3.584	16.956	113.293	185.031	40.527	37.951	7.467	1.286
2001	1.636	0.675	1.616	1.367	3.584	16.956	113.293	185.031	42.821	32.068	9.965	1.905
2002	1.626	0.406	0.936	1.415	0.347	44.778	113.293	184.957	94.690	33.514	9.638	4.847

Station Name: Tigder Nr. /@ Gumde-Woin

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1982	0.444	0.586	0.572	0.267	0.434	1.695	14.833	18.331	5.917	3.390	0.678	0.350
1983	0.277	0.212	0.191	0.121	0.245	0.316	4.020	19.770	7.620	1.490	0.553	0.258
1984	0.151	0.073	0.063	0.048	0.111	2.800	11.220	6.620	3.880	1.303	0.427	0.227
1985	0.424	0.293	0.393	0.257	0.276	0.308	5.405	14.535	5.079	1.116	0.301	0.196
1986	0.131	0.305	0.534	0.873	0.611	3.719	14.259	10.376	4.907	2.150	0.322	0.232
1987	0.154	0.100	0.262	0.175	2.040	1.130	3.090	8.250	2.750	0.696	0.422	0.269
1988	0.207	0.175	0.669	0.919	1.050	1.370	14.740	15.250	4.500	4.400	0.571	0.318
1989	0.238	0.123	0.234	0.204	0.308	0.226	7.450	9.520	4.430	1.030	0.298	1.030
1990	0.282	0.430	0.171	0.086	0.159	0.199	7.350	12.730	2.700	0.634	0.238	0.161
1991	0.137	0.080	0.109	0.048	0.078	0.436	18.960	24.030	2.900	0.467	0.138	0.128
1992	0.117	0.096	0.064	0.280	0.553	0.309	4.380	24.130	4.960	6.420	1.420	0.721
1993	0.405	0.189	0.176	0.684	1.662	2.978	21.240	13.490	14.470	3.370	0.765	0.360
1994	0.251	0.137	0.124	0.086	0.561	4.051	23.721	26.978	7.322	0.605	0.282	0.180
1995	0.102	0.260	0.344	0.364	0.822	1.278	13.687	19.900	8.190	0.838	0.346	0.255
1996	0.238	0.082	0.332	0.795	1.026	1.683	18.421	25.578	5.865	1.569	0.319	0.205
1997	0.183	0.084	0.173	0.941	0.870	2.487	29.707	9.785	2.377	4.637	2.550	0.549
1998	0.254	0.115	0.245	0.441	0.885	1.749	24.066	26.846	11.619	18.490	1.354	0.465
1999	0.396	0.163	0.251	0.479	0.650	1.016	21.570	21.450	8.376	10.864	1.021	0.429
2000	0.246	0.340	0.806	1.159	0.988	1.226	16.277	24.922	5.122	5.566	1.545	0.525
2001	0.274	0.227	1.070	0.977	0.935	5.135	25.166	23.752	6.352	1.642	0.477	0.282
2002	0.268	0.091	1.291	1.129	0.797	1.478	11.929	28.708	4.919	0.511	0.220	0.206

Station Name: Yeda Nr.@ Amber

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988	0.744	0.665	0.484	0.594	0.003	0.152	0.625	4.270	4.240	1.839	0.355	0.231
1989	0.096	0.058	0.100	0.042	0.062	0.069	1.900	6.340	1.200	0.486	0.390	0.391
1990	0.369	1.323	0.468	0.347	0.347	0.331	1.109	5.360	9.348	2.080	1.002	0.732
1991	0.642	0.530	0.469	0.389	0.394	0.529	1.514	3.874	9.348	0.559	0.529	1.096
1992	0.451	0.399	0.282	0.239	0.236	0.296	0.829	4.121	9.348	1.478	0.931	1.096
1993	0.25	0.085	0.094	0.091	0.204	0.669	1.033	4.894	4.790	2.396	1.333	1.075
1994	3.092	2.728	2.884	2.447	1.416	3.264	12.203	20.354	15.381	4.196	2.188	1.922
1995	1.682	0.978	0.160	0.130	0.120	0.156	4.042	14.079	6.005	1.127	0.509	0.700
1996	0.468	0.221	0.143	0.154	0.502	1.968	8.225	14.340	8.024	2.054	0.863	0.727
1997	0.644	0.481	0.406	0.335	0.552	2.953	9.477	14.600	7.193	3.242	2.509	1.743
1998	0.599	0.449	0.472	0.369	0.514	1.014	13.771	18.410	20.469	19.193	4.156	2.759
1999	0.553	0.418	0.372	0.252	0.289	1.278	8.554	12.806	8.430	7.041	1.618	0.885
2000	0.503	1.012	0.289	2.719	0.459	1.723	13.495	14.454	11.283	7.691	2.545	0.941
2001	0.600	0.426	0.415	0.393	0.395	0.391	1.749	15.814	22.676	10.923	3.710	0.836
2002	0.462	0.206	0.227	0.404	0.665	8.286	18.100	8.122	2.479	1.538	1.359	1.311