



Addis Ababa University
Addis Ababa Institute of Technology
School of Graduate Studies
School of Civil and Environmental Engineering
Assessment and evaluation of surface water potential
and demands in Baro-Akobo river basin, Ethiopia.

By

Muhammed Alkasim

Advisor: - Dr.Ing. Geremew Sahilu, School of Civil and Environmental Engineering, Addis Ababa University, Ethiopia

June 2016



Addis Ababa University
Addis Ababa Institute of Technology
School of Graduate Studies
School of Civil and Environmental Engineering
Assessment and evaluation of surface water potential
and demands in Baro-Akobo river basin, Ethiopia.

By

Muhammed Alkasim

Advisor: - Dr.Ing. Geremew Sahilu, School of Civil and Environmental Engineering, Addis Ababa University, Ethiopia

Addis Ababa,

Ethiopia
June 2016

Addis Ababa University
School of Graduate Studies
Addis Ababa Institute of Technology

**Assessment and evaluation of surface water potential
and demands in Baro-Akobo river basin, Ethiopia.**

A thesis submitted and presented to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the Degree of Masters of Science in Civil and Environmental Engineering (Hydraulic Engineering Major)

By

Muhammed Alkasim

Approval by Board of Examiners

----- Advisor	----- Signature	----- Date
----- Internal examiner	----- Signature	----- Date
----- External examiner	----- Signature	----- Date
----- Chair man (Department of Graduate Committee)	----- Signature	----- Date

DECLARATION

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Addis Ababa University, I grant to Addis Ababa University the nonexclusive royalty-free right to archive, reproduce, distribute and display the thesis in any and all forms, including electronic format, via any digital library mechanisms maintained by AAU.

I represent and warrant this is my original work, and does not infringe or violate any rights of others.

I acknowledge that I retain ownership rights to the copyright of this work, including but not limited to the right to use all or part of this work in future works, such as articles or books.

Library users are granted permission for individual, research and non-commercial reproduction of this work for educational purposes only. Any further digital posting of this document requires specific permission from the author.

Any copying or publication of this thesis for commercial purposes, or for financial gain, is not allowed without my written permission.

ACKNOWLEDGMENT

It is my great pleasure to be grateful to my advisor Dr.Ing Geremew Sahilu; His much needed Encouragement has been with me from the conception up to the birth of this thesis. I would like to thank him again for his valuable suggestions and advice in improving the manuscript.

I am very grateful to the School of Civil & Environmental Engineering, Institute of Technology, Addis Ababa University, for facilitating my work. I would like to thank all of Hydraulics Engineering department staffs who gave me the post-graduate courses.

I would like to express my deepest love and respect to my parents, families and friends for their endless support throughout my school time.

Finally, I would like to thank Ministry of Water & Energy, particularly for staff members under the Department of Hydrology, GIS and Library and National Metrological Agency (NMA).

ABSTRACT

Baro- Akobo river basin is located in the southwest part of Ethiopia. The objective of this paper is to assess surface water potential using SWAT model and estimation of water demands using the Water Evaluation and Planning (WEAP) model in the Baro-Akobo Basin.

According to the result obtained from SWAT model, the basin receives a mean annual rainfall of 1701.6 mm, which is 115.6BM³. The mean annual actual evapotranspiration is 30.8BM³ or 27% of the mean annual rainfall of the basin. The mean annual surface runoff that leaves from the basin is 19BM³ that corresponds to 279.68 mm. Out of the mean annual rainfall of 115.6BM³ and the other 18.6BM³ that is 273.71mm flows as lateral flow. The remaining 2.4BM³ is lost due to percolation for the recharging of the deep aquifer and 42.17BM³ revap from the shallow aquifer and flows as return flow.

For calibration, the model was run for a period of six years and the monthly calibration results for R² and NS were 0.83 and 0.56 respectively that are acceptable by the given ranges. For model validation, the model was run for a period of six years and the model validation results on monthly time step shows the results of R² and NS values were 0.81 and 0.67 respectively which is acceptable by the given ranges too.

The water demand estimation portion of this study was done for six water supply, three hydropower and seven irrigation projects in the basin. The water demand result shows there is no shortage of water supply for scenario year 2015 to 2030. The annual overall demand is 4.085BMC. The annual demand for irrigation projects is 4.077BMC. The water demand found by this analysis is about 21.5% of the total surface water potential of 19BMC of surface water potential per year.

The SWAT model is very sensitive and needs accurate input data. Using sufficient time and input data the model can simulate good result, which fits the observed stream flow data. In addition to this up to date land use and management data is essential for SWAT model. More efforts required to find best estimation of the surface water potential using SWAT model.

The water demands in the basin is very small so further investigation is essential to use the available surface water potential of the basin.

Key words: SWAT model, WEAP model, SWAT-CUP, surface runoff and water demands.

TABLE OF CONTENTS

DECLARATION.....	ii
ACKNOWLEDGMENT.....	iii
ABSTRACT.....	iv
LIST OF TABLES.....	viii
LIST OF FIGURES.....	ix
LIST OF ABBREVIATIONS.....	x
CHAPTER ONE.....	1
1.1. General Introduction.....	1
1.2. Statement of the Problem.....	1
1.3. Research Questions.....	2
1.4. Objective.....	2
1.4.1. General Objective.....	2
1.4.2. Specific Objectives.....	2
1.5. Scope of the Study.....	2
1.6. Outline of the Thesis.....	3
CHAPTER TWO.....	4
2. Literature Review.....	4
2.1. Water resources.....	4
2.1.1 Surface Water Potential.....	5
2.1.2 Water Resources in Ethiopia.....	5
2.2 water demand and use.....	7
2.2.1 Domestic water demand.....	8
2.2.2 Agricultural water demand.....	10
2.3 Water Resources Assessment.....	11
2.4 Water Resources Assessment Models.....	12
2.5 An over view of Rainfall Runoff Model.....	14
CHAPTER THREE.....	17
3. Materials and Methods.....	17
3.1. Description of the Study Area.....	17
3.2. Climate and topography.....	19
3.2.1. Rainfall.....	19
3.2.2. Topography and Slope.....	20
3.2.3. Land Use and Land Cover.....	22

3.2.4. Soil Types	26
3.3. Methodology and Materials Used	29
3.3.1. Materials Used.....	29
3.3.2. Methods	29
3.3.3. Model Selection Criteria	30
3.3.4. Description of SWAT Model	32
3.4. SWAT Model Inputs	37
3.4.1. Digital Elevation Model.....	37
3.4.2. Land Use Land Cover Data.....	38
3.4.3. Hydro-Meteorological data	40
3.4.4. Weather Generator	42
3.5 Analysis and Gap-Filling	43
3.5.1 Rainfall Data Screening	43
3.5.2 Missing Data Completion	44
3.5.3 Consistency of recording stations	46
3.5.4 Outlier Tests for precipitation data	49
3.5.4 Stream flow Data Screening	51
3.5.5 Outlier Tests for river flow data	52
3.6. SWAT Model Set Up.....	54
3.6.1. Watershed Delineation	54
3.6.2. Hydrological Response Units	54
3.7. Calibration and Validation of SWAT Model.....	54
3.7.1. SWAT-CUP	55
3.7. 2 Calibration of Model	55
3.7.3. Validation of SWAT Model.....	56
3.7.4. SUFI-2.....	57
3.7.5. Model Performance Evaluation	58
CHAPTER FOUR.....	60
4. Assessment of Water Demands in the Basin.....	60
4.1 Introduction	60
4.2 Irrigation water demands	61
4.3 Domestic water demands	62
4.4 Hydropower water demands.....	63
4.5 Environmental water demand.....	64

4.6. Method of Data Collection	64
4.6.1 Water supply data	66
4.6.2 Reservoir and irrigation input data.....	66
4.6.3 Input data hydropower generation for dam site	66
4.7 Method of Data Analysis	69
4.8. WEAP Model Input and Setup	69
4.8. 1. Description of Water Evaluation and Planning (WEAP) Model	69
4.8.2. Water evaluation and planning system (WEAP Model Setup)	72
4.9. WEAP Model Input.....	73
4.9.1. Demand Sites.....	73
4.9.2. Connecting the Demand with Supply	74
4.9.3. Creating the Return Flow Links.....	74
CHAPTER FIVE.....	75
5. Results and Discussions	75
5.1. Surface Water potential.....	75
5.1.1 Results on Surface Water Availability	75
5.1.2 Model Calibration and Validation.....	77
5.1.3 Comparison of Result with Previous Studies in the Study Area	83
5.2 Results on Water Demand.....	85
5.2.1. Demand analysis result for irrigation project	86
5.2.2 Demand analysis result for towns Water supply	90
5.2 .3 Cattle demand.....	95
5.2.3 Hydropower Water Demand	95
5.3 Comparison of demand and potential.....	98
CHAPTER SIX.....	100
6. Conclusion and Recommendation	100
6.1. Conclusions	100
6.2. Recommendations	101
7. REFERENCE.....	102
8. APPENDIXES.....	106
APENDEIX A.....	106
APENDIX B.....	125
APENDIX C.....	138
APENDIX D.....	140

LIST OF TABLES

Table2. 1 Surface water potential and coverage area of Ethiopian river basins.	7
Table 3. 1 Slope classes by area.	21
Table 3. 2 Comparisons of models for selection.....	31
Table 3. 3 Description of metrological stations with percentage missed data.	44
Table 3. 4 Regression equations for metrological stations missed data filling.....	46
Table 3. 5 Average Precipitation data at the stations.....	50
Table 3. 6 Description of the Stream flow recording stations with percentage missed.....	52
Table 3. 7 Average annual river flow data at Gambella station.....	53
Table4. 1 irrigation area and annual water use.	62
Table4. 2 Average monthly river flow data for town demands.....	63
Table4. 3 water supply input data for project in the basin.	66
Table4. 4 Input data for hydropower generation dams and net evaporation.	67
Table 5. 1 Average monthly basin values.....	76
Table 5. 2 Average annual basin values.	76
Table 5. 3 Model efficiencies parameters in calibration and validation periods.....	78
Table 5. 4 Most sensitive parameters.....	82
Table 5. 5 irrigation projects annual water demand (Billion M ³).....	86
Table 5. 6 Average monthly water demand for irrigation projects.....	87
Table 5. 7 Irrigation projects Monthly Average Supply Requirement.	89
Table 5. 8 Annual water demands for different towns.....	90
Table 5. 9 Monthly average water demands for different towns.....	91
Table 5. 10 monthly Average Supply Requirements.....	92
Table 5. 11 Monthly demand site coverage	93
Table 5. 12 Annual demand site coverage	94
Table 5. 13 average monthly water demand for cattles.....	95
Table 5. 14 Monthly averages Hydropower Demand.....	96
Table 5. 15 Hydropower coverage	97
Table 5. 16 Total monthly surface water potential and demands.	98

LIST OF FIGURES

Figure2. 1 Ethiopian river basins map.	6
Figure2. 2 Hydrological cycle, Chow et al. (1988).	14
Figure3. 1 Location of the study area.	18
Figure3. 2 average monthly basin rainfall.	19
Figure 3. 3 Slopes of the study area derived from the DEM value in percentage.....	22
Figure3. 4 Landscape of upper water Sori River near Mettu 2011.	23
Figure3. 5 Land use and/Cover in baro-akobo river basin derived from land sat image.	25
Figure3. 6 Hydrological Soil group of the basin derived from the DEM.....	27
Figure3. 7 Hydrologic cycle consider by SWAT model (from Neitsch et al.2001).	37
Figure3. 8 Digital elevation model for baro akobo river basin extracted from Ethio DEM90.	38
Figure3. 9 Land use/cover of Baro-Akobo river basin derived from land sat image.	39
Figure3. 10 Soil map of Baro-Akobo river basin.	40
Figure3. 11 Itang metrological station.	41
Figure3. 12 Baro-Akobo metrological gauging station.....	41
Figure3. 13 Average Monthly Rainfall Data (mm/day) series for years 1992 to 2013	43
Figure3. 14 double mass curves for the stations.	48
Figure3. 15 schematic of the linkage between SWAT and five optimization programs.....	55
Figure3. 16 The SWAT-CUP Dialog box showing calibrated data sheet.....	56
Figure 4. 1 HP dam volume elevation curves	68
Figure 4. 2 Demand sites in schematic view.....	73
Figure 5. 1 General SWAT model result.....	77
Figure 5. 2 Model calibration periods (1994-1999).....	79
Figure 5. 3 Model validation graphs.....	80
Figure 5. 4 Graphical view of sensitive parameters generated from SWAT-CUP.	83
Figure 5. 5 Graphical view of WEAP model output.....	85
Figure 5. 6 Irrigation projects annual water demand.....	87
Figure 5. 7 Monthly average water demand for irrigation projects.....	88
Figure 5. 8 Irrigation projects Monthly Average Supply Requirement.....	89
Figure 5. 9 monthly Average Supply Requirements.....	92
Figure 5. 10 Monthly demand site coverage.....	93
Figure 5. 11 Annual demand site coverage.....	94
Figure 5. 12 average monthly water demand for cattles.....	95
Figure 5. 13 Monthly average Hydropower Demand.....	96
Figure 5. 14 Hydropower coverage.....	97
Figure 5. 15 Comparison of total demand and potential.....	99

LIST OF ABBREVIATIONS

Hr	hour
Km	Kilometer
Ha	hectare
Km ²	Square kilometer
M ³	Cubic meter
M ³ /sec	Cubic Meter per Second
MW	Mega Watt
GWh	Giga Watt hours
GMT	Green witch mean time
MCM	Million Cubic Meter
BMC	Billion Cubic Meter
m.a.s.l	Meter above sea level
R ²	Coefficient of Determination
PET	Potential evapotranspiration
SWAT	Soil and Water assessment tool
NS	Nash-Sutcliffe(1970) coefficient
DEM	Digital elevation model
GIS	Geographic Information System
NMA	National Meteorological Agency
NMSA	National Metrological Service Agency
IAHS	International Association of Hydrological Science
GPCC	Global Precipitation Climatology Center
WEAP	Water evaluation and planning model
EEPCO	Ethiopian Electric Power Corporation Organization
SWAT-CUP	SWAT Calibration and Uncertainty Programs
GloVIS	Global Visualization Viewer
ETcrop	Crop Evapotranspiration
ETo	Reference Crop Evapotranspiration
FAO	Food and Agricultural Organization
GIS	Geographic Information System
GPS	Global Positioning System
Ha	Hectare
IRg	Gross Irrigation Requirement

IWR	Irrigation Water Requirement
Kc	Crop coefficients
MCM	million cubic meters
MOWR	Ministry of Water Resource
RH	Relative humidity
RF	Rainfall
ICID	International commission on irrigation and drainage
LPCD	liter per capita per day
Kcal	Kilo caloric
amsl	above mean sea level
REVAPMN	Threshold depth of water in the shallow aquifer for "revap" to occur
SOL_K	Saturated hydraulic conductivity
SOL_ZMX	Maximum rooting depth of soil profile
GW_DELAY	Groundwater delay
SOL_ALB	Moist soil albedo
BIOMIX	Biological mixing efficient
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur
SOL_AWC	Available water capacity of the soil layer
CN2	SCS runoff curve number
EPCO	Plant uptake compensation factor
ESCO	Soil evaporation compensation factor
SOL_Z	Depth from soil surface to bottom of layer
GW_REVAP	Groundwater "revap" coefficient
ALPHA_BF	Base flow alpha factor

CHAPTER ONE

1.1. General Introduction

The successful realization of any water resources activity is vital to a country like Ethiopia for the development of the national economy. The proper planning, design, construction and operation of water resource uses are therefore, essential.

Among the twelve river basins in Ethiopia, the Baro-Akobo basin has abundant water resources, which up to now have not been developed to any significant level. The Baro-Akobo basin has of great-unrealized potential, under-populated by Ethiopian standards, and with plenty of land and water. The abundance of water combined with the relief of the basin, from the high plateau at above 2,500m elevation down to the Gambella plain at an altitude of 430m provides favorable conditions for hydropower in this region.

For that reason, this study would be helpful on one hand for proper utilization and management of the basin, and on the other hand for reasonable share and allocation of the water of this trans-boundary river for future negotiation with the riparian countries, (TAMS & ULG annex 1 ,1997).

1.2. Statement of the Problem

Baro-Akobo river basin is the second next to Genale-Dawa from all basins in Ethiopia regarding irrigation potential. Even though it has such vast surface water potential, it is not yet fully assessed to what extent it will supply for different demands in the basin and what type of demands there are. Currently large scale private farms are established in the lower basin of Baro-Akobo cultivating rice, oilseeds, palm oil and sugarcane like Saudi stars Plc and Karuturi Global Ltd. Moreover, different small scale and medium scale projects are engaged in the area. All of which leads to different impacts on the river basin such as deforestation and population re settlement which will bring considerable effects on the catchment hydrological processes and surface water potential. Hence, assessment and evaluation of surface water potential, current and future water demands of the river basin is essential.

1.3. Research Questions

To achieve the research objective, it was tried to answer the following research questions based on the data collection and analysis outputs.

- ✓ What is the status of the surface water potential to meet the current and future demands for medium and large-scale irrigation, hydropower and water supply projects in the river basins?
- ✓ How much surface water is available in the Baro-Akobo?
- ✓ What types of large-scale and medium-scale project demands are there in river basin?
- ✓ What is the status of future water demands?
- ✓ How much surface water is required for planned and ongoing large-scale projects for different water use requirements (i.e. irrigation, hydropower and domestic) in the basin?

1.4. Objective

1.4.1. General Objective

The general objective is to assess the surface water potential of the river basin and its current and future demands for integrated water resource management system of Baro-Akobo River Basin.

1.4.2. Specific Objectives

Based on the statement of the problem the following specific objectives were proposed which will be evaluated and achieved by the research outputs.

- To evaluate observed stream flow and hydro-meteorological data of the river basin for surface water resource potential assessment of the basin.
- To estimate the total surface water potential of the river basin.
- To compare the current surface water potential with the previous studies.
- To estimate the current and future water use demands in the basin.

1.5. Scope of the Study

The research topic encompasses very wide area and parameters. However, the given period was very short which forces to focus on the medium and large-scale projects in the basin such as large-scale irrigations, water supply and hydropower projects.

1.6. Outline of the Thesis

Chapter one: contains general introduction, statements of the problems objectives of the study and the research questions, which should be answered.

Chapter two: contains rationalization of the surface water potential and demands, and a brief description about the review of Rainfall-Runoff model. Hydrologic processes are covered in this chapter, which describe the scientific principle governing hydrologic phenomenon that is a system concept.

Chapter three: describes the study area. The types of catchment and flow characteristics selected for use in this study, land use, soil and slope of the basin. The methodology and model selection, and data quality and adjustment. Applied methodology with respect to SWAT model calibration and validation is described and model performance evaluation.

Chapter four: would focus water demand assessment WEAP model setup and input data collection and analysis.

Chapter five: detailed discussion on the results of SWAT model calibration and validation. Comparison of observed and simulated flow. Results of the WEAP model also discussed and compared with the available surface water.

chapter six: will be conclusions and recommendations of this study.

CHAPTER TWO

2. Literature Review

2.1. Water resources

The World's total water resources are estimated at 1.36×10^8 M ha-m. Of these global water Resources, about 97.2% is salt water mainly in oceans, and only 2.8% is available as fresh water at any time on the planet earth. Out of this 2.8% of fresh water, about 2.2% is available as surface water and 0.6% as ground water. Even out of this 2.2% of surface water, 2.15% is fresh water in glaciers and icecaps and only of the order of 0.01% is available in lakes and streams, the remaining 0.04% being in other forms. Out of 0.6% of stored ground water, only about 0.25% can be economically extracted with the present drilling technology (the remaining being at greater depths). (Raghunath, 2006).

Very little of the Earth's abundant water is actually accessible and suitable for human needs. This is especially true in Africa. At the continental level, Africa's 3 931 km³ of renewable water resources represent around 9 per cent of the world's total freshwater resources. Africa is the world's second-driest continent, after Australia, but also the world's most populous continent after Asia. (UNEP, 2010).

The origin of water resources is rainfall. As rainfall reaches the surface, it meets the first separation point. At this point part of the rainwater returns directly to the atmosphere, which is called evaporation from interception I . The remaining rainwater infiltrates into the soil until it reaches the capacity of infiltration. This is called infiltration F . If there is enough rainfall to exceed the interception and the infiltration, then overland flow (also called surface runoff) Q_s is generated. The overland flow is a fast runoff process, which generally carries soil particles. A river that carries a considerable portion of overland flow has a brown muddy color and carries debris. The infiltration reaches the soil moisture. Here lies the second separation point. From the soil moisture part of the water returns to the atmosphere through transpiration T . If the soil moisture content is above field capacity (or if there are preferential pathways), part of the soil moisture percolates towards the groundwater. The reverse process of percolation is capillary rise. The percolation feeds the groundwater and renews the groundwater. On average the percolation minus the capillary rise equals the seepage of groundwater Q_g to the surface water. The seepage water is clean and does not carry soil particles. A river that has clear water carries water that stems from groundwater seepage. This is the slow component of runoff. During the rise of a flood in a river when the water color is brown,

the water stems primarily from overland flow. During the recession of the flood, when the water is clear, the river flow stems completely from groundwater seepage. The water that is consumed by the vegetation through transpiration is called "green water". It is an important water resource for agriculture, nature and livestock. The surface water and groundwater which are intimately intertwined are the "blue water". Although the ground water and surface water cannot be separated and although surface water consists to a large extent of groundwater, they are often dealt with separately. This is because they have quite different characteristics (time scales, quantities, availability) and because they obey different laws of motion. (Pieter van der Zaag, 2003).

2.1.1 Surface Water Potential

Surface water resources are water resources that are visible to the eye. They are mainly the result of overland runoff of rain water, but surface water resources can also originate from groundwater. Surface water is linked to groundwater resources through the processes of infiltration (from surface water to groundwater) and seepage (from groundwater to surface water). Surface water occurs in two kinds of water bodies:

- Water courses, such as rivers, canals, estuaries and streams;
- Stagnant water bodies, such as lakes, reservoirs, pools, tanks, etc. (Pieter van der Zaag, 2003)

Earth's surface water is held in two different kinds of water bodies: Salt-water bodies and Fresh water bodies. Fresh water is defined as water that contains less than 0.5 parts per thousand (ppt) of dissolved salt. 99 % of the fresh water is locked up in snow and ice or in lakes, while rivers and other surface fresh water bodies make up 0.01 % of all the water in the world. When the surface water level is high enough, ground water comes to the surface naturally, like springs and may form lakes, ponds and rivers (Nata, 2006).

2.1.2 Water Resources in Ethiopia

2.1.2.1 Surface Water Resources: Lakes and Reservoirs in Ethiopia

Ethiopia has 11 fresh and 9 saline lakes, 4 crater lakes and over 12 major swamps or wetlands. Majority of the lakes are found in the Rift Valley Basin. The total surface area of these natural and artificial lakes in Ethiopia is about 7,500 km². The majority of Ethiopian lakes are rich in fish. Most of the lakes except Ziway, Tana, Langanu, Abbaya and Chamo have no surface water outlets, i.e., they are endhoric. Lakes Shala and Abiyata have high concentrations of chemicals and Abiyata is currently exploited for production of soda ash.

2.1.2.2 Surface Water Resources: River Basins in Ethiopia

The geographical location of Ethiopia and its endowment with favorable climate provides a relatively higher amount of rainfall in the region. Much of the water, however, flows across the borders being carried away by the Transboundary Rivers to the neighboring countries.

Ethiopia has 12 river basins. The total mean annual flow from all the 12 river basins is estimated to be 124.25 billion cubic meters (Seleshi et al, 2010). The idea of a river basin, despite its physical or natural attributes, is more than an engineering concept and encompasses the magnitude and dynamics of a resource that must be harnessed for the common good (Molle, 2006). It has often been advocated that the most logical unit for water resources planning and optimum utilization of available water resources is the river basin.

All major river basins in Ethiopia have an integrated development master plan study, and their potential in terms of economic development be known. The surface runoff potential of all the river basins is shown in table 2.1 and figure2.1 shows the map of Ethiopian River Basins.

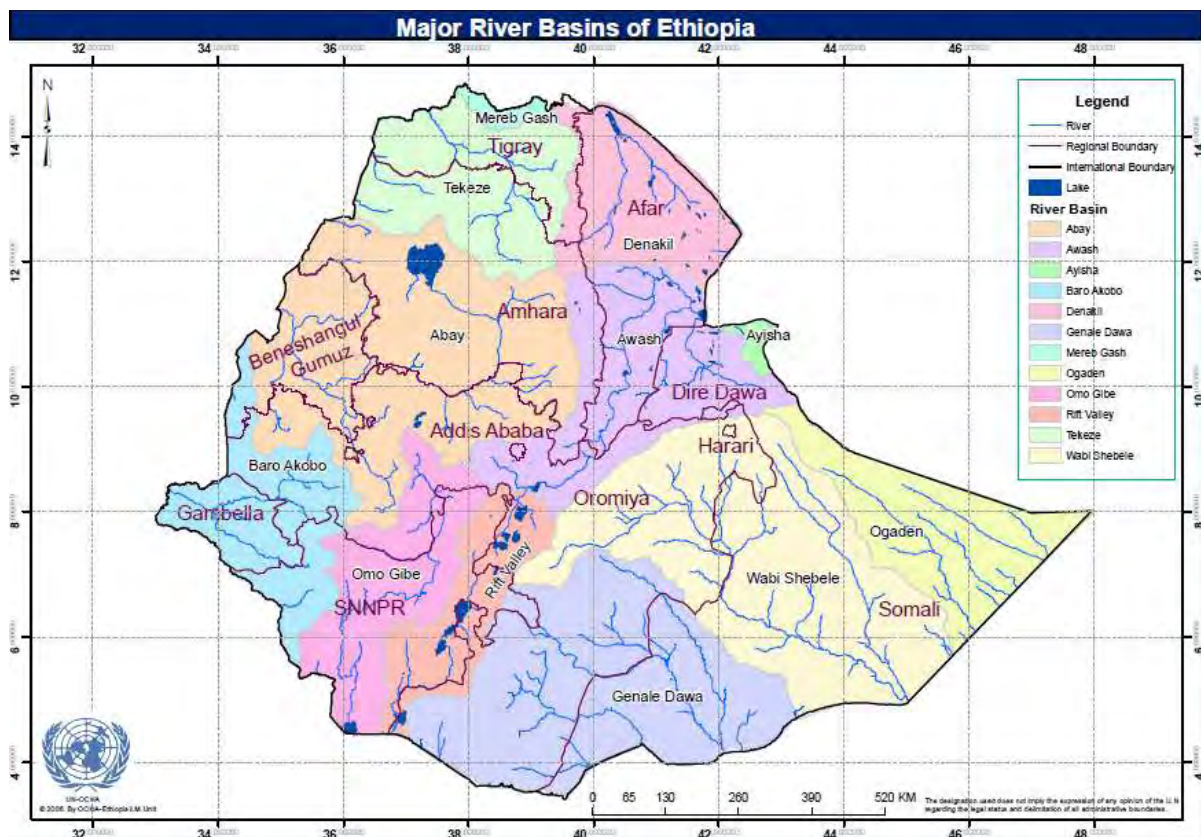


Figure2. 1Ethiopian river basins map.

Table2. 1 Surface water potential and coverage area of Ethiopian river basins.

River Basin	Area (K m ²)	Surface runoff(Bm ³)	River Basin	Area (K m ²)	Surface runoff(Bm ³)
Tekeze	82,350	8.2	Afar /Denakil	74,002	0.86
Abbay	199,812	54.8	Awash	112,696	4.9
Baro –	75,912	22.6	Aysha	2,223	-
Omo- Ghibe	79,000	16.6	Ogaden	77,121	-
Rift valley	52,739	5.6	Wabi-	202,697	3.16
Mereb	5,900	0.65	Genale dawa	171,042	5.88

Source: (Seleshi et al, 2010)

Integrated water resources management is a process which promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromise the sustainability of vital ecosystems.

The overall aim of the national water resources management policy is to enhance and promote all national efforts towards the efficient, equitable, and optimum utilization of the available water resource of Ethiopia for significant Socio-Economic development on substantial basis (MOWR, 2002).

2.2 water demand and use

Water demand is defined as the volume of water requested by users to satisfy their needs. In a simplified way it is often considered equal to water consumption, although conceptually the two terms do not have the same meaning. (Peter Ashton et al.2003).

Water demand forecasting is a process achieved through several techniques and is typically used to predict future water requirements for different uses including hydropower, domestic and agriculture water demands. The type of technique used depends on the availability of the data needed, the general scope of the region for which the forecast is being conducted, and the resources available to the organization for which the forecast is being conducted. For all intensive purposes, future water demand is derived from basic functions. For instance, municipal demand is generally projected using population size and the number of house holds, industrial demand is often based on number of employees, and agricultural demand commonly relies on crop type and irrigated land(Water Resources Planning (Dzurik,1996).

The key variables such as population growth, urbanization, increasing irrigation water consumption, changes in cropping patterns, increasing productivity of rain fed agriculture and the water demand for environment and pollution controls were considered in estimating future water demand.

The amount of water that people use depends on minimum needs, amount of water available for use, level of economic development and extent of urbanizations. There are three categories of fresh water use globally: for agriculture, industry and domestic (personal, household and municipal) of which agriculture dominates (Gleik, 1996).

Over the years, population growth, urbanization, industrialization and the expansion of irrigated agriculture are arresting rapidly increasing in demands and pressure on the water resources, besides contributing to the rising of water pollution (Global Water Partnership, 2000).

2.2.1 Domestic water demand

Public water companies provide water for different use categories:

- Domestic use by households
- Municipal use by government agencies for public functions, e.g. watering public lawns
- Commercial use by all kind of public and private offices, agencies and institutes
- Industrial use by factories.

The following deals with the demand of the first three categories; domestic, municipal and commercial water demand. These demands depend, among other things, on:

- number of people within the considered area
- connection rate for different types of supply; e.g. stand pipe, piped supply
- per capita consumption, which depends on such factors as level of development, type of supply and price of water
- losses in infrastructure for transport, treatment and distribution.(Pieter van der Zaag,2003)

Municipal water use is directly related to the quantity of water withdrawn by populations in cities, towns, housing estates, domestic and public service enterprises. The public supply also includes water for industry that provides directly for the needs of urban populations and this demand also consumes high quality water from the city water supply system. In many cities, a considerable quantity of water is used in market gardening and for watering vegetable gardens and domestic garden plots.

The volume of public water use depends on the size of an urban population and the services and utilities provided, such as the extent of pipe networks for supply and sewerage, or centralized hot-water supply where available. In addition, much depends on climate conditions. In many large cities, present water withdrawal amounts to 300-600 litres per day per person. By the end of this century, the specific per capita urban water withdrawal is expected to increase to 500-1000 liters per day in the industrially developed countries of Europe and North America. On the other hand, in developing, more agricultural countries found in Asia, Africa and Latin America, public water withdrawal is a mere 50-100 l/day. In certain individual regions with insufficient water resources, it is no more than 10-40 l/day of fresh water per person.

A greater part of the water that has been withdrawn from the urban water supply system is returned to the hydrological system after use (purified or not) as wastewater, if urban sewerage networks operate effectively. The major sources of actual consumption consist of water lost through evaporation from leaking supply and sewerage pipes, from watering plants and recreational areas, washing streets, and garden plots. Thus, largely, the extent of the loss also depends on climatic conditions. In hot, dry regions, losses are certainly larger than those are where it is cold and humid: water consumption for personal needs is insignificant as compared with water losses through evaporation.

Relative values for consumption are usually expressed as a percentage of water intake and depend to a considerable extent on the volume of water withdrawn for public supply. Thus, in modern cities equipped with centralized supply and efficient sewerage systems, the specific water withdrawal can be 400-600 l/day, and consumption is usually not above 5-10% of total water intake. Small cities with a large stock of individual buildings not fully provided with a centralized system, may have a specific water withdrawal of 100-150 l/day.

Consumption increases significantly in this context and can reach 40-60%, with the lesser values occurring in northernmost and the larger values in the dry, southernmost regions. The modern trend in the development of public water supply all over the world is the construction in both large and small cities of effective centralized water supply and sewerage systems, connecting together an even greater number of buildings and populated areas. In the future, however, the specific per capita water withdrawal is expected to increase, while water consumption per se, expressed as a percentage of water intake, will decrease considerably. (UNESCO, 1998).

2.2.2 Agricultural water demand

Rain fed agriculture remains the bulk producer of our food and fiber. Since there is little scope of policy-makers influencing rainfall, at this level there is little to plan and forecast. We can safely leave this task to our rain fed farmers. In this section we rather concentrate on irrigation water demand. One remark however: there is still a lot of scope to improve the productivity of rain fed farming, and the water utilization efficiency, for instance through:

- Alternative tillage techniques best suited for the local climatic and soil conditions, which conserve soil and water;
- Appropriate fertilization; as water is not the only constraint in crop production, improved fertilization will result in higher production per mm of rain water
- The best possible choice of crops and crop varieties given local conditions; this includes the option of e.g. intercropping.

Such measures may translate into higher production, offsetting the need to create new irrigation schemes, and thus freeing water and monetary resources. Irrigation is in many river systems the main water user. Often water use for irrigation accounts for at least 80% of total water use in a water resources system. For the proper planning and management of such a system it is therefore important to have adequate tools to reliably estimate the demand for irrigation water, the possible yield reductions due to water shortages, and the economic benefits of irrigation water.

The present subject belongs to the working area of specialists such as agriculturalists and irrigation engineers. However, it is important that water resources managers have a basic understanding of the subject matter, such that they can weigh the water demand from the agricultural sector vis-a-vis the demands for water from other sectors. (Pieter vanderZaag, 2003)

Land irrigation has been practiced for millennia through the necessity to maximize food supply for humanity but the dramatic expansion in irrigated land has mainly taken place during the 20th century, with irrigation becoming the principal water use in many countries. Indeed, agriculture is now reckoned the largest consumer of water, accounting for some 80% of total water use. Before the late 1970s, intensive irrigation development could be found in all the continents, forcing the growth in irrigated areas and guaranteeing an increase in crop production. In the 1980s, however, the rate of global increase in irrigated areas dropped considerably in both developed and developing countries. (UNESCO, 1998).

Ethiopia has a significant irrigation potential identified from both available land and water resources. Irrigation would provide farmers with sustained livelihoods and improve their general well-being (Belay et al. 2013). However, the country's irrigable land has been underutilized, and only 4 to 5% of the potential area has been developed for irrigation (Awulachew et al., 2007). Consequently, the agricultural economy of the country is largely based on rain fed cultivation, but while employing 85% of the population, it only contributes 50% to the gross domestic product (Berry et al., 2003). Ultimately, increasing agricultural production using irrigation is one of the main drivers to end poverty caused by insufficient output from these rain fed systems

According to the Ministry of Water, Irrigation & Energy of Ethiopia irrigation command areas can be classified into three groups (Awulachew et al., 2005). The first group is small-scale irrigation areas of less than 200 ha, medium-scale between 200 and 3000 ha and large-scale above 3000 ha. For this study, medium and large-scale projects are considered based on this classification.

Currently, the government is giving more emphasis to the sub-sector by way of enhancing the food security situation in the country. Efforts are being made to involve farmers progressively in various aspects of management of small-scale irrigation systems, starting from planning, implementation and management aspects, particularly, in water distribution and operation and maintenance to improve the performance of irrigated agriculture.

2.3 Water Resources Assessment

Surface water is water that is open to the atmosphere and fed by runoff from the surface, such as in a stream, river, lake, or reservoir. Water discharged into a river is the runoff from the watershed drained by the river (Taffa, 2002; Durrans, 2003). Surface water is a valuable resource that can use for public, industrial, navigation and agricultural supply purposes, etc. Therefore, understanding surface water resources potential and use is a key aspect of water resource assessment, evaluation and development. The assessment of water availability at watershed level is realized by quantifying runoff generated in the watershed (Daniel *et al.*, 2011). Water resources assessment relies on a full understanding of all the water flows and storages in the river basin or catchment under consideration.

Accurate information on the condition and trend of a country's water resources surface water and groundwater, quantity and quality is required to support sustainable economic and social

development whilst addressing maintenance of environmental quality. Uses of water resources information are many and varied. Almost every sector of a nation's economy uses water information for planning, development or operational purposes. As a necessity, water is often difficult to value in absolute economic terms, but in all countries as competition for water increases, water information grows in value. Because the cost of government programs must be properly justified, it is becoming very important to demonstrate the benefits of hydrological information and analysis.

Water resources assessment relies on a full understanding of all the water flows and storages in the river basin or catchment under consideration. The process of water resources assessment involves developing as complete an understanding as possible of these flows and stores and their interrelationship over time. Only then is it possible to estimate what sustainable surplus flows may be made available for human or other uses as both sources and systems change in the future through climate change, natural evolution or human made interventions. (WMO, 2012).

Surface water is water that is on the Earth's surface, such as in a stream, river, lake, or reservoir. Surface water is a valuable resource, which can be used for public, industrial and agricultural supply purposes. Surface watercourses also provide important natural habitats and environmental and leisure resources. Therefore, understanding surface water resources is a key aspect of water resource assessment and evaluation

In order to properly state the available water resource potential of a certain river basin it is first essential to determine the amount of water available in that system. Accordingly, that requires understanding of the hydro-system and its interaction with the environment and to be able to properly describe the water flow, „in and out“, of the basin. Information and data regarding the basin such as runoff, evaporation and rainfall, for example, are some of the components that would be necessary in describing the water movement or circulation (Daniel, 2007).

2.4 Water Resources Assessment Models

Several hydrologic models are widely used for the assessment of the water resource. Rainfall-runoff models have broadly used in hydrology over the last century for a number of applications, and play an important role in optimal planning and management of water resources in catchments (O.,Loughlin *et al.*, 1999; Munyaneza, O., *et al.*, 2013). Oyebande (2001) reported that the main challenge associated with applying successfully rainfall-runoff model lies in the lack of monitoring data, mainly rainfall spatial distribution over the

catchment area, since rainfall is the primary input in any hydrological model. Another potential problem is having no reliable flow data that can lead to reliable calibration and validation of catchment parameters.

Those models include SCS-CN (NEH, 1985), HEC-1, HEC-HMS (HEC 1990, 2001), SWAT (Arnold *et al.*, 1996), the MIKE BASIN (Supiah and Normala, 2002), WatBal (Water Balance Model) (Loucks, 2006; Mugatsia, 2010), WatBal is lumped conceptual model which consists of two major components. The first one calculates the potential evapotranspiration using Priestley-Taylor method and the other component calculates the water balance of the basin (Kaczmarek, 1993). The WEAP model simulates the natural hydrological processes (e.g., rainfall, evapotranspiration, runoff and infiltration) enable assessment of the availability of water within a catchment (basin) (Sieber *et al.*, 2005), etc.

The Soil Conservation Service Curve Number (SCS-CN) is use to predict runoff, which links rainfall response to soils, land use, and antecedent moisture condition (AMC), and it is widely applicable in predicting event-based runoff volume (SCS, 1972; NRCS, 2004; Teku, 2014). The SCS-CN is one of the most enduring methods for estimating the volume of direct surface runoff in ungauged catchment (watershed) and is developed from an empirical study of runoff in small catchments (Kousari, M.R., *et al.*, 2010). In addition, the model has been widely used with success, providing consistently useful results (Soulis *et al.*, 2009; D,Asaro and Grillone, 2010). The Soil and Water Assessment Tool (SWAT) model is a basin scale model where runoff is based on land use and soil type (Arnold *et al.*, 1998; Das *et al.*, 2004), has a comprehensive structure that models basically all hydrologic processes in the watershed over long periods of time (Neitsch *et al.*, 2002b). The model has also been applied in the many basins for example: Githui *et al.* (2009) used SWAT model to simulate stream flow in Western Kenya. Sang (2005) also applied the SWAT model in the Nyando Basin in Kenya and Magoma (2009) examined the applicability of SWAT in the Rugezi wetland catchment in Rwanda. The results showed important rainfall-runoff linear relationships that could extrapolate to estimate amounts of stream flow under various climates. Then the Water Evaluation and Planning (WEAP) model attempts to address the gap between water management and watershed hydrology and the requirements that an effective IWRM be useful, easy to-use, affordable, and readily available to the broad water resource community (Yates, 2005). In addition, the data structure and level of detail may easily customize to meet the requirements of a particular analysis and to reflect the limits imposed when data are limited (Yates *et al.*, 2005b).

2.5 An over view of Rainfall Runoff Model

2.5.1 Rainfall Runoff Process

The surface subsystem of the hydrologic cycle is where the rainfall and runoff interaction takes place. The input to this system is the rainfall and the output taken as the stream flow at the outlet of the system.

2.5.1.1 Rainfall

In the hydrologic cycle, moisture comes from the atmosphere to the surface as precipitation. The rainfall pattern and intensity greatly influences the runoff. If the rainfall intensity is lower than the equilibrium capacity, then all the water reaching the land surface will infiltrate. If the rainfall intensity is greater than the equilibrium infiltration capacity, but less than the initial infiltration capacity, at the beginning all the water will infiltrate, but when the infiltration capacity drops below the rainfall intensity, some of the water will remain on the ground surface. Finally, if the rainfall intensity is greater than the initial infiltration capacity, some water will immediately remain on the land surface.

Therefore, the nature of rainfall pattern is of great importance in dealing with runoff process. (Chow et al, 1988) give a summary of the cycle and a brief description illustrated in Figure 2.2

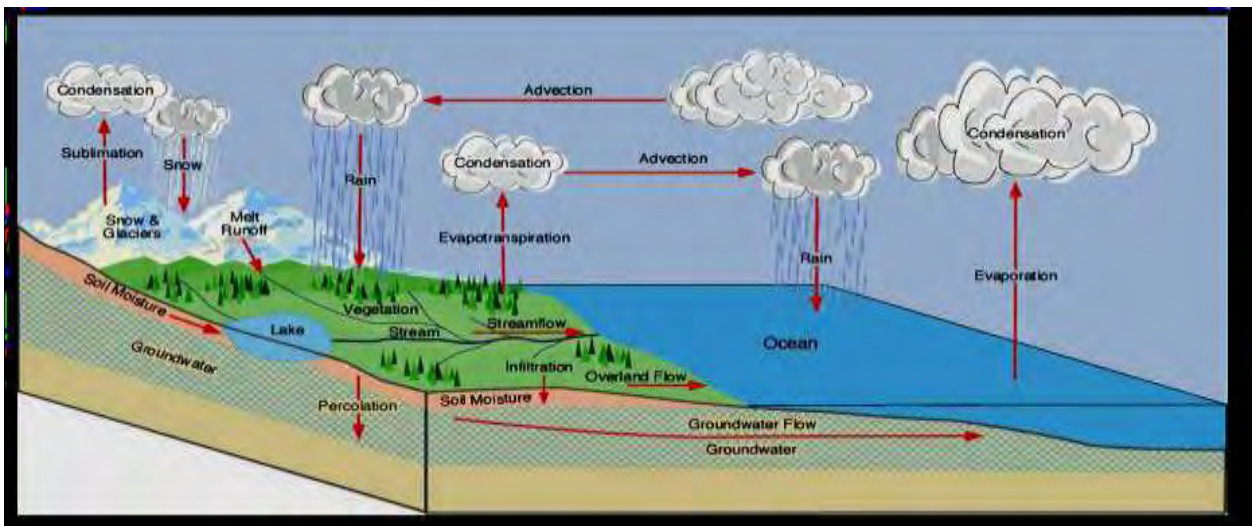


Figure 2. 2 Hydrological cycle, Chow et al. (1988).

Rainfall is extremely variable both in time and in space. The variation is brought about by differences in the type and scale of development of precipitation-producing processes, and is strongly influenced by local and regional factors, such as topography and wind direction at

the time of rainfall, however; it is assumed that each individual rain gauge is representative of a very considerable area around it. This assumption is not correct. Because of the very considerable spatial variation of precipitation depth and intensity, particularly for short durations and for severe convectional storms as is the case in most parts of Ethiopia. There is no guarantee that point rainfall will any way provide a reliable guide to the rainfall of immediate surrounding areas.

Hence to account the spatial and time variation of rainfall, one can derive the areal rainfall from a number of point rainfall data. The simplest and most obvious initial approach to the derivation of areal rainfall is to calculate using the arithmetic-mean method. This method is satisfactory if the gauge is uniformly distributed over the area and the individual gage measurements do not vary greatly about the mean. The Thiessen polygon method is the second and generally more accurate than the arithmetic-mean method. The Isohyetal method is flexible than Thiessen polygon but it is more time-consuming, (Chow et al.1988).

2.5.1.2 Runoff

A considerable portion of water from the hydrologic cycle after flowing on land is returned as stream flow, which is defined as the movement of water under the force of gravity through well-defined channels. Sometimes the water that moves in defined channel or all the water that moves over the land in undefined channel is termed as runoff, Chow et al. (1988).

During precipitation, some of the rainfall is intercepted by vegetation before it reaches the land surface. This may later fall to the ground or evaporate. Meteoric water, which is not intercepted by the vegetation cover falls on the ground surface, where it evaporates, infiltrates into pervious soils, lies in the ground depression or flows down giving rise to runoff. The runoff process is strongly influenced by infiltration capacity. The infiltration capacity varies not only from soil to soil, but is also different for dry versus moist conditions in the same soil. After a certain time it reaches a regime value, which is called equilibrium infiltration capacity, Chow et al. (1988).

The water, which does not infiltrate, forms puddles or flows as a thin sheet across the land surface, which is called overland flow or surface runoff. Hydrologists refer to the water trapped in puddles as depression storage.

The overland flow, sometimes called Horton overland flow, occurs only when the rainfall intensity exceeds the infiltration capacity. In areas in which soils have a high infiltration

capacity, this process may occur only during very intense storms or when the soil is saturated or frozen.

If the unsaturated zone is uniformly permeable, most of the infiltrated water percolates vertically (percolation). If layers of soil with a lower vertical hydraulic conductivity occur beneath the surface, then infiltrated water may move horizontally giving rise to what is called interflow. This interflow is substantial in some drainage basins, and contributes significantly to the total stream flow. Thin permeable soil overlying fractured bedrock of low permeability would provide a geological condition contributing to significant interflow,(Chow et al. 1988).

The infiltrated water that percolates into the saturated zone below the water table becomes stored in the groundwater reservoirs or aquifers. This is not a static storage, as groundwater is in constant movement. While freshly infiltrated water is entering the groundwater reservoir, other groundwater, known as base flow, is discharged into a stream.

Water that infiltrates into the soil on a slope can move down slope as lateral unsaturated flow (through flow). The difference between through flow and interflow is that through flow emerges as seepage at the foot of the slope rather than entering a stream, as does interflow.

Thus, through flow appears as overland flow before entering a stream channel. This peculiar overland flow is called return flow, which is different from the Horton overland flow. Direct precipitation is also very important for the stream flow, especially when it falls onto the surfaces of large lakes or reservoirs.

CHAPTER THREE

3. Materials and Methods

3.1. Description of the Study Area

The Basin is located in the southwestern part of Ethiopia. It covers approximately 75,912km². The area includes all or part of the four administrative regions: SNNPRS (Southern Nations & Nationalities People Regional State) in the south, Oromiya in the northeast, Gambela in the central western part and Benishangul Gumuz in the northwestern extremity.

The Baro-Akobo basin is the fourth largest basin in the country, after the Wabi Shebelle, Abbay and Tekeze river basins. It is located in the south west of the country, between latitudes 5° 31' and 10° 54' north and longitude 33° and 36° 17' east. The western, north western and south western side of the basin borders with the Sudan, while in the northern and north east it is bordered by the Abbay river basin and in the east and south east it is bordered by the Omo-Ghibe river basin.

The Baro-Akobo basin is the second most important basin, next to Genale Dawa, as far as irrigation potential is concerned. The population is settled sparsely in the lowlands of the basin which offers a conducive environment for water resources development. Because of regular flooding, the lowland areas are mainly used as pastures for grazing and no major water resources development has taken place to-date (Awulachew, et. al 2007). The location of the river basin is shown in Figure 3.1.

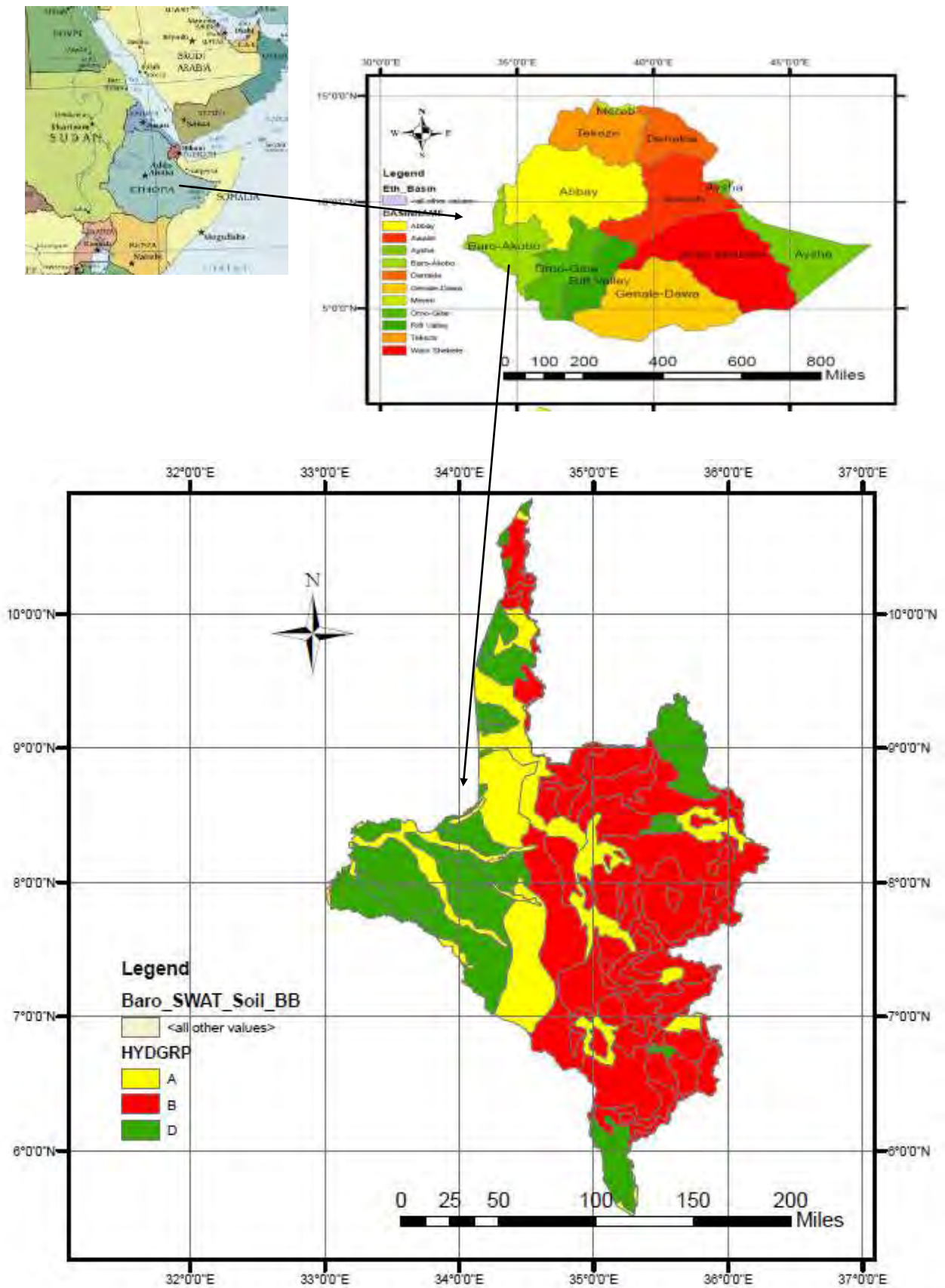


Figure3. 1 Location of the study area.

3.2. Climate and topography

The entire area is characterized by a single monsoon wet season that runs from late May or early June to the end of September / late October. The wet season is followed by a long dry season. Rainfall is highest at altitudes of 2,000masl and over, where it reaches 2,400mm but is only 900 to 1,500mm in the lower areas. The mean annual rainfall is estimated to be 1588 mm. The mean annual evaporation over the basin is 1468-mm. Mean annual air temperatures also vary with altitude from a high 28⁰c in the lowland to a low of 17⁰c in the mountains. December is usually the coldest month and March, April and May are the hottest months, but the variability over the year is not large.

3.2.1. Rainfall

The Baro-Akobo basin enjoys varied climate conditions due to its wide elevation differences ranging between 300 meters and 3000 meters. It has been observed that rainfall and temperature are correlated with altitude. As a result, temperature varies from about 40°C in the lowlands around Abebo and less than 22°C around Kombolcha. Similarly, rainfall varies between less than 1000mm in the western lowland and more than 2500mm in the far eastern highland of the basin, ARDCO-GEOSERV (1996).

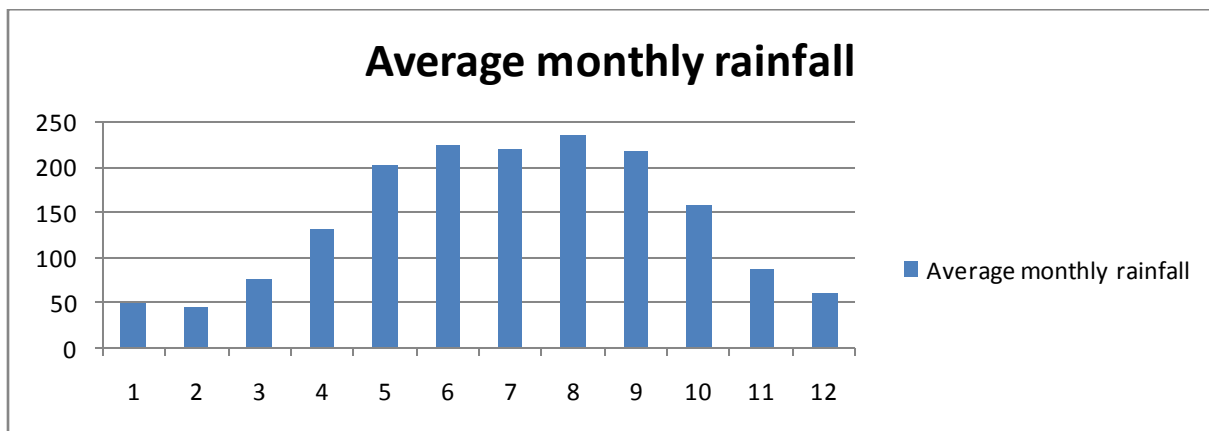


Figure3. 2 average monthly basin rainfall.

In terms of the circulation of the atmosphere the weather systems affecting the area, Kiremt is the main rainy season which results from the ITCZ activity, interaction between the mid latitude depressions and tropical air mass from the southern Atlantic ocean across central Africa; disturbances from northern Indian ocean, coupled with occasional easterly waves. During the Bega (dry) season, warm and cool dry air masses from the Saharan and Siberian or Arabian anticyclones, respectively predominantly influence the Baro-Akobo basin. The area shows mono-modal (single peak) rainfall pattern, and Tropical rainy climates dominate

the area. Appendix B illustrates climatic zones of the Baro-Akobo basin, (ARDCO-GEOSERV, 1996) and its rainfall distribution.

3.2.2. Topography and Slope

Recurrent dissection and highland rolling and Steep slopes are basic features which characterizes the basin physiographic Characteristics. Highlands with altitude ranging between 1500m and 3000m and peaks rising over 3000m constitute the basin. Half of the basins topography is lowland, ranging from 300m up to 1000m in elevation. Due to dissection and associated erosion, the north-south escarpment separates the basin in to two parts namely upper basin that is cool and moist and the lower basin of the Illubabor plain that is warm and humid. The rainy season peaks during August. Major rivers include the Baro and Akobo, both of which are perennial tributaries of the White Nile. The flow of major rivers closely matches the rainy season with peak discharge occurring during September, TAMS & ULG (1997).

The diverse physiographic characteristic of the basin creates both potentials for development and margins on development. The highland mass causes the rain-bearing air masses to uplift, leading to the dominantly plentiful rainfall, which provides for both agriculture and hydropower. The wide range of altitudes and associated climates offer potential to grow a wide range of crops, from temperate to tropical species. On the contrary, the frequent and deep dissection creates major barriers to communication, while the associated steep slopes creates direct and indirect impediments to agriculture, resource management and infrastructure development, TAMS & ULG (1997)

There is high interrelation between slope and total runoff. Slope is important feature of a catchment as it gives an indication of the kinetic energy available for water to move towards the basin outlet. Slope is variable within a basin. Table 3.1 gives the composition of the topography of the project area by Slope class. It shows that more than half the landscape is flat or undulating, about one-third is rolling or hilly, and the remainder is steep, TAMS & ULG (1997).

Table 3. 1 Slope classes by area.

Slope class (%)	Description	Area of slope (%)
0-2	Flat	25.6
2-8		31.5
8-16	Hilly	19.7
16-30		14.2
30-50		6.6
>50	Steep	2.4

Source: Copeland, 1996

Area= 76,098 km²

The landscape is flat and low-lying (elevation less than 450 m) in the most western extent at Ethiopia,,s joint border with the Sudan. Deep, cracking clays make up its soils and its vegetation is reminiscent of Guinean savannah (coarse grasses, *Acacia* spp., and *Combretum* spp.). Further inland (about longitude 34°E) the terrain becomes slightly undulating, while soils remaining deep and become more variable with isolated areas of ironstone and leached surface from which the iron, aluminum, and organic matter have been removed. Clay alleviations becomes increasingly pronounced as does surface drainage, although the effects of the latter remain subject to large-scale flooding during the rainy season, an average of 3530 km² inundate annually (Cowx, 1995). Channels, free from the controls imposed by the terrain of higher elevations, migrate; join with other channels, separate, and occasionally from transient lakes, which supply an important part of the region,,s aquatic habitat, TAMS & ULG (1997).

About longitude 34° 30'E (east of Gambela), the terrain abruptly becomes first hilly and then steely dissected as one climbs the escarpment separating the eastern boundary of the plains from the western plateau and mountains of central Ethiopia. The leading edge of the plateau summit is about 500 m above the altitude of the plains, causing its climate to become both cooler and more humid, TAMS & ULG (1997).

Moving eastward, the general impression is one of persistently increasing elevation, occasionally by climbing the leading edge of small escarpments, at other times by climbing ridges whose summit is always higher than the one preceding. By the time, one reaches the divide of the catchment the elevation is over 2000 m. This study uses a 90m resolution DEM to estimate slopes for all sub catchment. Furthermore, slopes for all sub catchment can also be found either in TAMS & ULG, (1997) and/or in ARDCO-GEOSERV (1996). The following Figure 3.3 shows the basin slope.

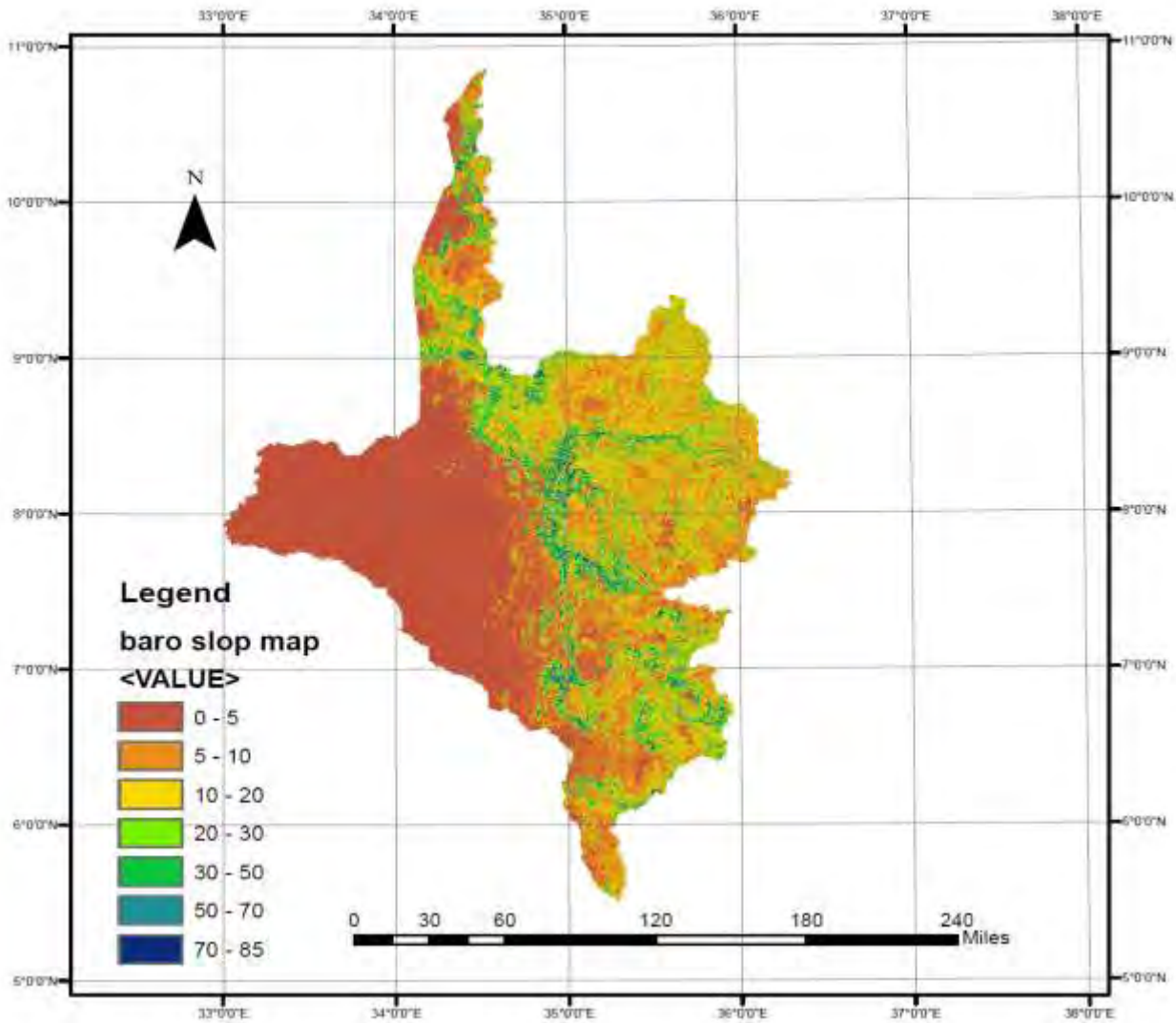


Figure 3. 3 Slopes of the study area derived from the DEM value in percentage.

3.2.3. Land Use and Land Cover

The land covers of the basin follow the divide between highland and lowland. The landscape is made up of numerous westerly flowing rivers and their contributing basins; the area is an important watershed of the White Nile. Its drainage covers about 75,912km². Figure 3.3 Shows Land Escapes of the Baro-Akobo River Basin (Mow&E team January, June 2011). The natural vegetation of the area reflects differences between the plains and uplands in landscape, soil, climate, and history of land use. Daviesson (1999) classified Ethiopia,s natural forests as being:

- Riparian,
- Mixed deciduous
- Coniferous, and

- Transitional zone(Oleo spp),



Figure3. 4 Landscape of upper water Sori River near Mettu 2011.

Agriculture with dense Forest or with woodland (cultivated area with perennial crop) is largely the land property of upper basin, where they are either under active conversion to cultivation or are protected „through serving as shade for coffee trees. Other agricultural land with cultivated area of nearly 60 % exists along the mid altitude highland-lowland divide defined fault escarpments, generally on rolling and hilly slopes, and in the eastern highland tips of the basin. The other major highland land cover is forests with very distributed forest range, which occurs primarily either in poorly drained depressions or no level (and often poorly drained) and exposed high altitude locations are inhabited in the eastern regions of the study area. Extensive areas of grassland also occur within the farmland. Similarly, bush and shrub occur as inclusions thought the landscape, but rarely form significant areas, TAMS & ULG (1997).

On the other hand, the lowlands, by contrast, are still largely untouched by development. This is not to say, however, that they are uninfluenced by man. Indeed, most of the lowland vegetation probably represents fire climax vegetation, with resistance to the frequent burning that occurs. The dominant vegetation is Combretum woodland underlain by tall grasses. Woodland is the second most important map unit and the third most important cover, most of it occurs in the lowlands. Large area of grassland, bush land and shrubland also occur, responding to local edaphic condition. There are two vegetation types of economic importance. Extensive areas of bamboo occur, primarily on lower areas (often associated with the break between the highland and the lowlands) characterized by moderately deep soils (Cambisols). Land use in these regions is largely of traditional. Such uses include fishing,

hunting and gathering, scattered cultivation primarily with hand tools, and animal husbandry, TAMS & ULG (1997).

In addition to types composed principally of highland bamboo, *Aningeria* ssp, and *Acacia* ssp occurs. Although the area contains different type of forests, its coverage is declining from time to time. Daviesson (1996) observes how even two decades ago much of the area was forested, but that now its forest area is depleted due to large scale farming and to a certain extent due to fuel wood consumption. FAO (1990) computed Ethiopia,s fuel wood requirement to exceed increment yield by 60 %, Daviesson believes the current imbalance to be 80%. Therefore projected fuel wood demands show that current stocks could last about 30 years before being depleted. Like many of Ethiopia,s forests, those of the study area are not monitored (Daviesson, 1996). TAMS & ULG (1997),

The land use image was down loaded from USGS GLOVIS as a separate pixel each one covering an area of 182 km x 185 km. For baro-Akobo river basin about seven pixels were used. These pixels were combined in to one image using arc GIS mosaic processing and finally clipped by the river basin boundary. The whole process is shown in the figure 3.4 below.

The land sat image has problem since 2003 at the center of the images which a strip line reduced the quality of the vision of the images. That results the basin land use a shaded images.

3.2.3.1 Supervised and Unsupervised Land Use Classification

In order to make use of the multitude of digital data available from satellite imagery, it must be processed in a manner that is suitable for the end user. For many projects this processing includes categorizing the land into its various use functions. There are two main categories that can be used to achieve this outcome and they are called Supervised and Unsupervised Classification techniques. In supervised land classification, the individual processing the imagery guides the image processing software to help it decide how to classify certain features. This is done by the use of a vector layer containing training polygons. In unsupervised classification, the software does most of the processing on its own generally resulting in more use categories than the user is interested in. This is the point where the user has to make decisions on which categories can be grouped together into a single land use category. In either case additional image processing may be used to help determine which method is better for a given situation. Thus in this project these two techniques were applied.

The land use image was down loaded from USGS GLOVIS as a separate pixel each one covering an area of 182 km x 185 km with 90m resolutions. For baro-Akobo river basin about seven pixels were used. These pixels were combined in to one image using arc GIS mosaic processing and finally clipped by the river basin boundary. The whole process is shown in the figure 3.5 below.

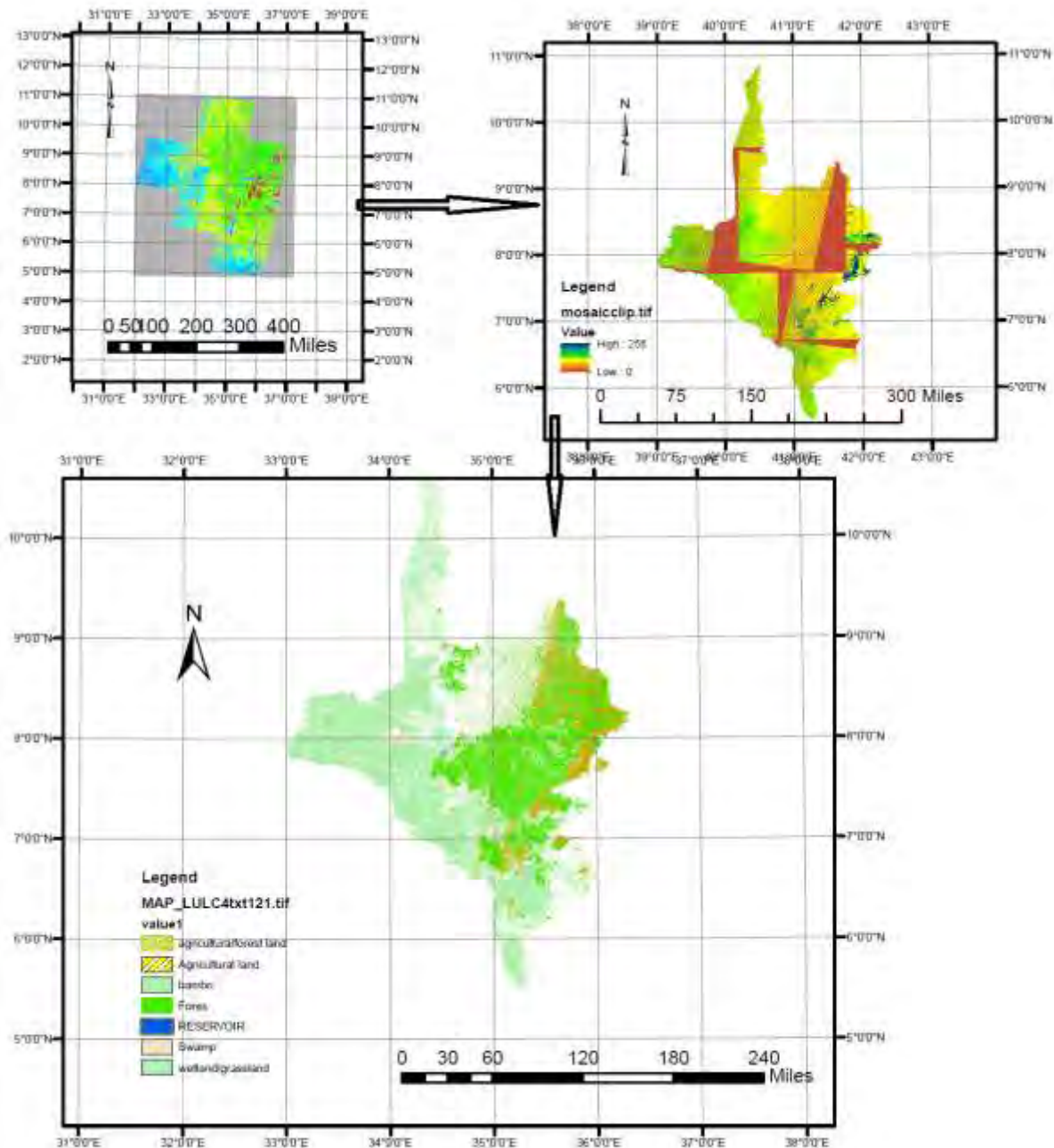


Figure3. 5 Land use and/Cover in baro-akobo river basin derived from land sat image.

3.2.4. Soil Types

Soils of the Baro-Akobo basin reflect the collective effects of the five factors of soil formation-geology (primary fine grained, weathering to produce clays); climate (moderate to high rainfall); topography, with distinctive variations between sites of water buildup or restricted drainage (Vertisols) and well drained sites on slopes (red soils); and time, the western.

Lowland soils especially reflecting the long period of stability that produces soils similar to those of the highlands, which generally receive much higher rainfall. The fifth factor, the biotic factors, is more complicated. The highland soils in particular were developed first under conditions of forest with a regular cycling of nutrients between the trees and the topsoil, and with the subsoil deeply leached under conditions of high rainfall. However, in the present day the dominant biotic factor is human being who has vacated the forest and placed the land under cultivation but with insufficient management; many (most) soils now truncated profiles due to the impact of erosion, TAMS & ULG (1997).

Orthic Acrisols (4287 Km²) and Dystric Nitisols (18,900 Km²) are the predominant soil associations, with inclusions of dystric Cambisols (2540 Km²) and Lithosols (1559 Km²) on the steep slopes. The Nitisols are normally found in undulating topography with good drainage. Inherent fertility is usually good and agricultural potential high. The next most significant soils are the black Acrisols (1239 Km²) which has no critical importance for cultivation because it creates drainage difficulties and workability problem for both hand tillage and mechanized farming. Cambisols (1534 Km²) also are widespread in areas that range from moderate to steep slopes where the land is continuously cultivated and eroded. Regardless of the fact that these soils are shallow and stony: they are chemically rich, ARDCO-GEOSERV (1996).

In areas of inadequate drainage and/or moisture inflow weathering has produced expanding clays which fracture severely and become very hard when dry, but swell and become sticky when wet. These Vertisols are self-mulching in that the repeated shrinking and swelling tends to mix and remix the upper soil layers. This, plus the recurrent high water table, reduces leaching and produces a fertile soil with fertility well dispersed through the profile. Under the right conditions, these soils are highly productive, and are definitely often favored by smallholders. Nevertheless, the soil properties--especially the firmness when dry and the adhesiveness when wet--make them difficult to cultivate, especially with traditional tools.

These are only a narrow window of opportunity when the soils are moist, but not wet, when they can be easily cultivated. That window is broadened with mechanization, but the difficulties remain. They also tend to remain saturated for long periods, and are often not cultivated for this reason; however, on such sites in the highlands (normally broad, shallow alleys) they provide favored grazing land, including critical dry-season forage. The most important soil texture within the basin is Dystric Nitosols, and clay soil being least abundant, ARDCO-GEOSERV (1996). Figure 3.6 show the basin soil shape.

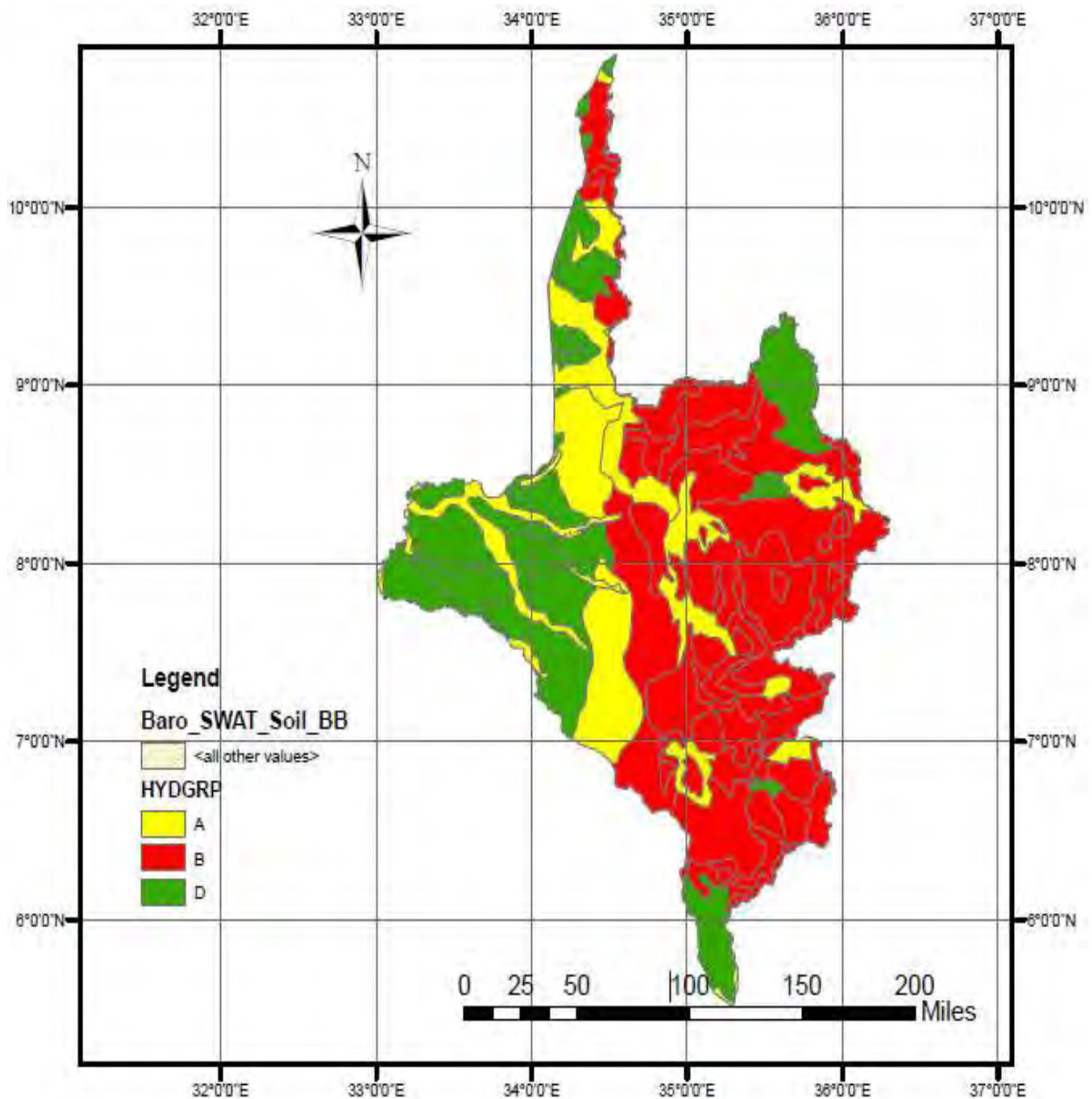


Figure 3.6 Hydrological Soil group of the basin derived from the DEM.

Soil types of Chromic Vertisols, Eutric fluvisols are characterized on landscape units of western and most western seasonally wetlands (Gambela, Itang, Jikawo, and Akobo plains) with comparatively very lowland areas having geomorphology (seasonal swamps and marshes, meander belts and alluvial plains). On the other hand, plains and undulating landscapes of the Asosa, Kumruk, begi and Kelem areas i.e. north of Gambela plain, the geomorphology (Alluvial/Colluvial slopes and out wash fans, piedmont zones strongly influenced by Colluvial processes) with soils of Eutric fluvisols, chromic Vertisols and Eutric Nitosols , and dystric Nitosols are dominant ones, ARDCO-GEOSERV (1996).

The lowland and highland divide dissected fault escarpments with landscape units of moderately dissected plateau, plateau with hills and rolling, and moderately dissected side slopes and dissected plains with geomorphology (severely dissected side slopes and piedmont zones, moderate to high relief hills) are having soil type features of dystric Nitosols, chromic Luvisols, Lithosols, ARDCO-GEOSERV (1996).

Eastern highlands of the Baro-Akobo basin with better drained sites of moderate slopes, particularly in areas of high altitude and or rainfall having geomorphology (rolling to hilly plateau, moderate to high relief hills) are characterized by the predominant soil features as Lithosols, Cambisols, Acrisols, and Nithosols. These are deep, non-swelling clay soils, with favorable physical possessions (drainage, structure, workability) but are deeply leached, ARDCO-GEOSERV (1996).

All the above illustration of the basin soil type gives a broad-spectrum optimistic picture of soils within the basin. On the other hand, 34 % of the basin is covered by shallow and moderately profound soils with undulating topography, good drainage and fertility, i.e. dystric Nitosols (24.9 %), orthic Acrisols (5.6 %) and dystric Cambisols (3.3 %). The major important area of such soils is in the dissected plateau of the highland and lowland divide escarpments, and in areas of high rainfall regions of the eastern and southeastern regions of the basin. This area also characterizes Cambisols (5.5%), moderate to steep slope with shallow and stony soils. These restricted soil depth with shallow and very shallow soils without question result from clearing and cultivation, without proper management, on slopes which are steep to very steep. While soils with seasonal swamps and marshes, meander belts and alluvial plains are characterized with soils types of chromic Vertisols, Eutric fluvisols. In general, soils of the basin are reasonably fertile, and are capable of producing satisfactory yields for a range of fields and cash crops.

3.3. Methodology and Materials Used

3.3.1. Materials Used

In the assessment and evaluation of the baro akobo river basin surface water potential and demands for the medium and large-scale projects the following materials were used.

The materials used for this research are

- Hydrological data (stream flow data).
- Meteorological data (daily Rainfall, Temperature, RH, Sunshine hours, wind speed)
- 90 by 90m DEM data was used as an input data for Arc GIS and Arc SWAT software
- Arc GIS 10.2.1 was used to obtain hydrological and physical parameters and spatial information, to locate geographical location of the study area, to classify land use land cover map etc.
- SWAT software was used to delineate the basin, sub basin and HRUs of the study area and to estimate surface runoff.
- SWAT CUP- was used for sensitivity analysis, calibration and validation of SWAT model.
- WEAP (Water Evaluation And Planning) to estimate water requirements for different uses in the basin.

3.3.2. Methods

For different research, there are different methods. For this research, the following methodologies were used.

- Review of previous related studies on the area
- Collection of Secondary data from institutions such as Ethiopian Water Resource, Irrigation and Energy Minister, Gambella town water supply, Mines and Energy and Ethiopian National Meteorological Service Agency.
- Field observation and collect necessary data and information in the basin.
- After collecting all data, filling of missed data and quality checking have been done
- Preparation of necessary input data for SWAT model.
- Preparing DEM and delineating the watershed of the basin.
- Then the SWAT model is used to simulate surface runoff and WEAP was used for estimation of water demands from large scale projects for the basin

3.3.3. Model Selection Criteria

Several lumped models exist and the following points guide the selection of models for use in this study. There are a number of criteria, which can be used for choosing the right model. These criteria are mainly dependent on the use of the model. Furthermore, some criteria are also user dependent such as personal preference; computer operation system; input/output management etc.

SWAT

The SWAT model is a complex semi-distributed process-based model. It was developed by the Agricultural Research Service of the United States Department of Agriculture and can model changes in hydrology processes, vegetation, erosion, and nutrient loadings at the catchment scale. It divides the catchment into sub catchments and subsequently into Hydrologic Response Units (HRUs). Different combinations of land use, soil types and slope in each sub catchment can be represented by the HRUs. The processes related to water, sediment and nutrient transport are modeled at the HRU scale. The hydrological processes are distributed in five compartments: the stream, the soil surface, the soil layers, the shallow unconfined aquifer, and the deep confined aquifer. Up to ten soil layers can be divided in SWAT. With the daily time step, SWAT simulates nutrient transports and transformations in soil profiles, river network, various water bodies (e.g., pond, lakes, and wetland), and the interaction processes between different systems. It can also differentiate between nutrient fluxes from different sources, e.g., urban areas. More information about the model is provided in.

SWIM

The SWIM model is an integrated, semi-distributed model based on SWAT and MATSALU. It simulates hydrological processes, vegetation, erosion and nutrient cycles at the catchment scale.

GWLF

GWLF is a combined distributed/lumped parameter, continuous process-based model, which is able to simulate runoff, erosion, and nutrient loads from various source areas. Each source area is considered uniform with respect to soil and land cover. Surface runoff is calculated with the SCS-CN method. Erosion is simulated with the Universal Soil Loss Equation (USLE).

HSPF

HSPF is a continuous, semi-distributed, watershed scale model. It was developed to simulate the hydrological system and associated nutrient states of the pervious and impervious land, stream and reservoir. The model disaggregates the catchment into land segments of uniform characteristics on the basis of land use.

HEC-HMS

The Hydrologic Modeling System (HEC-HMS), developed by US Army Corps of Engineers Hydrologic Engineering Center, is designed for both continuous and event-based hydrologic modeling. It provides several different options to the users for modeling various components of hydrologic cycle. The applications of the models are summarized in the table 3.2

Table 3. 2 Comparisons of models for selection

SWAT	SWIM	GWLF	HSPF	HEC-HMS
Surface Runoff	Surface Runoff	Surface Runoff	Surface Runoff	Surface Runoff
Infiltration	Infiltration	Infiltration	Infiltration	infiltration
Evapotranspiration	Evapotranspiration	Evapotranspiration	Evapotranspiration	Base flow
Interflow	Interflow	Percolation flow	Interflow	Flow routing
Percolation flow	Percolation flow	Base flow	Percolation flow	Evapotranspiration
Base flow	Base flow	Seepage flow	Base flow	Snow accumulation
Revap flow	Revap flow		Interception	
Pumping flow	Seepage flow			
Interception				
Drainage flow				
Seepage flow				

Cunderlik (2003) suggested four criteria for the selection of models.

These are:

1. Required model outputs for the needed purpose.
2. Different hydrological processes that are required to be modeled for the desired purpose,
1. Availability of input data and.

2. Price of the soft ware.

Based on the above selection criteria and comparisons of the models for this research Soil and Water Assessment Tool (SWAT) for assessment of surface water potential was selected since.

- Soil and Water Assessment Tool (SWAT) is a public domain model Supported by the USDA Agricultural Research Service at the Grassland, Soil and Water Research Laboratory in Temple, Texas, USA.
- SWAT is a river basin scale, a continuous time, spatially distributed model developed to predict the impact of land management practice on water, sediment and agricultural chemical yields in large complex water sheds with varying soils, and land use and soil management over long period of time(Neitsch.et al 2005).

3.3.4. Description of SWAT Model

US Department of Agriculture – Agriculture Research Service (USDA-ARS), developed the Soil and Water Assessment Tool (SWAT) model. It is a conceptual model that functions on a continuous time step. Model components include weather, hydrology, erosion/sedimentation, plant growth, nutrients, pesticides, agricultural management, channel routing, and pond/reservoir routing. Agricultural components in the model include fertilizer, crops, tillage options, and grazing and have the capability to include point source loads (Neitsch et al., 2001a; Neitsch et al., 2001b). The SWAT model predicts the influence of land management practices on constituent yields from a watershed. SWAT is the continuation of over 30 years of model development within the US Department of Agriculture’s Agricultural Research Service. The CREAMS, GLEAMS, and EPIC models (Knisel, 1980; Leonard et al., 1987); Williams et al., 1984) have each contributed to the scaling up of past field-scale models to one which includes large river basins. SWAT is a public domain model, which is actively supported by the USDA Agricultural Research Service at the Grassland, Soil, and Water Research Laboratory in Temple, Texas, USA.

SWAT is a theoretical model that operates on a daily time step. In order to adequately simulate hydrologic processes in a basin, the basin is divided into sub basins through which streams are routed. The subunits of the sub basins are referred to as hydrologic response units (HRU’s) which are the unique combination of soil and land use characteristics and are considered hydrological homogeneous. The model calculations are performed on a HRU basis and flow and water quality variables are routed from HRU to sub basin and subsequently to the watershed outlet. The SWAT

runoff will start. Surface runoff occurs whenever the rate of precipitation exceeds the rate of infiltration. SWAT offers two methods for estimating surface runoff: the SCS curve number procedure (USDA-SCS, 1972) and the Green and Ampt infiltration method (Green and Ampt, 1911; as cited in Neitsch *et al.*, 2005). Using daily or sub daily rainfall, SWAT simulates surface runoff volumes and peak runoff rates for each HRU. The SCS curve number equation is (SCS, 1972):

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)} \text{-----3.2}$$

Where, Q_{surf} is the accumulated runoff or rainfall excess (mm), R_{day} is the rainfall depth for the day (mm); S is the retention parameter (mm).

SCS defines three antecedent moisture conditions: I-dry (wilting point), II-average moisture and III-wet (field capacity). The moisture condition I curve number is the lowest value the daily curve number can assume in dry conditions. The curve numbers for moisture conditions I and III are calculated with the equations 3.3 and 3.4, respectively.

$$CN_1 = CN_2 - \frac{20 \times (100 - CN_2)}{(100 - CN_2 + \exp[2.533 - 0.0636 \times (100 - CN_2)])} \text{-----3.3}$$

$$CN_3 = CN_2 \times \exp[0.00673(100 - CN_2)] \text{-----3.4}$$

Where, CN_1 is the moisture condition I curve number, CN_2 is the moisture condition II curve number, and CN_3 is the moisture condition III curve number.

The retention parameter is defined by equation 3.5

$$S = 25.4 \left(\frac{1000}{CN} - 10 \right) \text{-----3.5}$$

SWAT includes two methods for calculating the retention parameter; the first one is retention parameter varies with soil profile water content and the second method is the retention parameter varies with accumulated plant evapotranspiration. The soil moisture method (equation 3.6) over-estimates runoff in shallow soils. But calculating daily CN as a function of plant evapotranspiration, the value is less dependent on soil storage and more dependants on antecedent climate. Runoff will only occur when $R_{day} > 0.2S$. The retention parameter varies with soil profile water content according to the following equation:

$$S = S_{\max} \times \left(1 - \frac{SW}{SW + \exp(w_1 - w_2 \times SW)}\right) \text{-----3.6}$$

where S is the retention parameter for a given moisture content (mm), S_{max} is the maximum value the retention parameter can achieve on any given day (mm), SW is the soil water content of the entire profile excluding the amount of water held in the profile at wilting point (mm of water), and w₁ and w₂ are shape coefficients.

The maximum retention parameter value, S_{max}, is calculated by solving equation 3.7 using CN1

$$S_{\max} = 25.4 \left(\frac{1000}{CN_1} - 10\right) \text{-----3.7}$$

The shape coefficients are determined by solving equation 3.8 assuming that,

1) The retention parameter for moisture condition I curve number corresponds to wilting point soil profile water content.

2) The retention parameter for moisture condition III curve number corresponds to field capacity soil profile water content, and 3) The soil has a curve number of 99 (S = 2.54) when completely saturated.

$$w_1 = \ln \left[\frac{FC}{1 - S_3 \times S_{\max}^{-1}} - FC \right] + w_2 \times FC \text{-----3.8}$$

$$w_2 = \frac{\left(\ln \left[\frac{FC}{1 - S_3 \times S_{\max}^{-1}} - FC \right] - \ln \left[\frac{SAT}{1 - 2.54 \times S_{\max}^{-1}} - SAT \right] \right)}{(SAT - FC)} \text{-----3.9}$$

Where

- w₁ is the first shape coefficient,
- w₂ is the second shape coefficient,
- FC is the amount of water in the soil profile at field capacity (mm of water),
- S₃ is the retention parameter for the moisture condition III curve number,
- S_{max} is the retention parameter for the moisture condition I curve number,
- SAT is the amount of water in the soil profile when completely saturated (mm of water), and 2.54 is the retention parameter value for a curve number of 99.

The daily curve number value adjusted for moisture content can be calculated by rearranging equation 3.7 and inserting the retention parameter calculated for that moisture content:

$$CN = \frac{25400}{(S + 254)} \text{-----}3.10$$

Where, CN is the curve number on a given day and S is the retention parameter calculated for the moisture content of the soil on that day.

The moisture condition II curve numbers provided in the tables are assumed appropriate for 5% slopes. Williams (1995) developed an equation to adjust the curve number to a different slope:

$$CN_{2s} = \frac{(CN_3 - CN_2)}{3} \times [1 - 2 \times \exp(-13.86 \times slp)] + CN_2 \text{-----}3.11$$

Where, CN_{2s} is the moisture condition II curve number adjusted for slope, CN_3 is the moisture condition III curve number for the default 5% slope, CN_2 is the moisture condition II curve number for the default 5% slope, and slope is the average percent slope of the sub-basin. Runoff is calculated separately for each sub-basin and routed to obtain the total runoff for the basin.

SWAT calculates the peak runoff rate with a modified rational method. Many methods are developed to estimate potential evapotranspiration (PET). Three methods are incorporated into SWAT: the Penman-Monteith method (Monteith, 1965), the Priestley-Taylor method (Priestley et al, 1972) and the Hargreaves method (Hargreaves *et al.*, 1985) and the model will also read in daily PET values if the user prefers to apply a different PET methods.

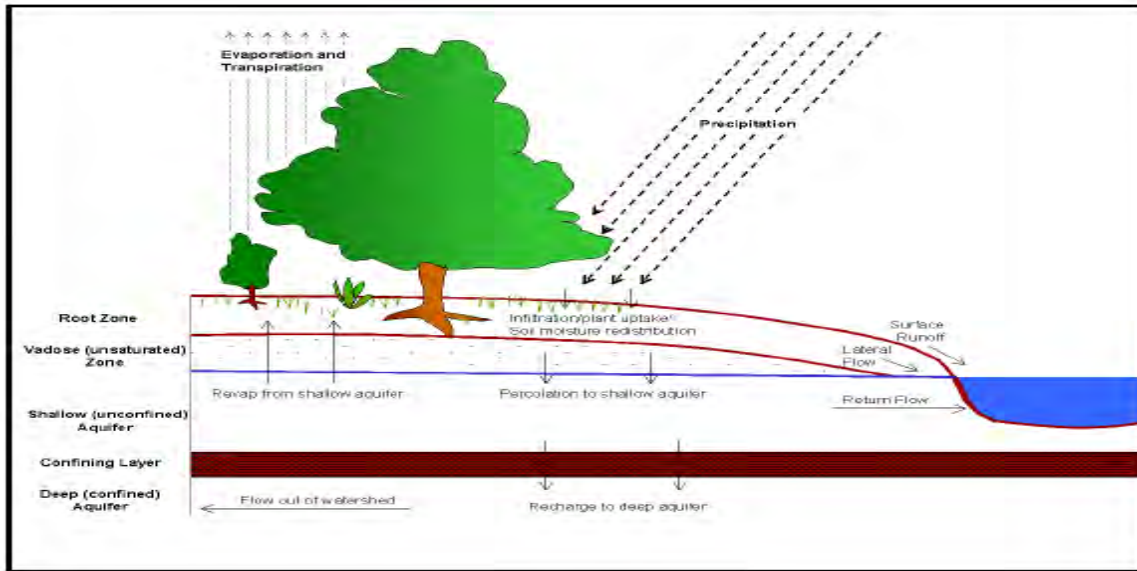


Figure3. 7 Hydrologic cycle consider by SWAT model (from Neitsch et al.2001).

3.4. SWAT Model Inputs

For the assessment of the available surface water potential, the SWAT model requires the following input data such as DEM of the study area, topography, soil, land use and meteorological data include, daily rainfall, minimum and maximum temperature, relative humidity, solar radiation, and wind speed are required.

3.4.1. Digital Elevation Model

Digital Elevation Model (DEM) is one of the inputs for SWAT model to delineate the watershed. Topography was defined by a DEM, which describes the elevation of any point in a given area at a specific spatial resolution as a digital file. For this research, a DEM with a resolution of 90 m was used, which was sourced from ASTER GDEM of official website, released by ERSDAC (Earth Remote Sensing Data Analysis Center) in collaboration with NASA and collected from Ethiopian Water Resource, Irrigation and Energy Ministry.

The catchment physiographic data were generally collected from topographic maps and 90mx90m resolution DEM. This DEM data was obtained from GIS data that found in Ministry of Water and Energy directorate of GIS. This DEM data was basic input for the water shed delineation and slope calculation of the basin in the SWAT model processing.

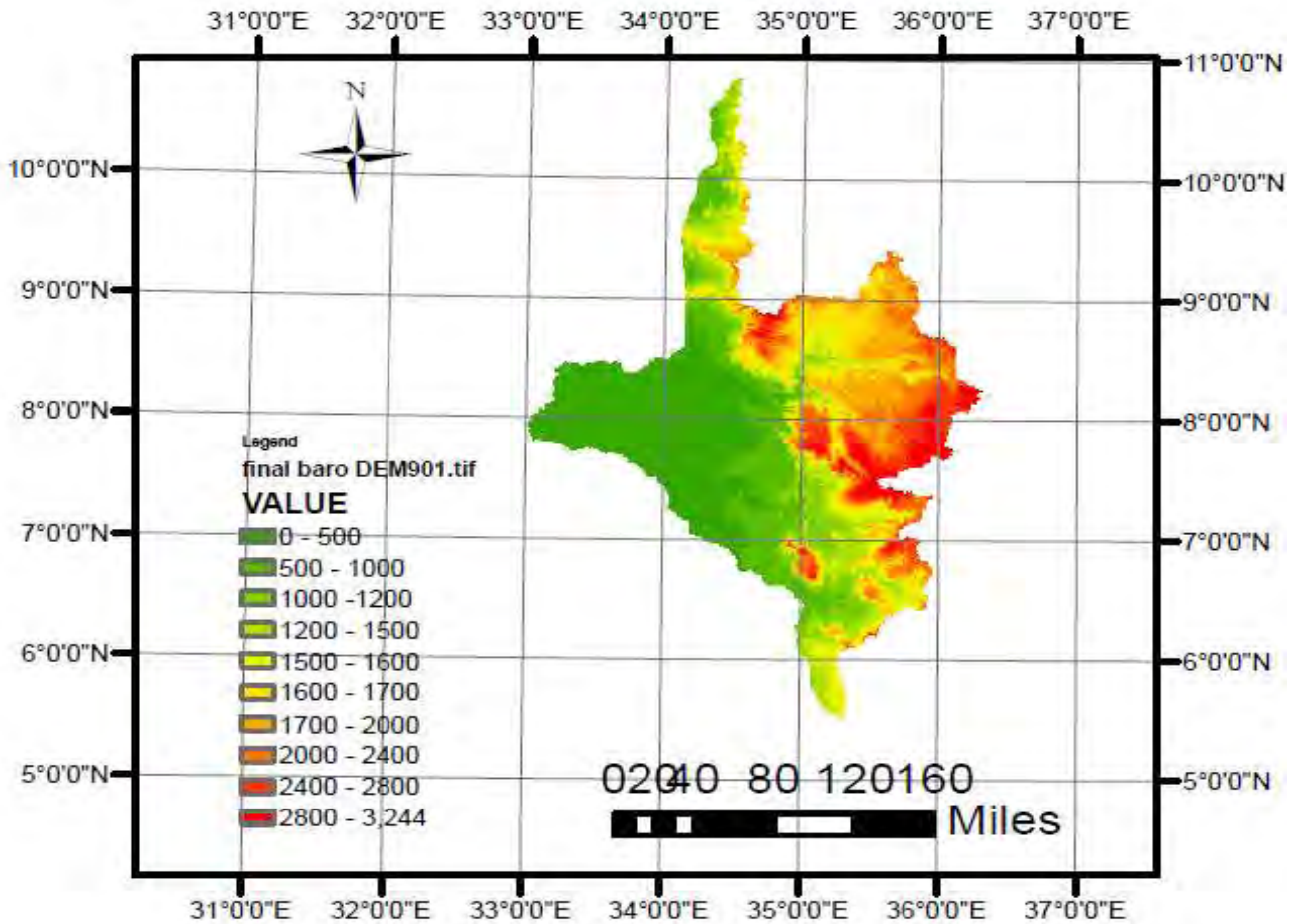


Figure 3. 8 Digital elevation model for baro akobo river basin extracted from Ethio DEM90.

3.4.2. Land Use Land Cover Data

Land use, land cover, of the catchments was obtained from GIS data that found in Ministry of Water and Energy directorate of GIS. The land use data was not latest to use in this research. It is the 1990 land use data. Hence, the latest land use data was essential for the analysis. This data found from Global Visualization Viewer (GloVIS) land sat image. The land sat image was downloaded from this site and mosaic to form the land use and land cover data of the river basin. The latest land sat image is shown in the figure 3.9 is the latest land use image. This image was re classified based on the field inspection and data collected from gambella region.

There are two main categories that can be used to achieve this outcome and they are called Supervised and Unsupervised Classification techniques. In supervised land classification, the individual processing the imagery guides the image processing software to help it decide how to

classify certain features. This is done by the use of a vector layer containing training polygons. In unsupervised classification, the software does most of the processing on its own generally resulting in more use categories than the user is interested in

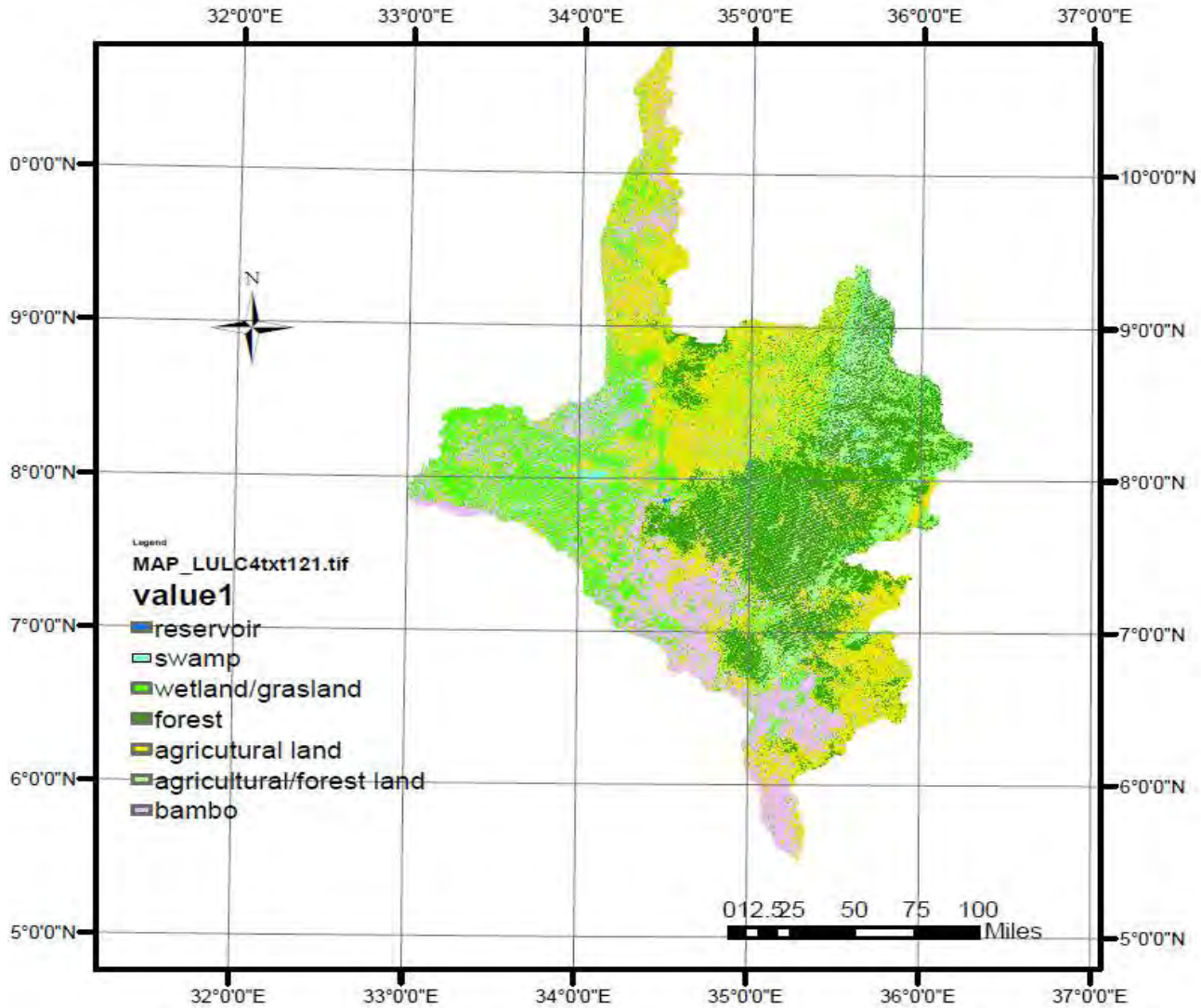


Figure3. 9 Land use/cover of Baro-Akobo river basin derived from land sat image.

Soil data of the basin was not found from the Minister of Energy and Water but the data was taken from Belete et al, 2013. The soil type data of the Baro-Akobo river basin is shown in the tables in appendix C.

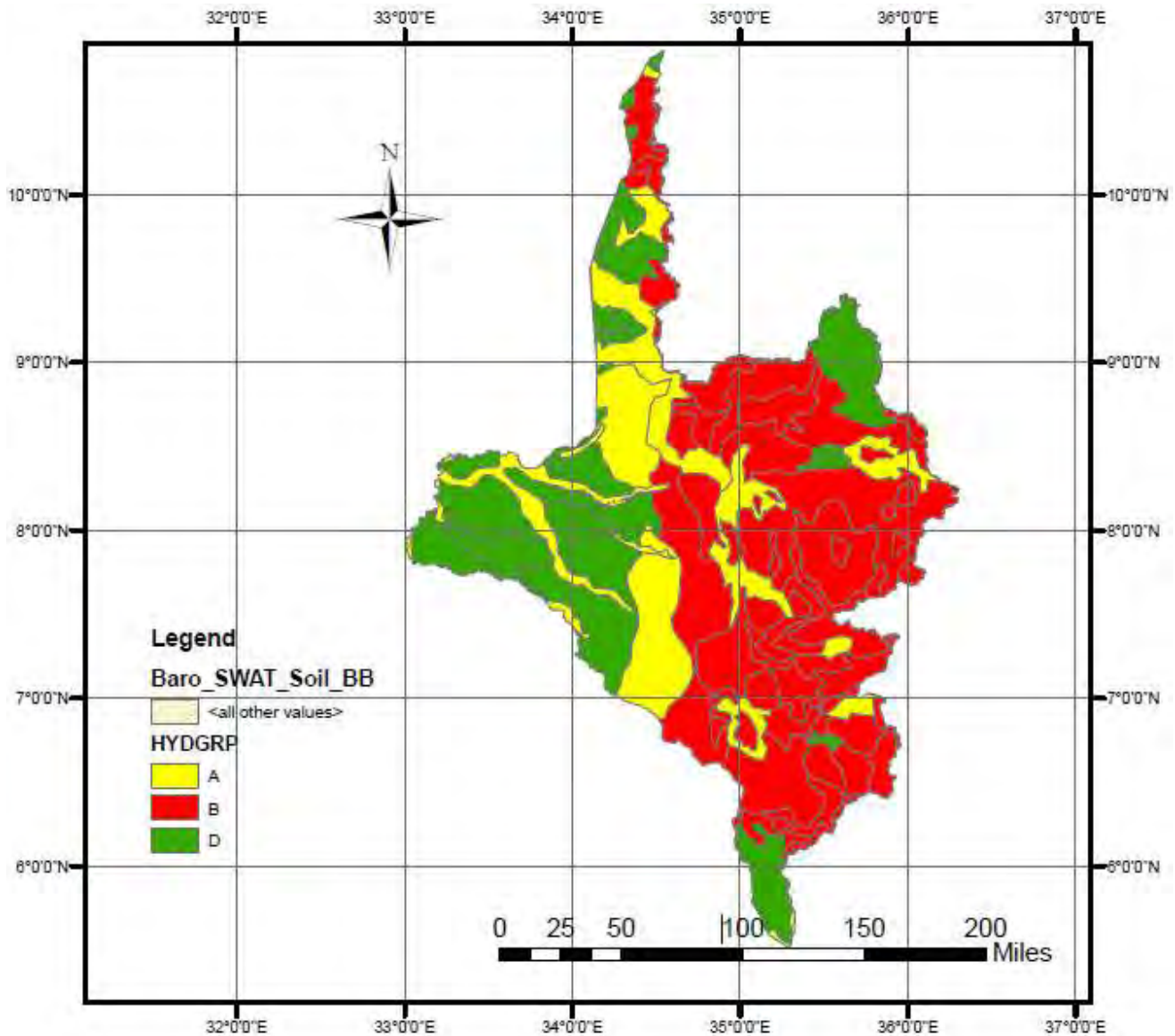


Figure3. 10 Soil map of Baro-Akobo river basin.

3.4.3. Hydro-Meteorological data

Hydrological modeling largely depends on hydro-meteorological (precipitation, temperature, relative humidity, wind run and sunshine hours) and hydrological (stream flow) data. Reliability of the collected raw hydro-meteorological and hydrological data significantly affects quality of the model input data and, as a result, the model simulation. This chapter sequentially presents, rough data screening of raw hydro-meteorological and hydrological data, completion of identified missing data. Figure 3.11 and 3.12 shows metrological and hydrological Gauging stations.



Figure3. 11 Itang metrological station.

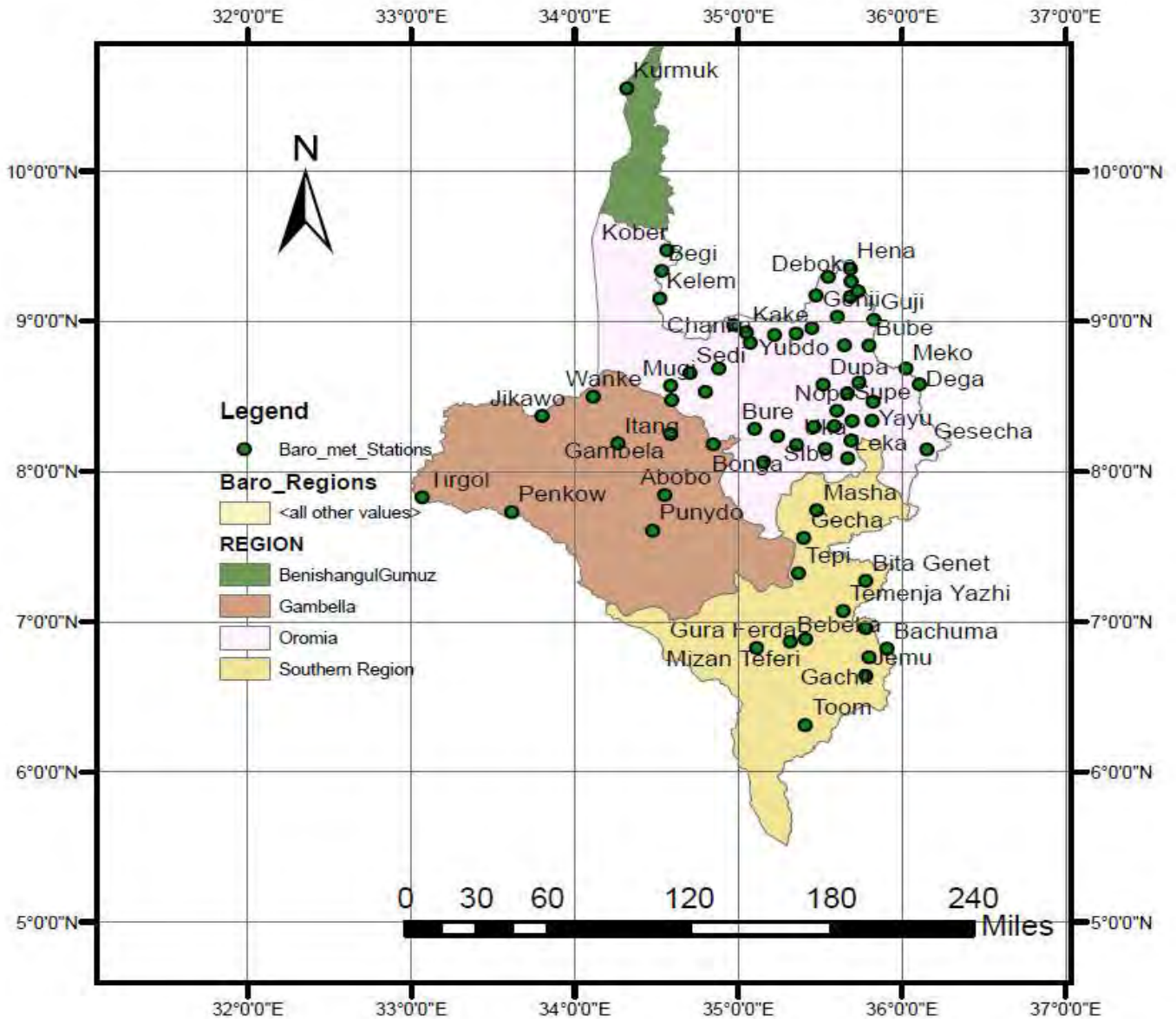


Figure3. 12 Baro-Akobo metrological gauging station

The SWAT model requires daily meteorological data that either could be read from a measured data set or be generated by a weather generator model which include daily precipitation, maximum and minimum air temperature, solar radiation, wind speed and relative humidity. Daily precipitation and maximum and minimum temperature data were collected from National Meteorological Service Agency (NMSA). These were used and for solar radiation, wind speed and relative humidity, different monthly parameters were estimated using pcp STAT and Dew point estimation program and sunshine hours was converted in to solar radiation energy (MJ/m²-day) using sunshine hour to radiation conversion tool which was created by Eric White, (2008) using the Angstrom –Prescott equation.

Hydrological data were the principal data set in the research work. Other sets of data were all collected depending on the availability and suitability of data from the hydrological stations. Eleven continuous water level recording stations were obtained from the Ministry of Water and Energy, Hydrology Directorate. The daily recorded of hydrological data was requested for twenty-two year and approved by the office to collect and use for the research work.

3.4.4. Weather Generator

The SWAT model has an automatic weather data generator. However, it needs some input data to run the model. The model can be run if the following data are available. Daily precipitation, maximum daily temperature, minimum daily temperature, sunshine hour, daily relative humidity and daily wind run data. If no data are available at the same time for all stations, the model can generate all the remaining data from daily precipitation and temperature data. For this purpose the model needs some main stations with full data and from that it can generate for the remaining stations.

In this research, fifteen stations were used to run the SWAT model for estimation of surface runoff. From the fifteen stations, three stations with full data were used to generate the missed data for the other station and used to run the model. These three stations are Masha, Tepi and Gore meteorological stations.

The model needs the following input data for these main stations.

- Maximum temperature
- Minimum temperature
- Dew point data
- Precipitation data

- Average solar radiation data
- Average wind run data
- Standard deviation for temperature

The above input data for weather generator are shown in appendix B

3.5 Analysis and Gap-Filling

3.5.1 Rainfall Data Screening

Rough rainfall data screening of the fifteen metrological stations in the study area was first done by visual inspection of daily rainfall data. Because of long braking in rainfall records of some stations, it was necessary to fill all the missed values in the recording stations for the years of 1992 to 2013.

Graphical comparison of the rainfall data done by creating time series plotting of monthly rainfall data (see figure 3.13) showed that the fifteen stations show similar periodic pattern of records. The rainfall data used in the model is given in Appendix A for these stations.

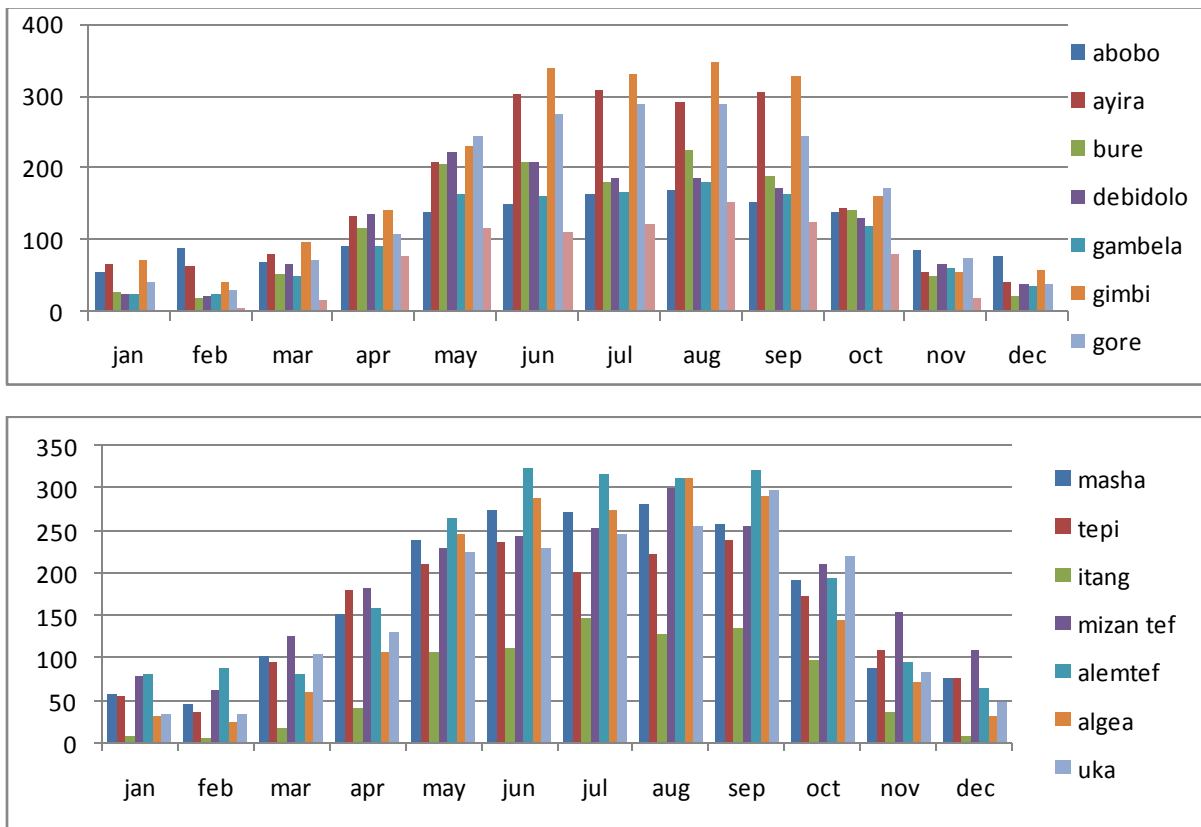


Figure3. 13 Average Monthly Rainfall Data (mm/day) series for years 1992 to 2013

3.5.2 Missing Data Completion

Missing data is a common problem in hydrology. To perform hydrological analysis and simulation using data of long time series, filling in missing data is very important. The missing data can be completed using metrological and/or hydrological stations located in the nearby stations, if the stations are located in hydrological homogenous region. Summary of all stations with their available metrological data shown in table 3.3.

Table 3. 3 Description of metrological stations with percentage missed data.

S. N	Station name	precipitation	Temperature	Sunshine hour	Relative	Wind run
		years With Data	years With Data	years With Data	years With Data	years With Data
1	Abobo	(27%)	(50%)	No data	No data	No data
2	Alem	(58%)	(55%)	No data	No data	No data
3	Algea	(66%)	(24%)	No data	No data	No data
4	Ayira	(70%)	(43%)	No data	(27%)	No data
5	Bure	(90%)	(53%)	(23%)	(10%)	No data
6	Dimbidol	(97%)	86%)	No data	No data	No data
7	Gambela	(30%)	(30%)	(27%)	(27%)	(27%)
8	Gore	(63%)	(57%)	(66%)	(66%)	(50%)
9	Itang	(56%)	(43%)	No data	No data	No data
10	Masha	(63%)	(47%)	(56%)	(50%)	(50%)
11	Mizan	(63%)	(13%)	No data	No data	No data
12	Tepi	(63%)	(63%)	(33%)	(36%)	(47%)
13	Uka	(93%)	(73%)	No data	No data	No data

- **Filling in Missing Stream flow Data**

A number of stations in the basin have incomplete records. Such gaps in the record are filled by developing correlations between the station with missing data and any of the adjacent stations with the same hydrological features and common data periods.

- **Filling in Missing Rainfall Data**

A number of methods have been proposed for estimate missing rainfall data (Richard H.McCuen (1989). the station average method is the simplest method. The normal-ratio and quadrant methods provide a weighted mean, with the former basing the weights on the mean annual rainfall at each

gauge and the latter having weights that depend on the distance between the gauges where recorded data are available and the point where a value is required.

The station average method for filling missing data is conceptually the same as the station average method for estimating a mean precipitation. This method may not be accurate when the total annual rainfall at any of the n region gauges differs from the annual rainfall at the point of interest by more than 10%.

The normal-ratio method is conceptually simple; it differs from the station-average method of that the average annual rainfall is used in deriving weights. If the total annual rainfall at any of the n region gauges differs from the annual rainfall at the point of interest by more than 10%, the normal-ratio method is preferable.

In this research because of the shortage of the total annual rainfall and normal rainfall, which is necessary conditions for the normal ratio and station average methods, the regression method was good methods of estimation to fill the gaps.

Method based on regression analysis

Assume that two precipitation gages *Y* and *X* have long records of annual precipitation, i.e.

*Y*₁, *Y*₂ ,..., *Y*_{*N*} and *X*₁, *X*₂ ,..., *X*_{*N*} . The precipitation *Y*_{*t*} is missing. We will fill in the missing data based on a simple linear regression model. The model can be written as:

$$Y_t = a + b X_t \text{3.12}$$

in which the parameters a and b can be estimated by:

$$\hat{a} = \bar{Y} - \hat{b} \bar{X}$$

$$\hat{b} = r_{XY} \frac{S_Y^*}{S_X^*} \text{3.13}$$

Where *Y* and *X* are the sample means, *S*^{*} *Y* and *S*^{*} *X* are the sample unbiased standard deviations of *Y* and *X*, respectively, and *r*_{*XY*} is the cross-correlation coefficient between *X* and *Y*. The latter term can be estimated as:

$$r_{xy} = \frac{\frac{1}{N} \sum_{i=1}^N [(X_i - \bar{X})(Y_i - \bar{Y})]}{S_X S_Y} \text{-----3.14}$$

Where S_Y and S_X are the sample biased standard deviations (add comments regarding: the Limitation of the method, not enough data, degree of correlation, sample size, etc.) R_{xy} indicates the relationship between the two variables. The higher the square value of R_{xy} indicates the best fit of the regression equation. Thus based on this for this estimation different R-values are calculated and the best fit selected for each station. Based on this method all the stations were filled and the regression equations with basic parameters are shown in the table 3.4.

Table 3. 4 Regression equations for metrological stations missed data filling.

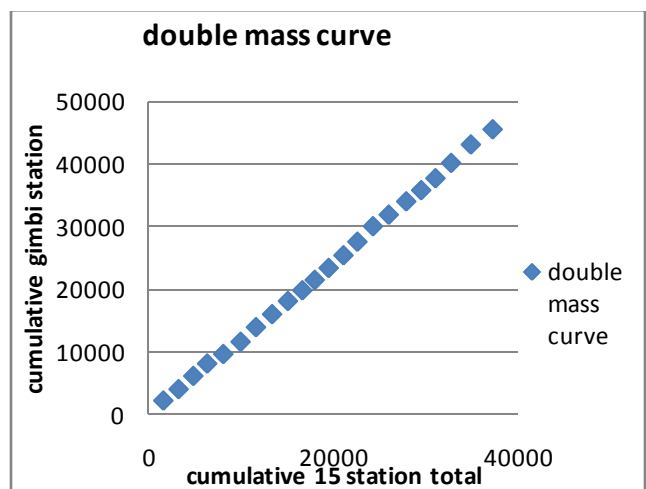
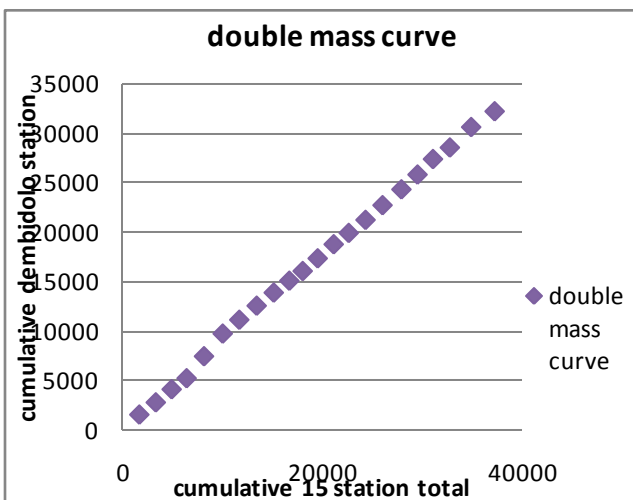
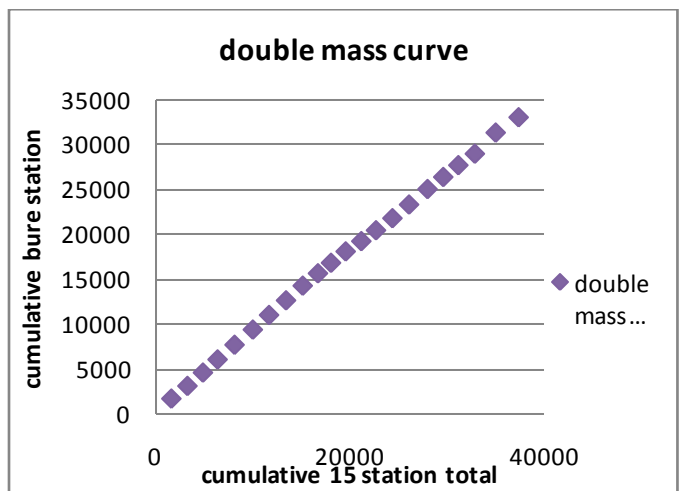
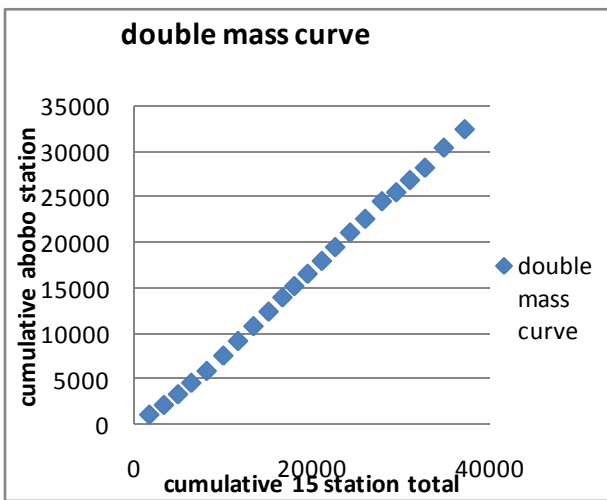
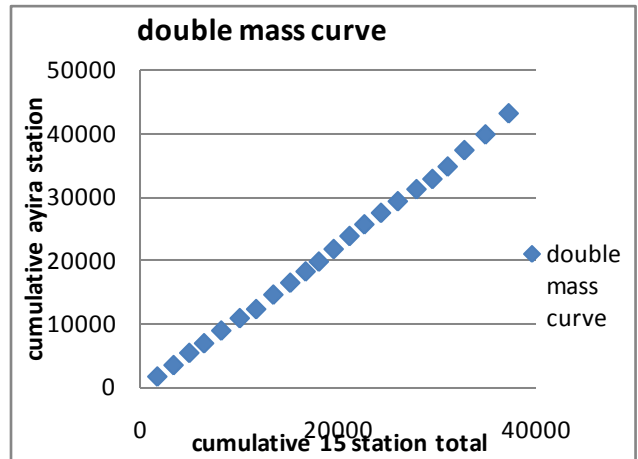
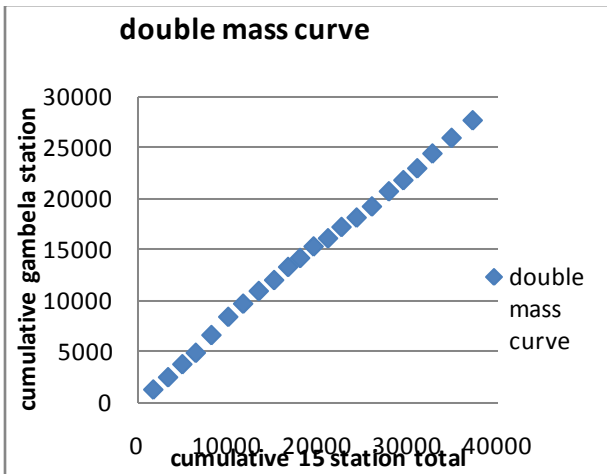
Station	R ²	Standard	Coefficient a	Coefficient b	Regression equation
Abobo	0.73	9.5	0.35	3.15	Y=0.35(Gambela)+3.15
Alem teferi	0.62	10.7	0.7	5.3	Y=0.7(Ayira)+5.3
Algea	0.81	6.6	0.4	4.1	Y=0.4(Ayira)+4.1
Ayira	0.74	10.9	0.7	2.75	Y=0.7(Gimbi)+2.75
Bure	0.64	7.5	0.65	1.35	Y=0.65(Uka)+1.35
Dembidolo	0.75	9.8	0.84	2.4	Y=0.84(Bure)+2.4
Gimbi	0.72	9.6	0.7	3.1	Y=0.7(Nolekaba)+3.1
Gore	0.76	7.8	0.9	0.8	Y=0.9(Algea)+0.8
Masha	0.65	8.8	0.6	1.6	Y=0.6(Bedele)+1.6
Mizan Teferi	0.66	14.8	0.9	5.9	Y=0.9(Tepi)+5.9
Uka	0.82	7.5	1	1.5	Y=(gore)+1.5

The final adjusted daily data was used for daily SWAT model run. The average monthly SWAT input data is shown in the appendix A.

3.5.3 Consistency of recording stations

If the conditions relevant to the recording of a rain gauge station have undergone a significant change during the period of record, inconsistency would arise in the rainfall data of that station. This inconsistency would be felt from the time the significant change took place. The checking for inconsistency of a record is done by double mass curve technique as shown in figure 3.14.

The accumulated total of the individual gauge is compared with the corresponding totals for a representative group of nearby gauge. If a decided change in the regime of the curve is observed it should be corrected. However, as all the selected stations in this study were consistent, there is no need of further correction.



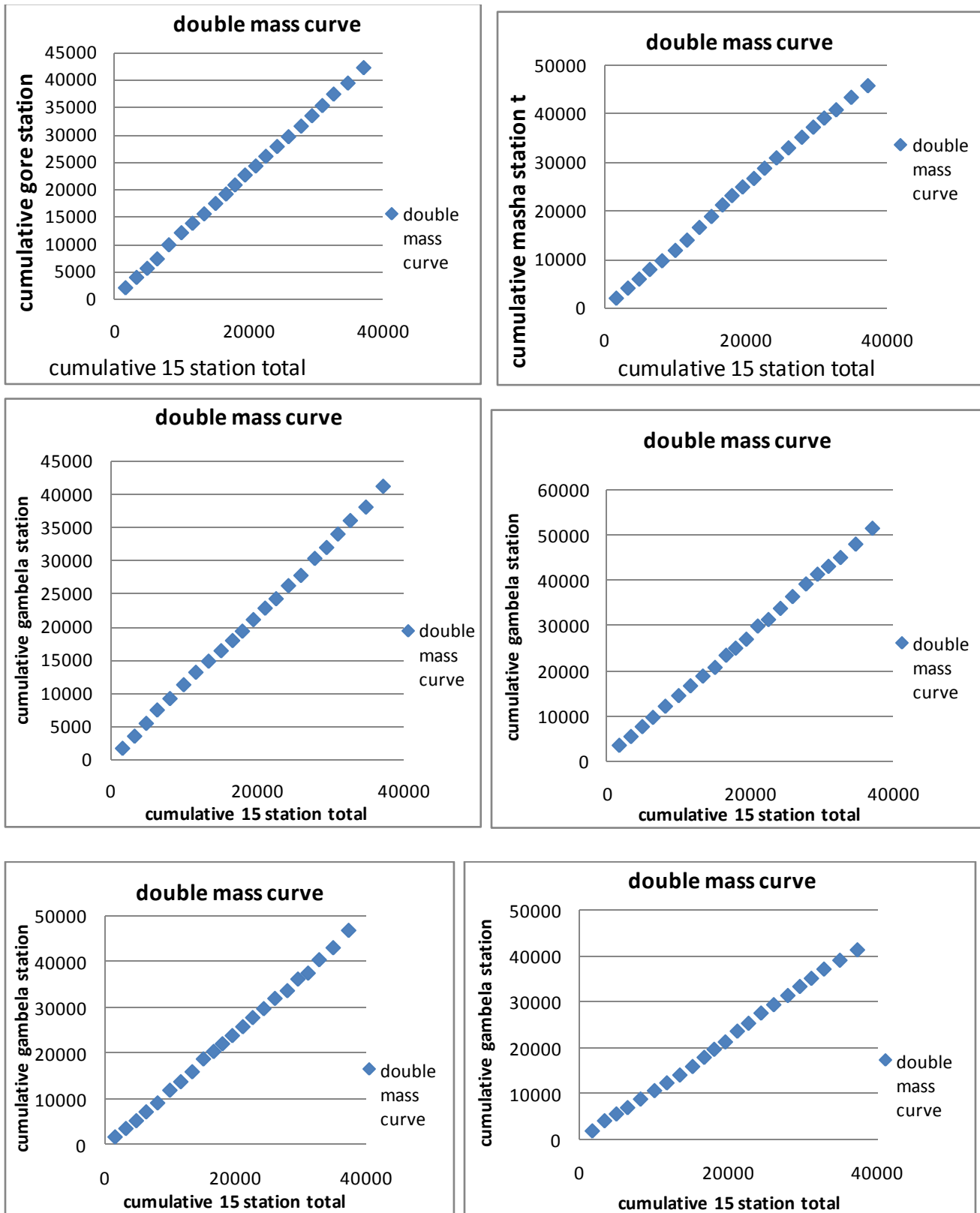


Figure3. 14 double mass curves for the stations.

The above graphs showed all points set on or form almost the straight lines, which was plotted for checking of consistency of rainfall, all stations were consistence and have more or less acceptable homogeneity. Therefore, the stations did not need further adjustment.

3.5.4 Outlier Tests for precipitation data

Outliers are data points that depart significantly from the trend of the remaining data or outliers are peaks that depart substantially from the trend of the remaining peaks. The Water Resources Council method recommends that adjustments be made for outliers. The retention or deletion of these outliers can significantly affect the magnitude of statistical parameters computed from the data, especially for small samples. Procedures for testing outliers require judgment involving both mathematical and hydrologic considerations. According to the Water Resources Council (1981), if the station skew is greater than +0.4, tests for high outliers are considered first; if the station skew is less than -0.4, tests for low outliers are considered first. Where the station skew is between ± 0.4 , tests for both high and low outliers should be applied before eliminating any outliers from the data set (Ven Te Chow).

The following frequency equation can be used to detect high outliers:

$$X_H = X_{av} + K_N S, \text{-----} 3.15$$

Where X_H = Logarithmic high-outlier test threshold,

S= standard deviation

K_N = 10-percent significance-level critical value for outlier test statistic for samples of size N from the normal distribution (See appendix C).

If the logarithms of values in a sample are greater than X_H in the above equations, then they are considered high outliers.

Table 3. 5 Average Precipitation data at the stations.

year	Abobo		Gore		Masha		Tepi		Gambela	
	Ave pcp	log value	Ave pcp	Log value	Ave pcp	Log value	Ave pcp	log value	Ave pcp	log value
1992	90.5	2.0	174.1	2.2	173.7	2.2	140.0	2.2	115.6	2.06
1993	88.7	2.0	157.9	2.2	172.3	2.2	177.7	2.3	100.3	2
1994	98.2	2.0	138.1	2.1	155.0	2.2	161.0	2.2	105.9	2.02
1995	79.6	1.9	144.1	2.2	163.2	2.2	159.8	2.2	93.0	1.97
1996	117.0	2.1	214.4	2.3	149.5	2.2	143.8	2.2	161.2	2.21
1997	157.3	2.2	184.2	2.3	177.4	2.3	157.4	2.2	165.1	2.22
1998	134.1	2.1	143.7	2.2	175.6	2.2	156.5	2.2	107.1	2.03
1999	135.9	2.1	143.9	2.2	217.2	2.3	139.4	2.1	111.6	2.05
2000	133.8	2.1	158.3	2.2	187.0	2.3	131.5	2.1	105.9	2.02
2001	130.6	2.1	143.9	2.2	197.8	2.3	128.1	2.1	98.4	1.99
2002	103.2	2.0	138.5	2.1	160.1	2.2	117.8	2.1	64.7	1.81
2003	112.3	2.1	151.3	2.2	147.5	2.2	145.5	2.2	52.5	1.72
2004	118.2	2.1	137.8	2.1	145.8	2.2	143.9	2.2	66.6	1.82
2005	126.9	2.1	147.6	2.2	174.3	2.2	118.5	2.1	91.9	1.96
2006	133.7	2.1	149.3	2.2	177.4	2.3	164.5	2.2	76.6	1.88
2007	125.3	2.1	149.2	2.2	170.8	2.2	128.6	2.1	90.6	1.96
2008	161.2	2.2	161.4	2.2	182.6	2.3	213.8	2.3	123.2	2.09
2009	82.7	1.9	158.5	2.2	172.1	2.2	137.3	2.1	90.8	1.96
2010	111.2	2.1	155.2	2.2	155.1	2.2	169.4	2.2	96.8	1.99
2011	113.6	2.1	174.6	2.2	142.1	2.2	169.4	2.2	120.5	2.08
2012	100.3	2.0	167.9	2.2	130.1	2.1	169.3	2.2	127.4	2.11
2013	85.8	1.9	151.8	2.2	198.6	2.3	178.4	2.3	101.4	2.01
	Xav	2.05	Xav	2.19	Xav	2.23	Xav	2.18	Xav	2
	skew	-0.15	skew	1.43	skew	-0.05	skew	0.26	skew	-0.4
	STDV	0.09	STDV	0.05	STDV	0.05	STDV	0.06	STDV	0.12
	Kn =2.175		Kn =2.176		Kn =2.177		Kn =2.178		Kn =2.179	
XH	2.244		2.29		2.34		2.317		2.254	
PCP(mm)	175.4		195		218.8		207.5		179.5	
XL	1.864		2.09		2.11		2.04		1.746	
PCP(mm)	73.1		123		128.8		109.4		55.72	

KN =2.175 from the table

According to the Water Resources Council (1981), if information is available that indicates a high outlier is the maximum over an extended period, the outlier is treated as historic flood data and excluded from the analysis.

If the record does not contain sufficient information to adjust for high outliers, they should be retained as part of the systematic record.

A similar equation can be used to detect low outliers:

$$X_L = X_{av} - K_N S \text{-----} 3.16$$

Where X_L = logarithmic low-outlier test threshold.

the outlier test for basic stations has been done as shown in table 3.5, so that tests for both high and low outliers were applied and the following results were obtained.

The outlier test result shows that, the largest recorded value for all stations do not exceed high outlier test respective threshold value and the smallest recorded value is not below low outlier test threshold value, so both high and low outliers were not detected.

3.5.4 Stream flow Data Screening

The initial step taken during the stream flow data screening as suggested by Gordon et al. (1992) was quick visual scan of the data time series to detect gross errors such as erroneous peak flow, missed recordings, and flow of constant rate. It helps to detect the year with magnitude change in the data, long period of missing records, and short-term missing data. In addition to this for SWAT model, it was compulsory to much the sub basin outlet and the stream flow gauging station which was used for calibration and validation steps. Thus in this research the Baro gauging station at Gambela town was selected as an input. It has relatively long year data with missed values which was filled regression. It was selected because it has high flow at this station. The stream flow recording stations with their percentage-missed values are shown in the table 3.6.

Table 3. 6 Description of the Stream flow recording stations with percentage missed

No.	Station name	Lat.(deg)	Long(deg)	Area (km2)	Years with data	Missed(%)
1	BaroGambella	8.15	34.35	23461.0	1994-2005	45%
2	Baro nr Masha	7.63	35.56	1653	1995-2006	45%
3	Beko	7.24	35.46	219	1993-2005	40%
4	Gumero	8.15	35.48	106	1995-2001	70%
5	Geba	8.48	35.65	3894	1997-2005	60%
6	Keto	7.78	35.03	1006	1995-2004	54%
7	Meti	8.55	34.85	144	1995-2005	50%
8	Sore	8.32	35.6	1622	1994-2005	54%
9	Uka	8.17	35.37	52.5	1994-2005	54%

3.5.5 Outlier Tests for river flow data

Outliers are data points that depart significantly from the trend of the remaining data or outliers are peaks that depart substantially from the trend of the remaining peaks. The Water Resources Council method recommends that adjustments be made for outliers. The retention or deletion of these outliers can significantly affect the magnitude of statistical parameters computed from the data, especially for small samples. Procedures for testing outliers require judgment involving both mathematical and hydrologic considerations. According to the Water Resources Council (1981), if the station skew is greater than +0.4, tests for high outliers are considered first; if the station skew is less than -0.4, tests for low outliers are considered first. Where the station skew is between ±0.4, tests for both high and low outliers should be applied before eliminating any outliers from the data set (Ven Te Chow).

The following frequency equation can be used to detect high outliers:

$$X_H = X_{av} + K_N S, \text{-----} 3.17$$

Where X_H = Logarithmic high-outlier test threshold,

S= standard deviation

K_N = 10-percent significance-level critical value for outlier test statistic for samples of size N from the normal distribution (See appendix C).

If the logarithms of values in a sample are greater than X_H in the above equations, then they are considered high outliers.

According to the Water Resources Council (1981), if information is available that indicates a high outlier is the maximum over an extended period, the outlier is treated as historic flood data and excluded from the analysis.

If the record does not contain sufficient information to adjust for high outliers, they should be retained as part of the systematic record.

A similar equation can be used to detect low outliers:

$$X_L = X_{av} - K_N S \text{-----} 3.18$$

Where X_L = logarithmic low-outlier test threshold.

Flood peaks considered as low outliers are deleted from the record and a conditional probability adjustment described by the Water Resources Council (1981) can be applied.

During the outlier test for Gambella station, the station skew (G) was found to be -0.1944, which is between ± 0.4 , so that tests for both high and low outliers were applied and the following results were obtained.

Table 3. 7 Average annual river flow data at Gambella station.

Year	Average flow(m ³ /s)	Logarithmic Value
1994	368.5364167	2.56648
1995	330.26	2.51886
1996	451.4629167	2.65462
1997	448.7505	2.652
1998	473.3235	2.67516
1999	469.9180833	2.67202
2000	439.0279167	2.64249
2001	401.7739167	2.60398
2002	294.4285	2.46898
2003	285.1859167	2.45513
2004	326.4176667	2.51377
2005	321.0684167	2.5066
Average		2.57751
skew		-0.1944
STDV		0.08218

$K_N = 2.134$ from the table

High outlier test, $X_H = X_{av} + K_N S, = 2.57750805651401 + 2.134 * 0.0822, X_H = 2.753$

$Q = 10^{2.753} = 566.13 \text{ m}^3/\text{s}$

And for low outlier test, $X_L = X_{av} - K_N S = 2.5775 - 0.1754 = 2.402, Q = 10^{2.402} = 252.4 \text{ m}^3/\text{s}$

The outlier test result shows that, the largest recorded value($473.3\text{m}^3/\text{s}$) does not exceed high outlier test threshold value($566.13\text{ m}^3/\text{s}$) and the smallest recorded value ($294.4\text{m}^3/\text{s}$) is not below low outlier test threshold value($252.4\text{m}^3/\text{s}$), so both high and low outliers were not detected.

3.6. SWAT Model Set Up

As discussed above, the input data for the SWAT model were Digital Elevation Model data; land use and land cover data, soil data, hydrological data and metrological data. The first step in the analysis of the SWAT model was watershed delineation and dividing the watershed in to sub basins of hydrological response units (HRU). After that the land use, soil and slope data were over lay on the delineated watershed. Finally SWAT model was run.

3.6.1. Watershed Delineation

The first step in creating SWAT model input is delineation of the watershed from a DEM. The SWAT model provides three spatial levels: the watershed, the sub-basins, and the hydrologic response units (HRUs). Each level was characterized by a parameter set and input data. The watershed and sub-basin delineation was done using DEM data with about one third ($1/3$) of the minimum suggested threshold area which is recommended by the arc SWAT interface manual for the delineation of the whole. 34 sub-basins were delineated in the basin area of 67917 km^2 .

3.6.2. Hydrological Response Units

The HRU Analysis tool in Arc SWAT helped to load land use, soil and slope map to the project for HRU definition. Prepared land use and soil maps were loaded. For slope, the multiple slope option (an option that considers different slope classes for HRU definition) was selected. The LULC, soil and slope map was reclassified in order to correspond with the parameters in the SWAT database. After reclassifying the land use, soil and slope in SWAT database, all these physical properties were made to be overlaid for HRU definition and 373 HRUs were obtained. Using 5% threshold value for land use, 10% for soil and 10% for slope. The soil database, which was obtained from “GIS-based hydrological zones and soil geo-database of Ethiopia (Belete et al, 2013)” was reclassified using Arc SWAT interface.

3.7. Calibration and Validation of SWAT Model

In SWAT, hydrological processes are simulated, as described above, based on a conceptual approximation. Consequently, it is necessary to adjust or optimize parameters until the model output

is an acceptable estimate of the observed runoff regime. In order to do this it is necessary to have observed runoff data against which to calibrate parameter values.

Ideally a split sample test should be performed. In this test, the observed runoff record is split into two segments: one is used for calibration and the other for validation. If the statistical Values derived from the calibration and validation procedure are similar, then the fitted model parameters are deemed acceptable.

3.7.1. SWAT-CUP

SWAT-CUP is an interface that was developed for SWAT. Using this generic interface, any Calibration/uncertainty or sensitivity program can easily be linked to SWAT. A schematic of the linkage between SWAT and five optimization programs is illustrated in the Figure below

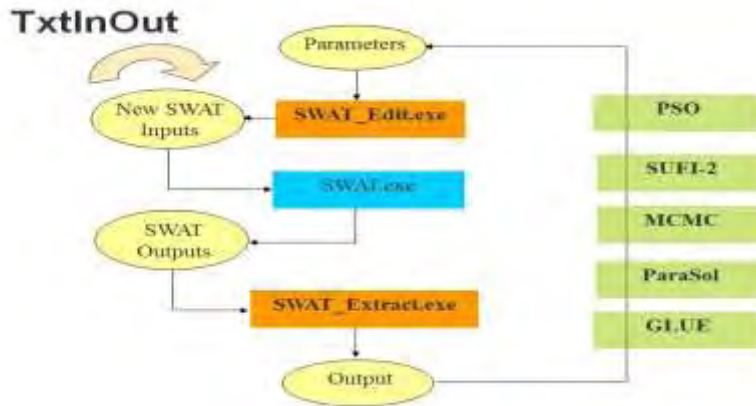


Figure3. 15 schematic of the linkage between SWAT and five optimization programs

3.7. 2 Calibration of Model

Calibration is the process whereby model parameters are adjusted to make the model output match with observed data. There are three calibration approaches widely used by the scientific community. These are the manual calibration, automatic calibration and a combination of the two.

Automated model calibration requires that the uncertain model parameters are systematically changed, the model is run, and the required outputs (corresponding to measured data) are extracted from the model output files. The main function of an interface is to provide a link between the input/output of a calibration program and the model. The simplest way of handling the file exchange is through text file formats.

The manual calibration approach requires the user to compare measured and simulated values, and then to use expert judgment to determine which variables to adjust, how much to adjust them, and ultimately assess when reasonable results have been obtained (Gassman *et al.*, 2007). Coffey *et al.* (2004) presented nearly 20 different statistical tests that can be used for evaluating SWAT stream flow output during a manual calibration process. They recommended using the Nash-Sutcliffe simulation efficiency ENS and regression coefficients R^2 for analyzing monthly output, based on comparisons of SWAT stream flow results with measured stream flows for the same watershed.



Figure3. 16 The SWAT-CUP Dialog box showing calibrated data sheet.

3.7.3. Validation of SWAT Model

Calibrated model parameters can result in simulations that satisfy goodness-of fit criteria, but parameter values may not have any hydrological meaning. Values of model parameters will be a result of curve fitting. This is also reflected in having different sets of parameter values producing simulations, which satisfy these criteria. It is necessary to test if parameter values reflect the underlying hydrological processes, and are not a result of curve fitting. Therefore; to conduct appropriate model validation results, it is necessary to carry out split sample test. The split-sample test involves splitting the available time series into two parts. One part is used to calibrate the model, and the second part is used for testing (validating) if calibrated parameters can produce simulations, which satisfy goodness-of-fit tests. The split sample test is suitable for catchments with long time

series, and it is applied in this study to catchments with over 12 years of data. For such catchments, the available record is split into two equal parts that is from 1994-1999 for calibration and 2000-2005 for validation.

3.7.4. SUFI-2

In SUFI-2, parameter uncertainty accounts for all sources of uncertainties such as uncertainty in driving variables (e.g., rainfall), conceptual model, parameters, and measured data. The degree to which all uncertainties are accounted for is quantified by a measure referred to as the *P-factor*, which is the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU). As all the processes and model inputs such as rainfall and temperature distributions are correctly manifested in the model output (which is measured with some error) - the degree to which we cannot account for the measurements - the model is in error; hence uncertain in its prediction. Therefore, the percentage of data captured (bracketed) by the prediction uncertainty is a good measure to assess the strength of our uncertainty analysis. The 95PPU is calculated at the 2.5% and 97.5% levels of the cumulative distribution of an output variable obtained through Latin hypercube sampling, disallowing 5% of the very bad simulations. As all forms of uncertainties are reflected in the measured variables (e.g., discharge), the parameter uncertainties generating the 95PPU account for all uncertainties. Breaking down the total uncertainty into its various components is highly interesting, but quite difficult to do, and as far as the author is aware, no reliable procedure yet exists.

Another measure quantifying the strength of a calibration/uncertainty analysis is the *R-factor*, which is the average thickness of the 95PPU band divided by the standard deviation of the measured data. SUFI-2, hence seeks to bracket most of the measured data with the smallest possible uncertainty band. As parameter uncertainty increases, the output uncertainty also increases (not necessarily linearly). Hence, SUFI-2 starts by assuming a large parameter uncertainty (within a physically meaningful range), so that the measured data initially falls within the 95PPU, then decreases this uncertainty in steps while monitoring the *P-factor* and the *R-factor*. In each step, previous parameter ranges are updated by calculating the sensitivity matrix (equivalent to Jacobian), and equivalent of a Hessian matrix, followed by the calculation of covariance matrix, 95% confidence 21 intervals of the parameters, and correlation matrix. Parameters are then updated in such a way that the new ranges are always smaller than the previous ranges, and are centered around the best simulation. (for more detail see Abbaspour et al., 2004, 2007)

The goodness of fit and the degree to which the calibrated model accounts for the uncertainties are assessed by the above two measures. Theoretically, the value for *P-factor* ranges between 0 and 100%, while that of *R-factor* ranges between 0 and infinity. A *P-factor* of 1 and *R-factor* of zero is a simulation that exactly corresponds to measured data. The degree to which we are away from these numbers can be used to judge the strength of our calibration. A larger *P-factor* can be achieved at the expense of a larger *R-factor*. Hence, often a balance must be reached between the two. When acceptable values of *R-factor* and *P-factor* are reached, then the parameter uncertainties are the desired parameter ranges. Further goodness of fit can be quantified by the *R2* and/or Nash-Sutcliff (*NS*) coefficient between the observations and the final “best” simulation. It should be noted that we do not seek the “best simulation” as in such a stochastic procedure the “best solution” is actually the final parameter ranges. If initially we set parameter ranges equal to the maximum physically meaningful ranges and still cannot find a 95PPU that brackets any or most of the data.

3.7.5. Model Performance Evaluation

To evaluate the performance of the SWAT model for better reliability and prediction compared to the observed flow, the following goodness of fit criteria were used in calibration and validation periods. The goodness fit in SUFI-2 is quantified by the ($R^2 > 0.6$) and Nash-Sutcliff ($NS > 0.5$) coefficient between the observation data and the best simulation.

The goodness of fit and the degree to which the calibrated model accounts for the uncertainties are assessed by the above two measures. Theoretically, the value for *P-factor* ranges between 0 and 100%, while that of *R-factor* ranges between 0 and infinity. A *P-factor* of 1 and *R-factor* of zero is a simulation that exactly corresponds to measured data. The degree to which we are away from these numbers can be used to judge the strength of our calibration. A larger *P-factor* can be achieved at the expense of a larger *R-factor*. Hence, often a balance must be reached between the two. When acceptable values of *R-factor* and *P-factor* are reached, then the parameter uncertainties are the desired parameter ranges. Further goodness of fit can be quantified by the *R2* and/or Nash-Sutcliff (*NS*) coefficient between the observations and the final “best” simulation.

3.7.5.1. Coefficient of Determination [*R2*]

The coefficient of determination, denoted R^2 , it provides a measure of how well observed outcomes are replicated by the model. The range of R^2 lies between 0 and 1 which described how much of the

observed desparation is explained by the prediction. A value of zero means no correlation at all; whereas one means that the desparation of the prediction is equal to that of the observation.

$$r^2 = \frac{\left[\sum_{i=1}^n (q_{si} - \bar{q}_s)(q_{oi} - \bar{q}_o) \right]^2}{\sum_{i=1}^n (q_{si} - \bar{q}_s)^2 \sum_{i=1}^n (q_{oi} - \bar{q}_o)^2} \text{-----} 3.19$$

Where: R^2 : coefficient of determination, q_{si} : simulated flow, q_{oi} : observed flow and q_o : average of observed flow (SWAT-CUP 2012 user manual). The calibration and validation were performed using observed data from the year 1994 to 2005 Using SWAT SUFI2.

3.7.5.2. Nash-Sutcliffe Coefficient [NS]

Nash-Sutcliffe coefficient measures the efficiency of the model by relating the goodness-of-fit of the model to the variance of the measured data, Nash-Sutcliffe efficiencies can range from $-\infty$ to 1. An efficiency of 1 corresponds to a perfect match of simulated discharge to the observed data. An efficiency of 0 indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero ($-\infty < NS < 0$) occurs when the observed mean is a better predictor than the model. Besides, due to frequent use of this coefficient, it is known that when values between 0.6 and 0.8 are generated, the model performs reasonably. A value between 0.8 and 0.9 tells that the model performs well and a value between 0.9 and 1 indicates that the model performs extremely well [Nash and Sutcliffe, 1970].

The formula for Nash Sutcliffe (NS) is:

$$E_{NS} = 1 - \frac{\sum_{i=1}^n (q_{oi} - q_{si})^2}{\sum_{i=1}^n (q_{oi} - \bar{q})^2} \text{-----} 3.20$$

Where: E_{NS} : Nash-Sutcliffe coefficient,

number of observed data points, q_{si} : simulated flow, q_{oi} :

observed flow and q_o : average of observed flow.

CHAPTER FOUR

4. Assessment of Water Demands in the Basin

4.1 Introduction

Water is a necessity for sustaining life and development of society. With the Increasing population including urbanization, economic growth, industrial production, agricultural and livestock production, demand for water has increased rapidly over the years (GWP, 2000). Population growth and economic development put constant pressure on the eco-systems of Water Resources (Alcamo et al., 2007). There is also a strong positive correlation between water demand and urbanization or population growth (Malmqvist and Rundle, 2002). Increase in water demand has reduced water availability during dry seasons and has as well increased water conflicts in the watersheds. Unless properly managed, increasing demand of the scarce water resources by different sectors will strongly affect all users and the environment (Hellström et al., 2000).

Water is a resource, which appears in different forms such as in surface streams, in ground water or in lakes and reservoirs. The developments of these resources for a variety of purposes (including water supply, irrigation hydropower, flood protection and the like) are the basis for socio- economic development of a society. The effective utilization of a country's water resources heavily depends up on the estimation of quality and quantity of the available water resources. In a very general way, water demand can broadly be classified in off stream and in stream use. In stream use refers to the water that is used but not withdrawn from groundwater or surface water for purposes such as hydroelectricity, navigation etc while off stream use refers to water that is withdrawn and diverted from a source. (Dominik Wisser, 2004)

Several demand types are distinguished: industrial demand, agricultural demand, domestic demand, demand for hydropower, environmental demand and demand for tourism. If these different demands are represented in a conceptual model it may be necessary to further subdivide the requirements. For example, it may be important to distinguish domestic demand that is largely influenced by tourism and residential domestic demand to take into account different underlying driving forces and demand patterns. (Dominik Wisser, 2004)

Forecasting water demand is the essential input for decision-making in water resources planning and management. The most influential factors affecting water demand and use are related to population,

level of service, tariffs, demand management measures as well as climatic conditions. A number of uncertainties heavily influences the demand forecast. These include general economic uncertainties, climate change implications, trends in population development and technology. (Dominik Wisser, 2004)

The Baro-Akobo basin has great-unrealized potentials, under populated by Ethiopian standards, and plenty of productive land and water resources.

4.2 Irrigation water demands

Ethiopia has a significant irrigation potential identified from both available land and water resources. Irrigation would provide farmers with sustained livelihoods and improve their general well-being (Belay et.al 2013). However, the country's irrigable land has been underutilized, and only 4 to 5% of the potential area has been developed for irrigation (Awulachew et al., 2007). Consequently, the agricultural economy of the country is largely based on rain fed cultivation, but while employing 85% of the population, it only contributes 50% to the gross domestic product (Berry et.al, 2003). Ultimately, increasing agricultural production using irrigation is one of the main drivers to end poverty caused by insufficient output from these rain fed systems

According to the Ministry of Water, Irrigation & Energy of Ethiopia irrigation command areas can be classified into three groups (Awulachew et al., 2005). The first group is small-scale irrigation areas of less than 200 ha, medium-scale between 200 and 3000 ha and large-scale above 3000 ha. For this study, medium and large-scale projects are considered based on this classification.

Currently, the government is giving more emphasis to the sub-sector by way of enhancing the food security situation in the country. Efforts are being made to involve farmers progressively in various aspects of management of small-scale irrigation systems, starting from planning, implementation and management aspects, particularly, in water distribution and operation and maintenance to improve the performance of irrigated agriculture.

Baro-Akobo Basin comprises a gross irrigable land of about 631, 000 ha in the lower basin alone. Based on water and land resources, the net area that can ultimately be developed is 480,000 ha. 18 irrigation projects with a total potential irrigation area of about 61,320 ha that were identified in the upper basin were found to be unsuitable for irrigation for a variety of reasons.

In the basin, there are many all type irrigation projects. Some projects are rain feed others, which ranges from small scale to large-scale projects, are irrigated by river diversion, and reservoir water supply. Irrigation projects which are in the basin are listed below with their areas.(TAMS and ULG,1997)

- Saudi star irrigation project area 350ha with future expansion to 10,000ha
- Bonga 100ha diversion from bonga river
- Baro pinke 200ha baro river diversion
- Adura irrigation scheme 200ha diversion from adura river
- Gog kuchala 200ha gillo river diversion

However, this research considered medium and large-scale irrigation projects, which are projects greater than 200ha. Thus in this basin there are about seven ongoing and proposed projects which were considered in the analysis. Currently the only project that is under cultivation of 350ha is the Saudi Star irrigation project, which is supplied by Alwero dam reservoir. The remaining six are proposed irrigation projects. The area and the annual water use for the proposed crop types and irrigation schedule is shown in table 4.1.

Table4. 1 irrigation area and annual water use.

s.no	Irrigation projects	Annual activity level(net area thousand ha)		Annual water use rate(m3/hectare)
		Net area	Gross area	
1	Baro irrigation	110	183.4	11,242
2	Chiru irrigation	10	12	9,545
3	Dumbong irrigation	15	23.2	9,545
4	Gilo 1 irrigation	100	160	12,533
5	Gilo 2 irrigation	46	61.3	12,533
6	Itang irrigation	50	66.6	11,242
6	Saudi star irrigation	10	15	14,707
	Total	341	516.1	

4.3 Domestic water demands

Public water companies provide water for different use categories: domestic use by households, municipal use by government agencies for public functions, e.g. watering public lawns, commercial use by all kind of public and private offices, agencies and institutes, industrial use by factories.

The following deals with the demand of the first three categories; domestic, municipal and commercial water demand. These demands depend, among other things, on:

- a. number of people within the considered area
- b. connection rate for different types of supply; e.g. stand pipe, piped supply
- c. per capita consumption, which depends on such factors as level of development, type of supply and price of water
- d. losses in infrastructure for transport, treatment and distribution.(Pieter van der Zaag,2003)

According to the information collected from Gambela Water Supply office and minister of water and mining the towns which serve from the surface water supply are Gambela, Metu, Gore, Mizanteferi, Dembidolo and Tepi. These towns water supply is derived from the nearby rivers with direct pumping to the treatment plants. Based on the master plan study the source of supply for the other towns is groundwater.(TAMS-ULG annex4, 1997)

Table4. 2 Average monthly river flow data for town demands

Average monthly river flow data for town demands (cmcs)						
month	METU (sore River)	DEMBIDOLO (Meti River)	MIZANTEFERI (Gachebriver)	TEPI (Beko River)	GORE (gumero river)	GAMBELA (Baro river)
Jan	6.47	1.28	0.73	3.79	0.21	93.76
Feb	3.72	1.04	0.44	3.17	0.07	54.87
Mar	3.45	0.89	0.44	3.69	0.05	48.48
Apr	4.44	0.91	0.99	4.71	0.15	57.31
May	12.37	1.59	2.45	6.36	0.74	162.21
Jun	44.51	2.44	4.71	8.13	2.23	403.95
Jul	97.80	4.19	6.88	9.39	4.13	666.97
Aug	137.35	5.06	6.87	9.50	5.43	854.04
Sep	152.30	6.67	4.92	9.28	6.04	964.84
Oct	88.80	6.22	3.42	9.16	4.12	756.46
Nov	26.17	4.02	3.33	5.77	1.58	378.2
Dec	11.44	2.53	2.90	4.45	0.56	169.27

4.4 Hydropower water demands

The abundance of water combined with the relief of basin provides favorable conditions for hydropower in this basin. In the lower basin alone, Selkhoodprom export has estimated the total

technically feasible hydropower potential as 13,765GWh/year. Most of the candidate hydropower projects in the basin would serve the ICS while some of the projects can be of use for basin's consumption and energy export purposes. According to the Master Plan study, there is about 221 MW small scales, 609 MW medium scale and 3,316 MW large scale hydropower potential in the Basin.

In the WAPCOS (1990) study, 11 hydropower sites were identified on the Baro River with a gross potential energy of 3,532 Gwh/yr. However, the Soviet team of experts SELKHOZPROMEXPORT (1990) study identified 14 dam storage/multipurpose projects for power generation in the Baro-Akobo basin. The primary purpose of the storage dams is not always hydroelectric power but all have been presented with a hydropower component. These on the Baro River are Gambella, Bonga and TAMS projects.

In this research all, the necessary data were found for TAMS, Baro1 and Baro 2 hydropower projects. These projects have feasibility and pre-feasibility data. Hence, the research considered these dams for the analysis.

4.5 Environmental water demand

Apart from the domestic, livestock and agricultural water use, other important uses of water include industry and the environment; there is no data available on these uses. One vital consideration for the use of the river flows in Baro-akobo is the environmental water requirements that need to be maintained in the river for aquatic as well as other environmental uses. The swamps that the Baro-Akobo River feeds would have an important ecological value in terms of sustaining the ecosystem as well as recharging the groundwater aquifers of the area.

Thus for the rivers considered in this analysis $1\text{m}^3/\text{s}$ monthly flow was left for the environmental demands.

4.6. Method of Data Collection

WEAP model applied by simulating recent base year account, for the water availability and demand was determined. This information obtained from different institutions in the sub-basin. The model used to simulate alternative scenarios of different development and management options in the future. The application defined by period, spatial boundaries and system components.

The modeling of a watershed using the WEAP consists of the following steps (Levite *et al.*, 2003):

- Define of the study area and period. The setting up of the period includes the last year of scenario creation (last year of the analysis) and the initial year of application.
- Create the current account, which is more or less the existing water resources situation of the study area. Under the current account, available water resources and various existing demand nodes are specified.
- Create the scenarios based on future assumptions and expected increases in the various indicators. This forms the core or the heart of the WEAP model since this allows for possible water resources management processes to be adopted from the results generated from running the model. The scenarios are used to address a lot of what if situations, like what if reservoirs operating rules are altered, what if groundwater supplies are fully exploited, what if there is a population increase. Scenario creation can take into consideration factors that change with time.
- Evaluate the scenarios about the availability of the water resources for the study area. Results generated from the creation of scenarios can help the water resources planner in decision making, which is the core of this study.

WEAP acts based on fundamental equations of the water budget and it can be used in urban and agricultural systems, complex river systems or independent basins.

The study has adopted a baseline scenario using the demand data of 2015, and simulated stream flow data (supply) 2015 assuming that similar trends of stream situation will exist in future without considering the climate and land use change. The modeling framework for this study consisted of: (1) The estimated monthly discharges converted into the volume of flow and; (2) an estimation of water demand and allocation modeling to allocate water for different sectors.

The data collection included the field visit and data collection, revision of design documents and interview of responsible officers. In the field visit, most of the water supply data were collected from Gambela water Supply office and minister of water and mining, which included water supply schemes, pumps type and capacity, population size and design period of the schemes.

4.6.1 Water supply data

Most of the water supply data for Gambela town were collected from Gambela water Supply office, which included water supply schemes, pumps type and capacity, population size and design period of the schemes. For the other towns the necessary data were collected from the master plan studies. The annual per capital water demand was taken based on the national Growth and Transformation Program 2, which states generally 25l/cap for rural and 30l/cap for urban water demands. But urban water supply access with GTP-2 minimum service level of 100 l/c/day for category-1 towns/cities Thus the annual per capital demand for a person is about 36.5m³/person. However as most of the towns are small 20% of this was assumed for future industrial uses. The data for the towns is shown in table 4.3.

Table4. 3 water supply input data for project in the basin.

towns	Annual activity (people)	Population growth rate	Annual water use (M ³ per person)
Metu	28,766	2.725	36.5
Dembidolo	28,679	2.725	36.5
Mizan Teferi	16,898	2.725	36.5
Gore	10,918	2.725	36.5
Tepi	17,198	2.725	36.5
Gambela	60,000	2.725	36.5

4.6.2 Reservoir and irrigation input data

The basic necessary irrigation data for the WEAP model set up in this analysis are the following. These data includes different type of storage levels, consumptions, net evaporations and annual activity levels. The reservoirs considered for the irrigation systems are Alwero, dumbong, Chiru, Baro, Gilo1, Gilo2 and itanng. These dams irrigate different area with different annual water use rate based on their proposed study. All the required input data are shown in table 4.1.

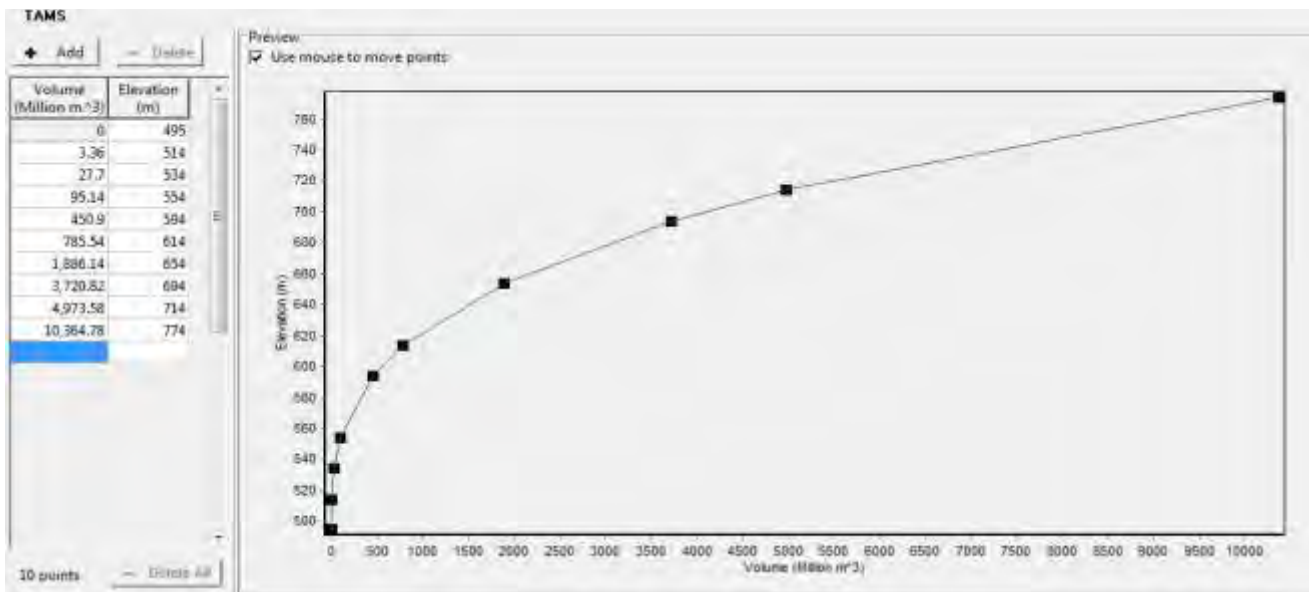
4.6.3 Input data hydropower generation for dam site

The hydropower dams, which have full data for water demand evaluation, are the TAMS, baro1 and Baro2 dam sites. These dams have feasibility study data. These data includes storages, demands all type of powerhouse data and evaporation losses etc.

Table4. 4 Input data for hydropower generation dams and net evaporation.

Reservoir input data	TAMS	Baro 1	Baro 2
Storag Capacity (million M3)	10000	1337	73
initial Storag (million M3)	5543	993	18
Istalled capacity (MW)	519	93.8	204
plant factor	0.4	0.55	0.61
Generator efficiency	0.94	0.97	0.97
Turbine flow (CUMS)	143.15	58.2	37.6

Net Evaporation (Monthly)(mm)			
month	TAMS Hydropower	baro 2 Hydropower	baro1 Hydropower
Jan	156.9	108	108
Feb	161.5	111	111
Mar	162.5	110	110
Apr	98.4	79	79
May	-42.4	-17	-17
Jun	-63.5	-19	-19
Jul	-88	-37	-37
Aug	-95.2	-33	-33
Sept	-69.5	-62	-62
Oct	-16.8	13	13
Nov	56.9	60	60
Dec	114.6	94	94



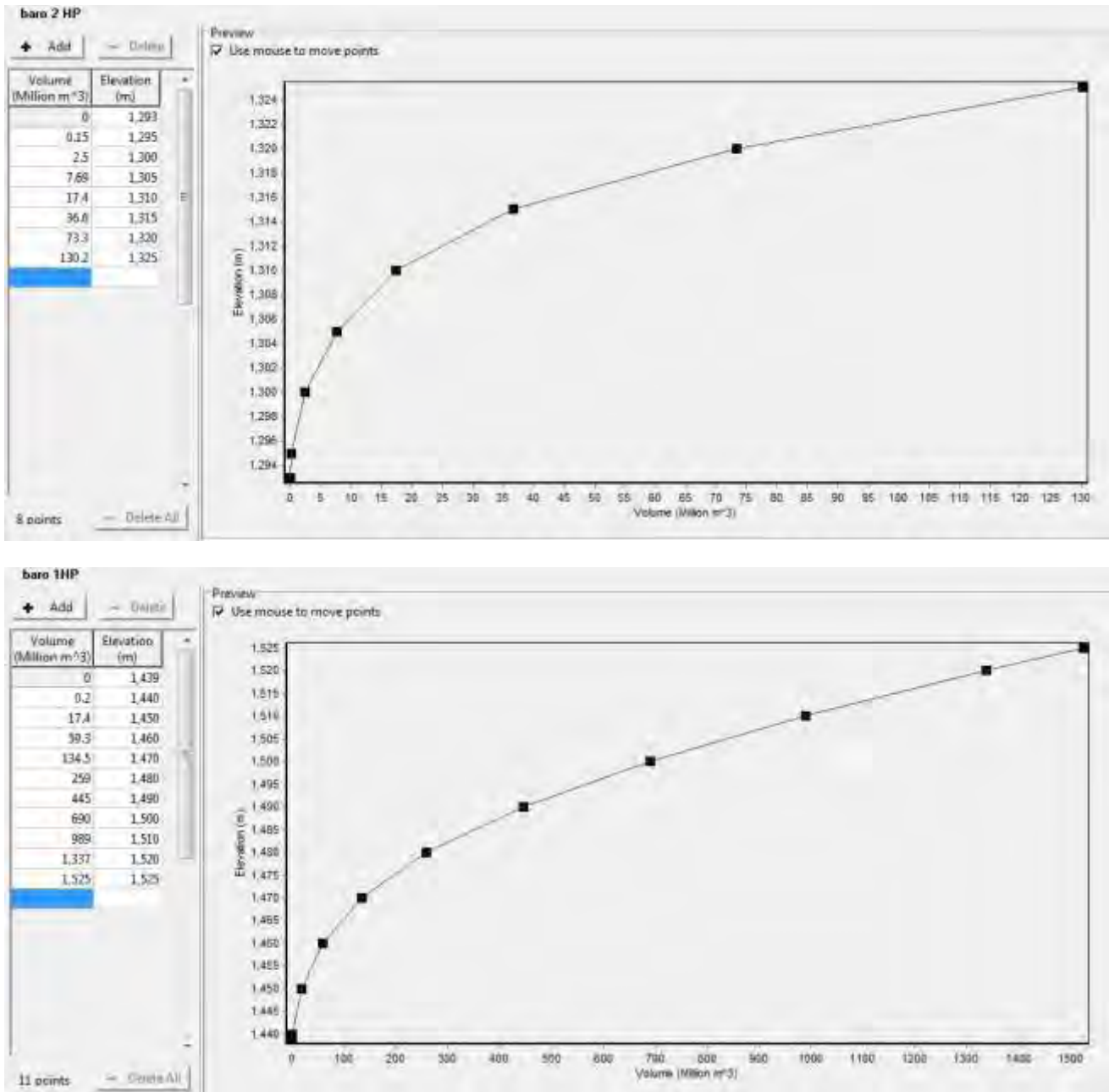


Figure 4. 1 HP dam volume elevation curves

4.6.4 Stream Flow

Continuous stream flow records are necessary to make accurate water resources assessment. Stream flow records representing historical, natural hydrology unaffected by humans are fundamental to modeling basin hydrology (WMO, 2012). In this, study the monthly stream flows data were obtained

for the current account year 2015 for each steams near the towns. The monthly flow data is shown in table 4.2.

4.7 Method of Data Analysis

Various data, which were used for the WEAP model to estimate water demands, were collected from different source these are

- population data,
- total agricultural land area,
- agricultural monthly variation demands,
- water requirements per hectare for estimation of future water demands for irrigation projects which is fed by respective dams and
- for planed TAMS,Baro1 and Baro2 hydropower project, head flow, storage capacity, initial storage, volume elevation curve, net evaporation from the reservoir, reservoir zoning, maximum turbine flow, tail water elevation, plant factor and generating efficiency.

The above data collected from different sources were analyzed with Water Evaluation and Planning (WEAP). Each demand site had its own input data and the analysis was done based on the current account year of 2015. The Current Accounts represent the basic definition of the water system as it currently exists, and forms the foundation of all scenarios analysis.

4.8. WEAP Model Input and Setup

After collecting all required data, WEAP software was used to estimate for one existing and six proposed irrigation demands, three-planned hydropower water demands and seven towns domestic water demands in the basin. In WEAP software, the typical scenario modeling effort consists of three steps. First, a Current Account year, which is chosen to serve as the base year of the model; second, a reference scenario that is established from the current account to simulate likely evolution of the system without intervention; and third “what-if” scenarios created to alter the “reference Scenario” and evaluate the effects of changes in policies and/or technologies.

4.8. 1. Description of Water Evaluation and Planning (WEAP) Model

Water Evaluation and Planning (WEAP) was developed by the Stockholm Environment Institute (SEI) and is a unique water resources and planning software where it stimulates hydrologic pattern based on climatic input. WEAP, which is an object-oriented computer-modeling package, having is

an Integrated Water Resources Management (IWRM) tool designed for simulation of water resources systems and trade-off analysis. The model simulates water system operations within a river system with basic principles of water accounting on a user-defined time step, usually a month. Simulation allows the prediction and evaluation of —what if scenarios and water policies such as water conservation programs, demand projections, hydrologic changes, new infrastructure and changes in allocations or operations priority (Raskin et al., 1992; Yates et al., 2005a, b; Purkey et al., 2007; SEI, 2008). This is a vital tool to inform the society on the adaptation of climate change towards the policymaking. WEAP uses climatic inputs such as precipitation, temperature, humidity, infiltration, and wind speed. It operates at a monthly step on the basic principle of water balance accounting. All these inputs can be derived from baseline scenarios, and used to predict the amount of precipitation that falls into a particular area, run-off into streams, recharge of groundwater, or evatranspiration through vegetation.

WEAP also allows user to build scenarios with scenarios, for instance, increase in temperature or heavier rainfall, along with assumptions towards water demand, infrastructure and regulation. All human activities can be incorporate in WEAP in order to predict water shortage and water quality base on a model scenario.

WEAP can be used to demonstrate the result of water demand quantity is met during a month, the degree of potential water shortage, level of reservoir storage for future use and measurement of water quality. WEAP also assesses the adequacy of environmental water flows, the level of hydropower generation capacity, the evolution of soil moisture, evapotranspiration rates, volume of surface run-off and the rate of groundwater recharge.

The Water Evaluation and Planning System (WEAP) aims to an integrated approach to water development into a practical tool for water resources planning. WEAP is distinguished by its integrated approach to simulating water systems and by its policy orientation. WEAP places the demand side of the equation--water use patterns, equipment efficiencies, re-use, prices, hydropower energy demand, and allocation--on an equal footing with the supply side--stream flow, groundwater, reservoirs and water transfers. WEAP is a laboratory for examining alternative water development and management strategies.

WEAP is comprehensive, straightforward and easy-to-use, and attempts to assist rather than substitute for the skilled planner. As a database, WEAP provides a system for maintaining water

demand and supply information. As a forecasting tool, WEAP simulates water demand, supply, flows, and storage, and pollution generation, treatment and discharge. As a policy analysis tool, WEAP evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems.

WEAP model has two primary functions (Sieber *et al.*, 2005):

- Simulation of natural hydrological processes such as evapotranspiration, runoff and infiltration to enable assessment of the availability of water within a catchment.
- Simulation of anthropogenic activities superimposed on the natural system to influence water resources and their allocation (i.e. consumptive and non-consumptive water demands) to enable evaluation of the impact of human water use.

It represents the system terms of its various supply sources (e.g. rivers, streams, groundwater, inter-basin transfer and reservoirs); withdrawal, transmission and wastewater treatment facilities; ecosystem requirements, water demands (i.e., user-defined sectors but typically comprising hydropower, irrigation, domestic supply, etc.). The model essentially performs a mass balance of flow sequentially down a river system, making allowance for abstractions and inflows. Typically, the model applied by configuring the system to simulate a recent —baseline year, for which the water availability and demands can be confidently determined. The model is then used to simulate alternative scenarios (i.e., possible futures based on —what if propositions) to assess the impact of different development and management options. Thus, WEAP is considered as an integrated water management tool for evaluating water use and allocation with a greater focus on balancing supply and demand in a swift and transparent way.

To allow simulation of water allocation, the elements that comprise the water demand-supply system and their spatial relationship are characterized for the catchment under consideration. The system is represented in terms of its various water sources (e.g. surface water, groundwater, and desalination and water reuse elements); withdrawal, transmission, reservoirs, and wastewater treatment facilities, and water demands (i.e. user-defined sectors but typically comprising industry, mines, irrigation, domestic supply, etc)

4.8.2. Water evaluation and planning system (WEAP Model Setup)

The Water Evaluation and Planning Integrated Water Resources Management (IWRM) model (WEAP) seamlessly integrates water supplies generated through watershed- scale hydrologic processes with a water management model driven by water demands and environmental requirements and is governed by the natural watershed and physical network of reservoirs, canals and diversions.

The WEAP model was developed by the Stockholm Environment Institute (SEI) and can be downloaded from www.weap21.org. It is a general multipurpose, multi- reservoir simulation program which determines the optimal allocation of water for each time step on the basic principle of water balance accounting.

The model provides a comprehensive flexible and user-friendly framework for planning and policy analysis. WEAP has an integrated approach of simulating both the natural inflows and engineered components of water system. This allows the planner access to a comprehensive view of the factors that must be considered in managing water resources for present and future use. This enables us to predict the outcomes of the whole system under different scenarios, and carry out comparisons between the different alternatives to evaluate a full range of water development and management options (SEI, 2005). Based upon the following criteria, WEAP was selected to perform water resources management modeling for the baro akobo river basins.

- ✓ The model can be used at different levels spatially and temporally.
- ✓ The mode is easy to use with a friendly interface.
- ✓ The model has been successfully used in many national and international applications.
- ✓ The model is able to simulate hydrology, groundwater utilization, surface ground water interactions, and wastewater treatment.
- ✓ The model has in-built capability to build and compare scenarios.
- ✓ The model is based on priority based water allocation system and can therefore be used in negotiation situations.
- ✓ The model can enable stakeholders to get involved in management procedures through interactive data driven model. This helps increase public awareness and acceptance.
- ✓ The model enables users to have interactive control over data input, editing, model operation and output display.

4.9. WEAP Model Input

In WEAP, models are called “areas”. The background raster data of the study area, which was created by GIS software, was added to the model. Once the area is open, the years, time steps and units are set. In this study, the current account is set to be year 2015 with the last year scenarios to year 2030. The time steps per year was set to be 12 and the time step boundary “based on calendar month”, starting with the month of January was selected.

The current account is the dataset from which the scenarios are built. A default scenario, the “reference scenario” carries forward the current accounts data into the entire project specified (2015-2030). Figure 4.2 shows the schematic view of river networks and demand sites for the study area.

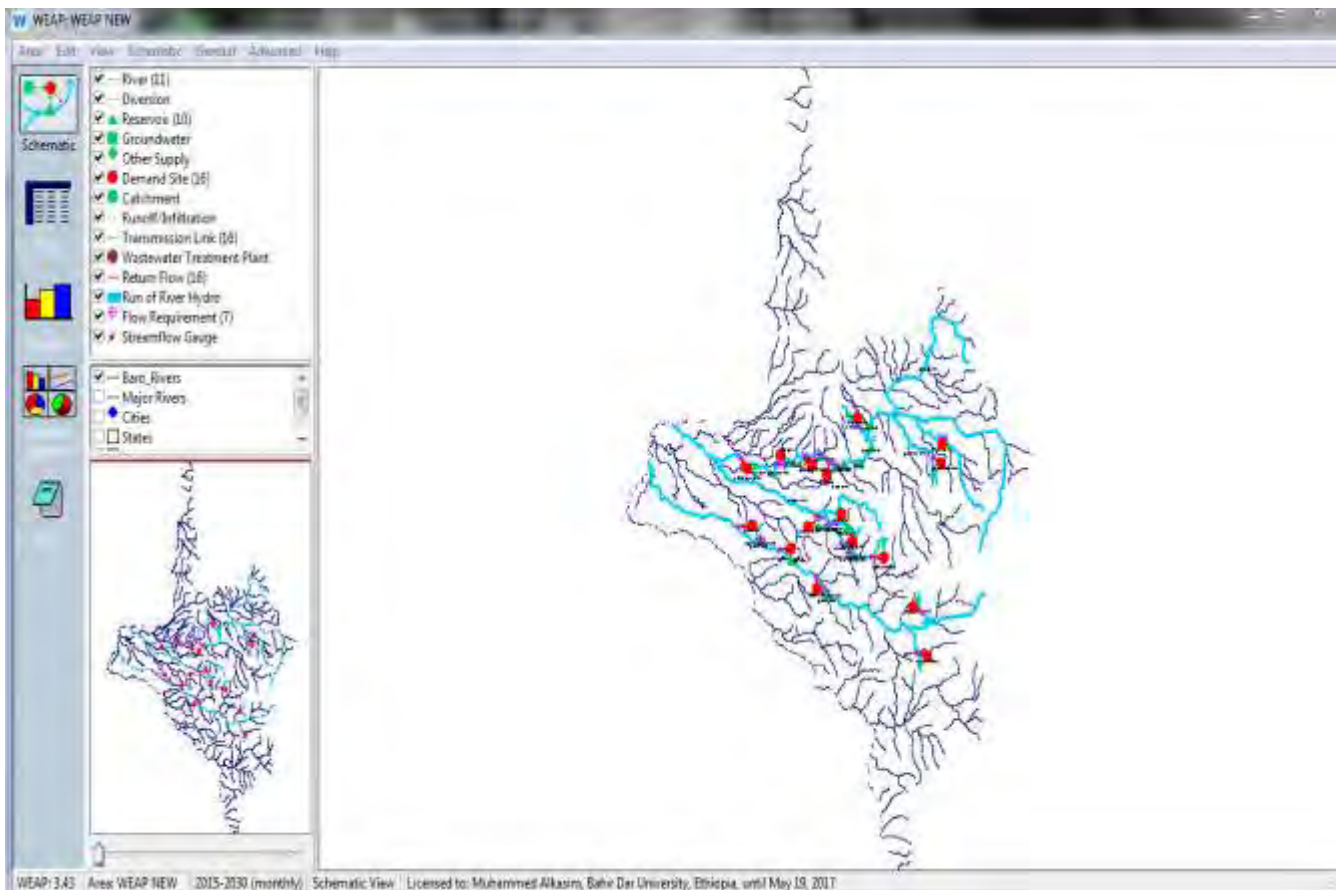


Figure 4. 2 Demand sites in schematic view.

4.9.1. Demand Sites

The demand sites of the model analysis are shown in the schematic view of the WEAP interface. The TAMS, Baro1 and baro2 hydropower projects and the six water supply towns are using on the different rivers and the seven-irrigation projects are supplied from their respective reservoirs.

4.9.2. Connecting the Demand with Supply

To run the model the demand sites should be connected with the supply of respective sources. This is accomplished by connecting a supply resource to each demand site which was done by dragging Transmission Link from each supply to the respective demand sites. After connecting the demands to the supply, the return flow link was done. Finally, the model run and found the results.

4.9.3. Creating the Return Flow Links

The return flow routing is the percent of total outflow from a demand node, and then the return flow routing for that link must be 100%. The return flow links were connected back to the rivers and return flow routing was set to be 100% to use the return flow for other demands effectively.

CHAPTER FIVE

5. Results and Discussions

5.1. Surface Water potential

5.1.1 Results on Surface Water Availability

After running the SWAT model to find the surface water potential of the baro-akobo river basin and SWAT-CUP for calibration of the model, the following results were found. The rainfall of the basin is **1701.6mm** and surface water runoff **279.68 mm** and lateral soil flow is **273.71 mm**. the total runoff found by the model in the basin area of **67,917km² is 19,000million m³ yearly**. The entire model output types, which have monthly and annual values shown in table 5.1. The total output of the model is shown in appendix D.

The result showed there is a reduction of estimated surface water potential compared to the values predicted on the master plan of the river basin by about 3.6billion m³. This would be due to the reduction of the area taken by the model when the watershed delineation was done. The model delineated the watershed from the basin DEM and computed other parameters from that area which excluded some areas around the boarder of Ethiopia from Kenya and South Sudan. The area was reduced by about 8000km², which is very much around 11% of the total river basin area.

Watershed delineation can be made by arc GIS manually by adding the area of interest. However, arc SWAT interface has its own automatic water shed delineator from the given DEM data of the river basin. For this purpose, it needs the final outlet of the whole basin and it has its own boundaries for the smallest thresholds area. However, to get detail information one third of this smallest limit can be used. So in this research this one third of the smallest area boundary was used. However, the model could not include all area. In addition to this, there are multiple out lets at the border, which join outside Ethiopia, which were excluded. This was one reason that the model needs one outlet but the river basin has multiple outlets hence the whole area could not be included.

Table 5. 1 Average monthly basin values.

AVERAGE MONTHLY BASIN VALUES						
MON	Rain (mm)	SURF Q (mm)	LAT Q (mm)	WATER YIELD (mm)	ET (mm)	PET (mm)
1	49.55	4.18	8.77	29.17	18.19	46.17
2	44.55	1.63	5.82	16.35	25.05	79.23
3	75.94	2.9	6.94	15.6	49.02	120.68
4	130.22	9.14	10.3	25.87	55.42	93.7
5	201.35	37.03	30.15	90.45	43.41	50.73
6	224.31	56.91	42.84	166.67	24.27	26.99
7	218.19	50.78	39.18	166.87	29.85	34.67
8	235.29	46.53	39.38	157.88	51.58	64.95
9	217.29	35.12	36.96	136.55	60.08	81.32
10	158.14	20.02	27.21	97.96	50.92	77.5
11	86.87	9.44	15.24	55.51	30.33	53.93
12	59.49	5.98	10.86	42.44	14.84	28.61

Table 5. 2 Average annual basin values.

AVE ANNUAL BASIN VALUES	
PRECIPTATION	1701.6 mm
SURFACE RUNOFF Q	279.68 mm
LATERAL SOIL Q	273.71 mm
GROUNDWATER (SHAL AQ) Q	413.63 mm
GROUNDWATER (DEEP AQ) Q	34.43 mm
REVAP (SHAL AQ => SOIL/PLANTS)	207.30 mm
DEEP AQ RECHARGE	34.69 mm
TOTAL AQ RECHARGE	693.83 mm
TOTAL WATER YLD	1001.45 mm
PERCOLATION OUT OF SOIL	694.62 mm
ET	453.2 mm
PET	759.2mm

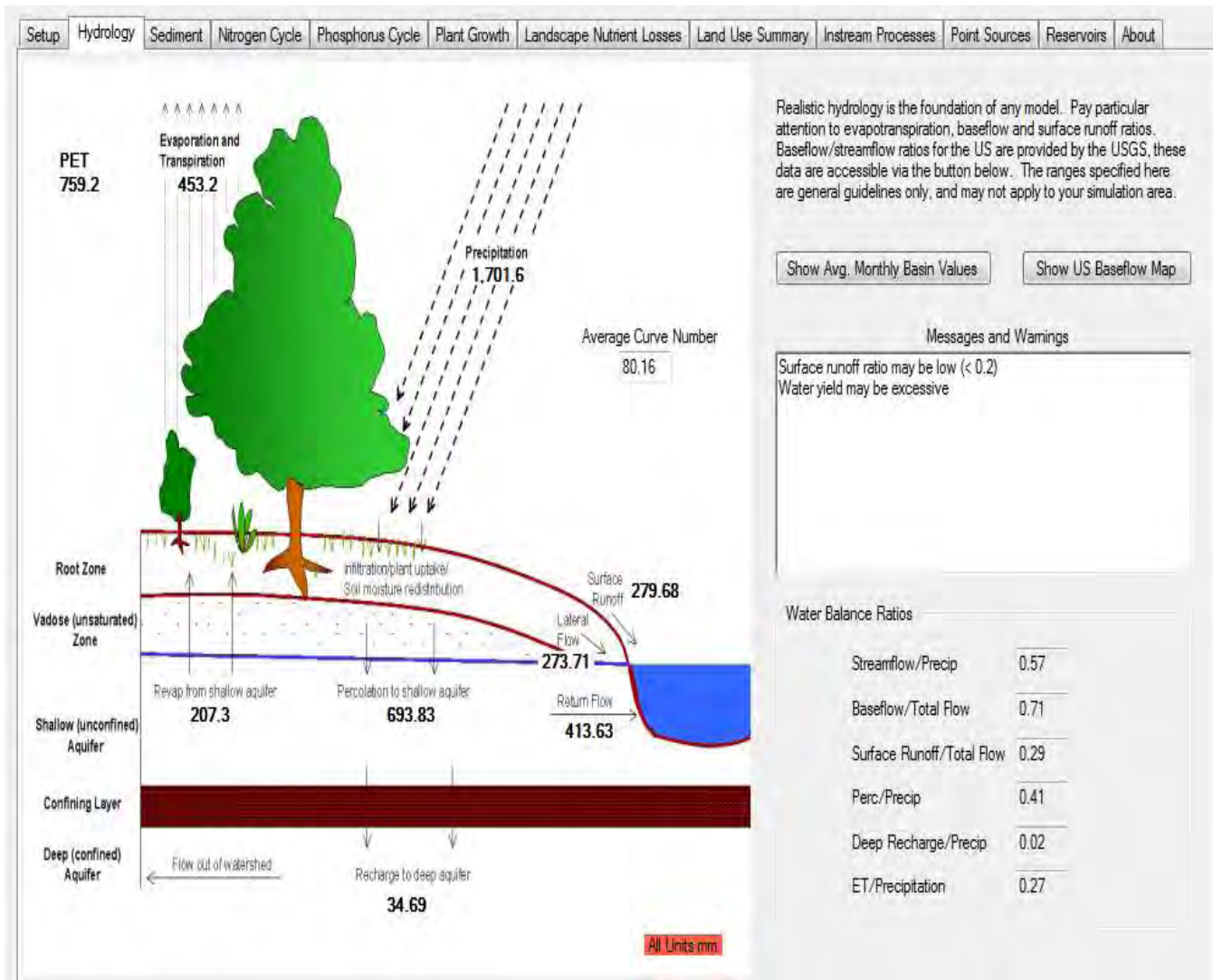


Figure 5. 1 General SWAT model result

5.1.2 Model Calibration and Validation

Model calibration and validation were done using SUFI2 with the objective function of R^2 and NS for more than 900 simulations and the results are presented below. Since it is difficult to estimate values of model parameters from the field measurements, all the model ranging from parsimonious lumped to complex distributed physically based need to be calibrated.

5.1.2.1 Model calibration

The SWAT model was calibrated by SWAT-CUP against the observed discharge and model parameters were found through trial and error analysis of daily and monthly runoff of the selected gauging station. The station, which was selected for calibration and validation purpose, is Gambela

gauging station, which has twelve years record data. Among these years, six-year data (1994-1999) was used for calibration and the other six-year data (2000-2005) was used for validation.

The SWAT model preserved the seasonal and inter-annual variation of flows. Some peak flows were not correctly simulated for some years by SWAT-CUP model. This may cause of thunderstorms, the total monthly rainfall can be due to a few storms within a month that are not captured by spare rain gauge networks. Hence, peak flows are not always correctly due to inaccurate estimation of catchment rainfall. The model simulated accurately relatively low season flows (see figure 5.2 below).

Within the model, an automatic optimizing routine can be utilized to calibrate these sixteen parameters, which are selected for model performance. This uses a statistical relationship to reduce the error between the observed and simulated runoff. Optimal model parameters were rarely found on the first attempt of automatic calibration. Consequently, even when using such a method it is best to combine it, with an element of manual adjustment of parameters. The other model parameters can be calibrated, but this has to be done manually.

Figure 5.2 shows the model performance during calibration period (close agreement between the goodness-of-fit criteria of the simulated and observed flow). Coefficient of determination, which is best if $R^2 > 0.60$ and Nash and Sutcliffe (1970) coefficient of efficiency, which is best if $NS > 0.5$. the Baro-Akobo catchment satisfies these criteria. This calibration showed the following results. Coefficients of efficiency, **NS=0.56**, coefficient of determination, **$R^2=0.83$** , which indicates goodness-of-fit criteria.

Table 5. 3 Model efficiencies parameters in calibration and validation periods.

Sub basin number	Simulation period	parameter	Period	monthly
15(Gambela gauging station)	1994-1999	R^2	calibration	0.83
		NS	calibration	0.56
	2000-2005	R^2	validation	0.81
		NS	validation	0.67

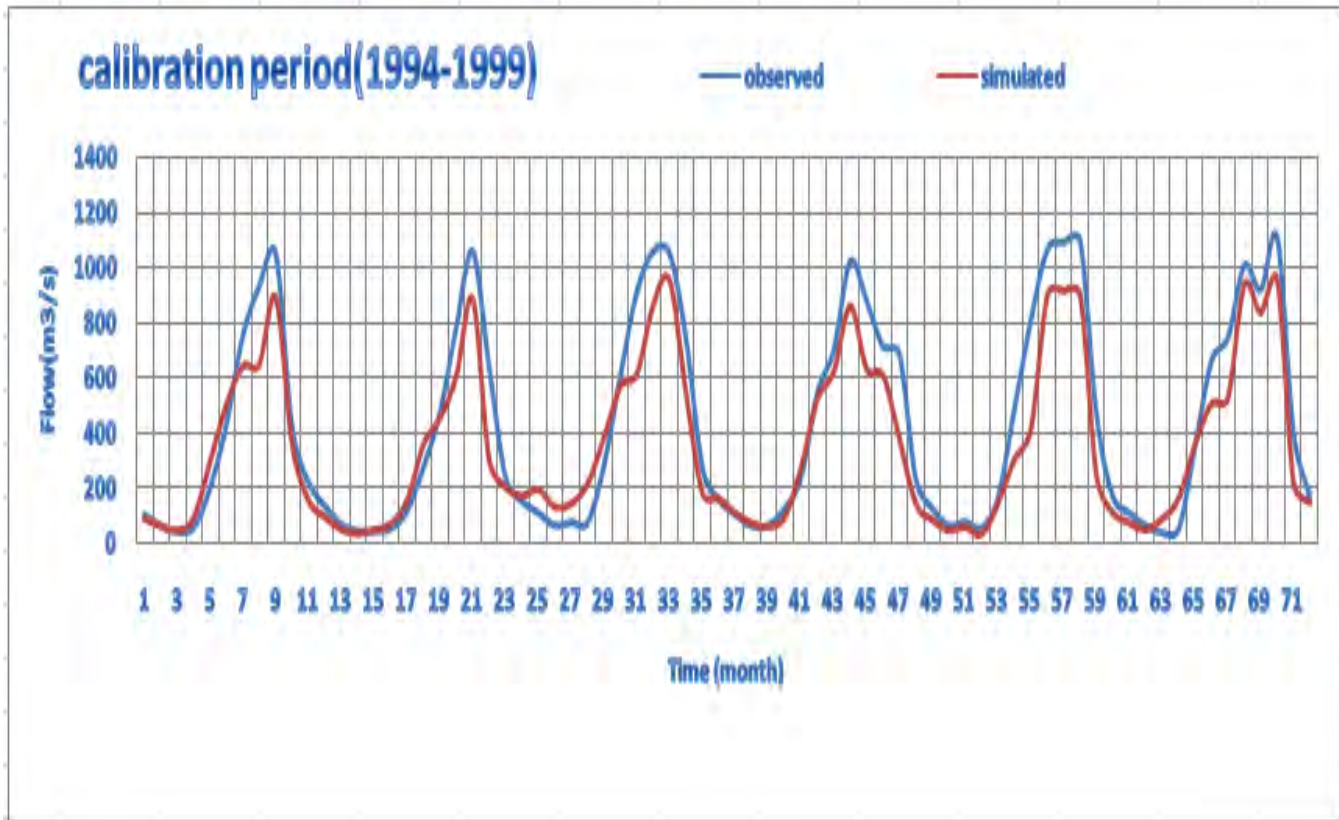


Figure 5. 2 Model calibration periods (1994-1999).

5.1.2.2 Model validation

Calibrated model parameters can result in simulations that satisfy goodness-of fit criteria, but parameter values may not have any hydrological meaning. Values of model parameters will be a result of curve fitting. This is also reflected in having different sets of parameter values producing simulations, which satisfy these criteria. It is necessary to test if parameter values reflect the underlying hydrological processes, and are not a result of curve fitting. Therefore; to conduct appropriate model validation results, it is necessary to carry out split sample test. The split-sample test involves splitting the available time series into two parts. One part is used to calibrate the model, and the second part is used for testing (validating) if calibrated parameters can produce simulations, which satisfy goodness-of-fit tests. The split sample test is suitable for catchments with long time series, and it is applied in this study to catchments with over 12 years of data. For such catchments, the available record is split into two equal parts. Thus, model parameters are found through empirical analysis of daily and monthly runoff. After calibration has been done, the model was validated using the second group of data (2000-2005) for validation. For both activities six-year data for calibration

parameter, while all other parameters are changing. Therefore, this gives relative sensitivities based on linear approximations and, hence, only provides partial information about the sensitivity of the objective function to model parameters. *t*-stat provides a measure of sensitivity (larger in absolute value are more sensitive), whereas *p*-values the significance of the sensitivity, a value close to zero is more significant.

The parameter which were most sensitive are listed below.

- Groundwater delay (GW_DELAY),
- Base flow alpha factor (ALPHA_BF),
- Threshold depth of water in the shallow aquifer required for return flow to occur (mm) (GWQMN),
- Groundwater "revap" coefficient, (GW_REVAP)
- Threshold depth of water in the shallow aquifer for "revap" to occur (mm) (REVAPMN).
- Depth from soil surface to bottom of layer (SOL_Z) .
- Available water capacity of the soil layer (SOL_AWC).
- Saturated hydraulic conductivity (SOL_K).
- Organic carbon content (SOL_CBN) .
- Moist soil albedo (SOL_ALB).
- Maximum canopy storage (CANMX).
- Soil evaporation compensation factor (ESCO).
- Plant uptake compensation factor (EPCO).
- Nitrogen percolation coefficient (NPERCO).
- SCS runoff curve number f (CN2)
- Minimum plant biomass for (BIO_MIN)

A t-test and p-values

The *t*-stat is the *coefficient* of a parameter divided by its *standard error*. It is a measure of the precision with which the regression coefficient is measured. If a coefficient is “large” compared to its standard error, then it is probably different from 0 and the parameter is sensitive.

. The *p-value* for each term tests the null hypothesis that the coefficient is equal to zero (no effect). A low *p-value* (< 0.05) indicates that you can reject the null hypothesis. In other words, a predictor that has a low *p-value* is likely to be a meaningful addition to your model because changes in the predictor's value are related to changes in the response variable. Conversely, a larger *p-value* suggests that changes in the predictor are not associated with changes in the response. So that parameter is not

very sensitive. A *p-value* of < 0.05 is the generally accepted point at which to reject the null hypothesis (i.e., the coefficient of that parameter is different from 0). With a *p-value* of 0.05, there is only a 5% chance that results you are seeing would have come up in a random distribution, so you can say with a 95% probability of being correct that the variable is having some effect.

Table 5. 4 Most sensitive parameters.

Parameter Name	t-Stat	P-Value
3:V__GW_DELAY.gw	0.032243678	0.974506475
11:R__GW_REVAP.gw	-0.094944334	0.925035266
2:V__ALPHA_BF.gw	-0.304068907	0.763323697
13:R__REVAPMN.gw	-0.350100372	0.728883315
16:R__CANMX.hru	0.494137120	0.625063821
9:R__SOL_AWC(..).sol	-0.802848519	0.428824880
12:R__SHALLST_N.gw	-1.016536914	0.318077593
5:R__ESCO.bsn	1.194737177	0.242212143
4:V__GWQMN.gw	1.499005070	0.145063526
6:R__NPERCO.bsn	1.530613767	0.137085802
7:R__SOL_Z(..).sol	1.636724983	0.112880269
8:R__SOL_ALB(..).sol	1.787961510	0.084610513
10:R__SOL_K(..).sol	-2.146396381	0.040650136
14:R__BIOMIX.mgt	-2.973427568	0.005998446
1:R__CN2.mgt	-3.779712111	0.000756108
15:R__EPCO.bsn	-3.858784832	0.000612838

Based on A *t*-test that was used to identify the relative significance of each parameter that was a value larger in absolute value was most significant and p-value the significance of the sensitivity, a value close to zero is more significant. From the model output, the first two most sensitive parameters are Plant uptake compensation factor (EPCO) and SCS runoff curve number f (CN2).

The graphical view of these parameters is shown below in figure 5.4, which is produced by the model itself.

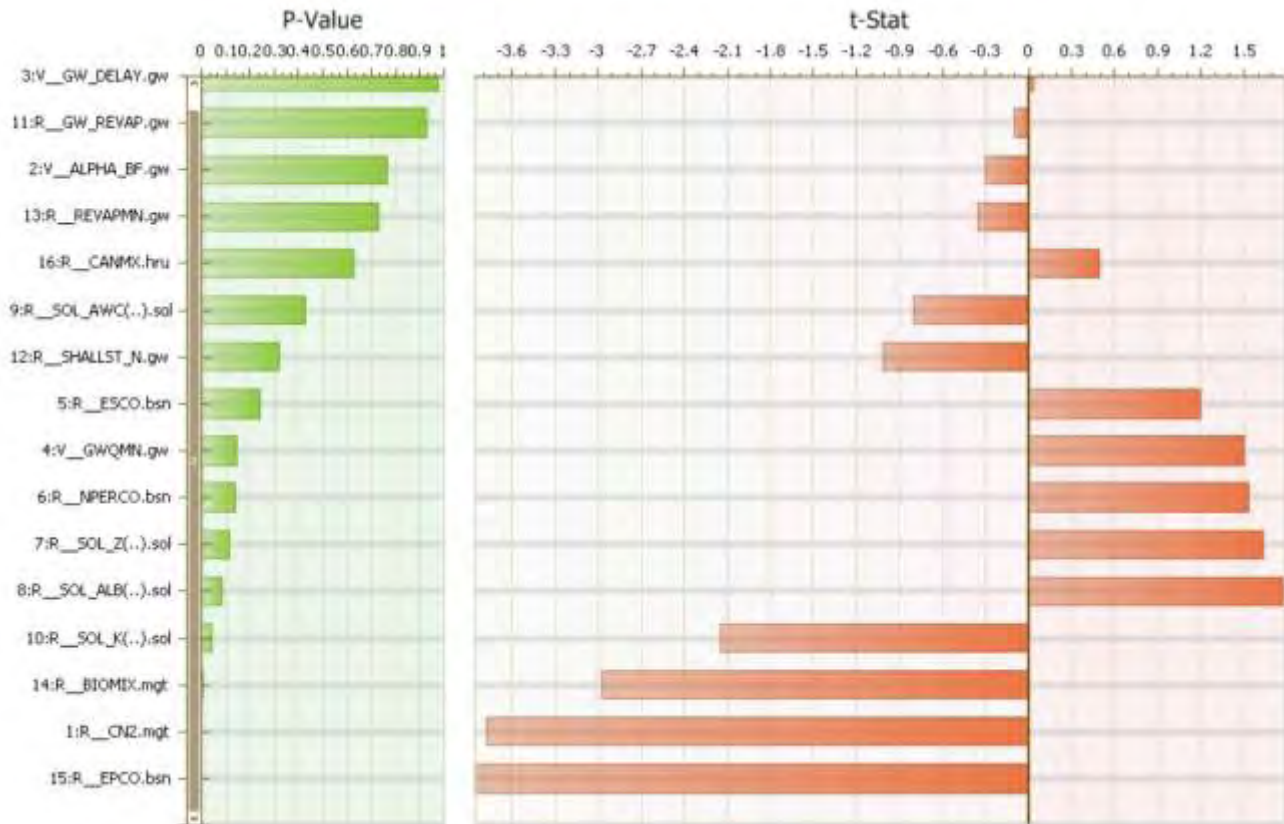


Figure 5. 4 Graphical view of sensitive parameters generated from SWAT-CUP.

5.1.3 Comparison of Result with Previous Studies in the Study Area

Baro akobo river basin is not researched in detail by any independent researchers. It was studied by consulting companies such as ARDCO-GEOSERV (1996), TAMS & ULG (1997) for master plan study of the river basin. The master plan study which was conducted before 20 year indicated the river basin has total surface water potential of about 22.6 Billion M³ for river basin area of 75,912 km². By this research with automatic delineation using SWAT model the area accounted for analysis was 67,917km² and the total surface water potential was about 19 Billion M³.

Comparing with previous master plan study, the model prediction of the surface water potential reduced by about 15%. The possible reason for the reduction is:

- When SWAT model delineate the basin water shed for the analysis, it removes areas at the boarders of south Sudan and Kenya with Ethiopia. These areas are tributaries of the baro and akobo river basin but the flow meet to the river outside Ethiopia. thus the areas cannot be added

to the analysis. This is because of the model needs one final outlet of the whole basin. Hence, about 11% of the total area was reduced.

- The second reason could be most of the rain fall data used for this analysis are filled data from nearby stations by regression method thus this will result some variation of the rain fall from the observed data.
- The SWAT model generated the all data by the weather generator from the basic stations with full data. The station used for this purpose were Masha, Gore and Tepi. These stations are found on the upper basin with a great variation in temperature and rainfall from the lower basin. However, there were no other stations with full data than these stations. Thus using these stations was necessary. Even the data found in these stations were with missed values as discussed above. Therefore, the final data used in the model to calculate the surface run off were adjusted twice which results in reduction of surface water estimation.
- The other reason is the land use, which was used taken from satellite image, and reclassified using arc GIS. The land use data reclassified from land sat image was done based on the local data collected in the Gambella region. This will not reflect the real land use data. That is because for a single land use change, SWAT model produced a huge runoff difference.

5.2 Results on Water Demand

At end of the run, the model produced different results. These includes water supply requirements, supply delivery, demand site coverage, for each medium and large-scale project and hydropower generation. Each of the above results is explained in figure 5.5.

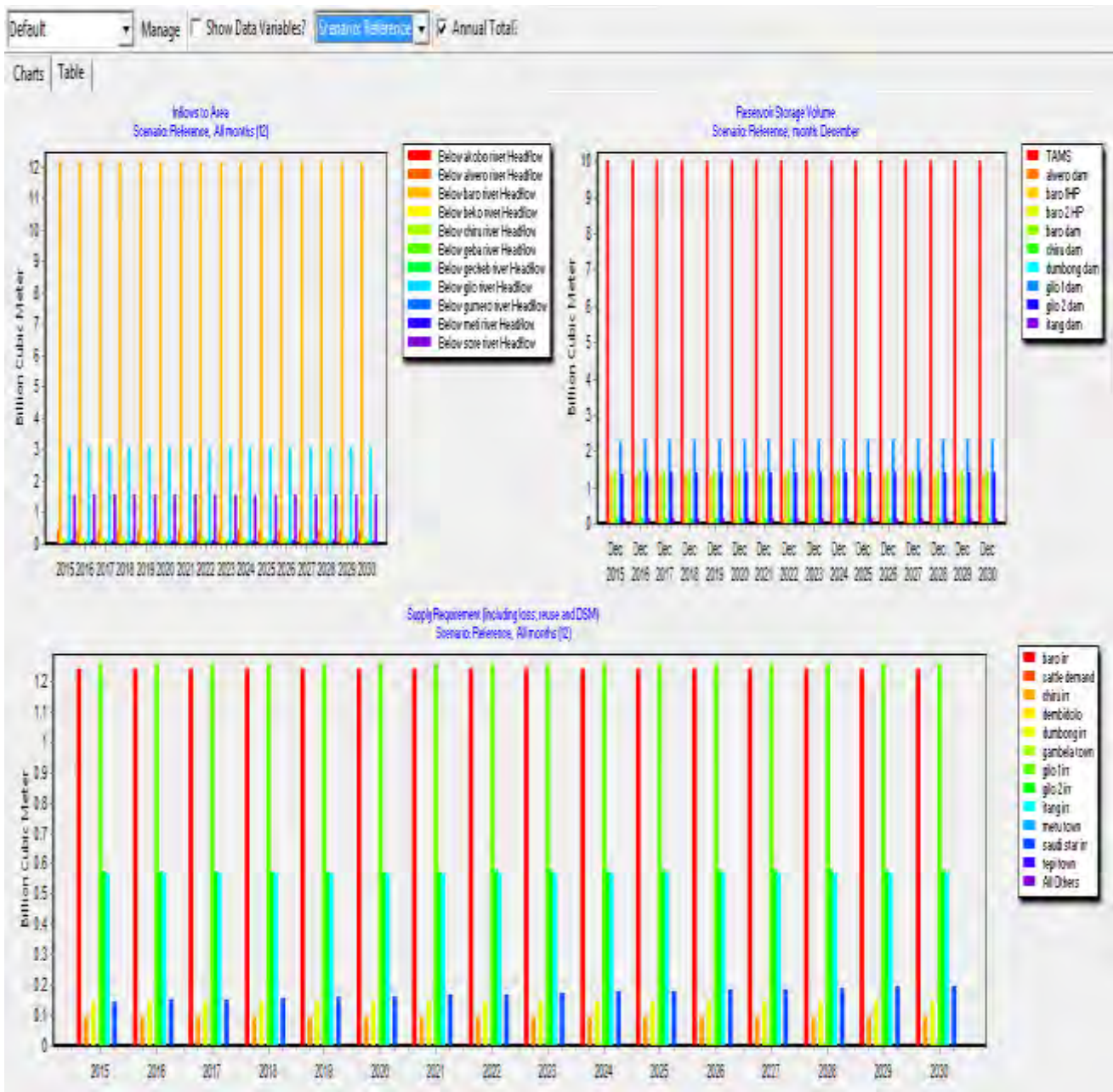


Figure 5. 5 Graphical view of WEAP model output.

5.2.1. Demand analysis result for irrigation project

5.2.1.1 Irrigation water demand

The irrigation water demand was calculated according to the seven dam storage data. These data included initial storage, storage capacity, volume elevation curve and net evapotranspiration of the dams. The WEAP model is flexible and predicts the water demands for the given project in monthly and yearly time steps. For these irrigation projects the total gross area considered to be irrigated are 516,000ha. These projects have different annual water use and 90% consumption of out of inflow water. The model produced the results for the water demand by excluding the loss and reuse of water. The model output for water demand analysis in annual time step for next fifteen years and the monthly average demands are shown in table 5.1. The analysis was done for the maximum project area supplied by the respective storage dams. The water demand increase in the scenario years as the irrigation area increases.

Table 5. 5 irrigation projects annual water demand (Billion M³).

Year	Baro Irrigation Project	Itang Irrigation Project	Saudi star Irrigation Project	Gilo 1 Irrigation Project	Gilo 2 Irrigation Project	Chiru Irrigation Project	Dumbong Irrigation Project	Sum(B MC)
2015	1.2366	0.5621	0.147	1.253	0.577	0.095	0.143	4.014
2016	1.2369	0.5622	0.150	1.254	0.577	0.095	0.143	4.018
2017	1.2371	0.5623	0.153	1.254	0.577	0.095	0.143	4.022
2018	1.2374	0.5624	0.156	1.254	0.577	0.096	0.143	4.026
2019	1.2376	0.5626	0.159	1.254	0.578	0.096	0.143	4.030
2020	1.2378	0.5627	0.162	1.255	0.578	0.096	0.144	4.034
2021	1.2381	0.5628	0.166	1.255	0.578	0.096	0.144	4.038
2022	1.2384	0.5629	0.169	1.255	0.578	0.096	0.144	4.042
2023	1.2386	0.5630	0.172	1.256	0.578	0.097	0.144	4.046
2024	1.2388	0.5631	0.176	1.256	0.578	0.097	0.144	4.050
2025	1.2391	0.5632	0.179	1.256	0.578	0.097	0.144	4.055
2026	1.2393	0.5633	0.183	1.257	0.578	0.097	0.144	4.059
2027	1.2396	0.5635	0.186	1.257	0.578	0.097	0.144	4.063
2028	1.2398	0.5636	0.190	1.257	0.579	0.097	0.144	4.068
2029	1.2400	0.5637	0.194	1.257	0.579	0.098	0.144	4.072
2030	1.2403	0.5638	0.198	1.257	0.579	0.098	0.144	4.077

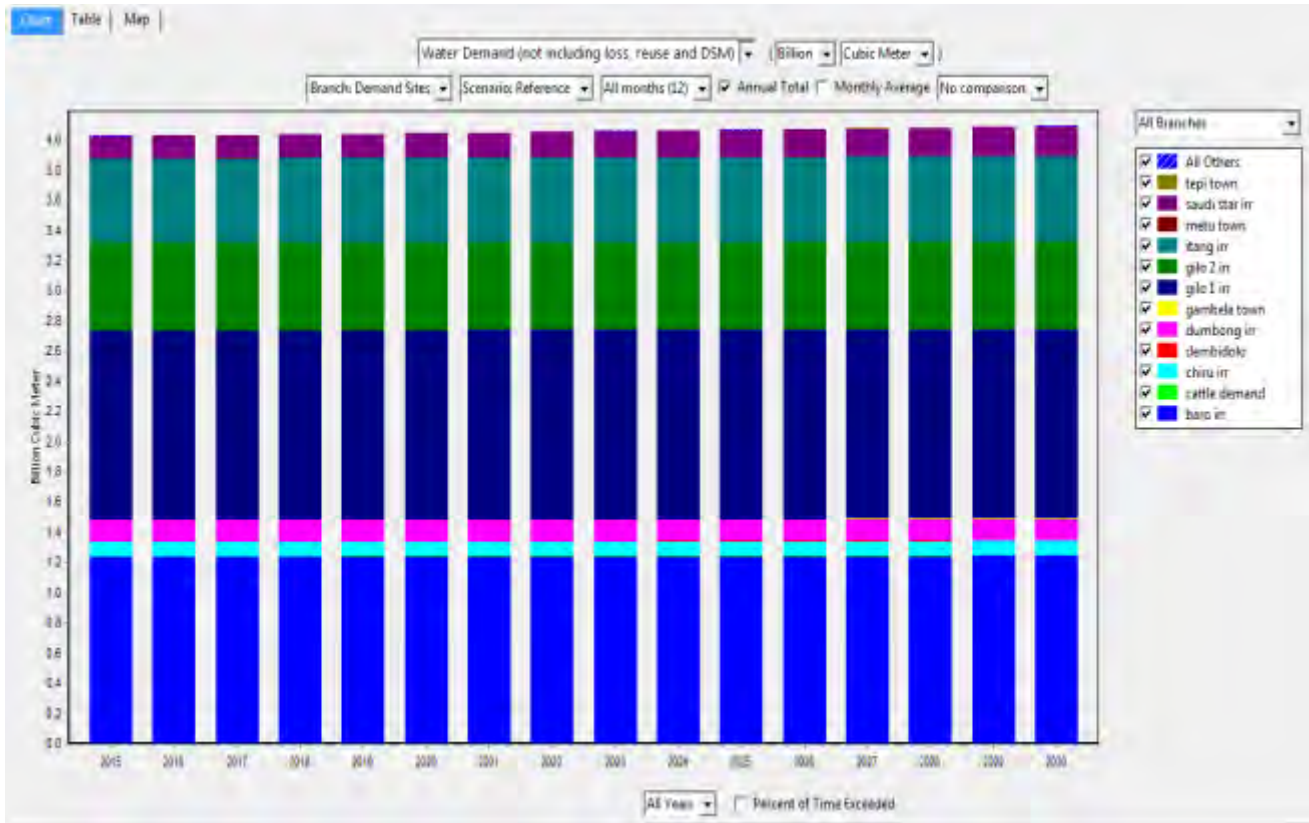


Figure 5. 6 Irrigation projects annual water demand.

Table 5. 6 Average monthly water demand for irrigation projects.

average monthly water demand not including loss and reuse(cubic meter)							
Mon	Baro Irrigation	Chiru Irrigation	Dumbong Irrigation	Gilo-1 Irrigation	Gilo-2 Irrigation	Itang Irrigation	Saudi Star Irrigation
Jan	235310565.9	20074594.8	30111892.25	263588158.2	121250552.8	106959348.1	34265996.0
Feb	272464865.7	17206795.5	40149189.66	138069987.6	63512194.3	123847666.2	14563048.3
Mar	136232432.9	13383063.2	20074594.83	75310902.4	34643015.0	61923833.1	0
Apr	49539066.5	2294239.4	573559.85	18827725.6	8660753.8	22517757.5	0
May	24769533.2	0	0	12551817.0	5773835.8	11258878.8	20559597.6
Jun	12384766.6	0	0	94138627.9	43303768.8	5629439.4	22272897.4
July	86693366.4	9176957.6	13765436.46	87862719.4	40416850.9	39406075.6	17132998.0
Aug	61923833.1	6691531.6	8603397.8	25103634.1	11547671.7	28147196.9	8566499.0
Sep	37154299.9	3823732.3	2867799.3	50207268.2	23095343.4	16888318.1	0
Oct	30961916.6	4779665.4	4301698.9	112966353.5	51964522.6	14073598.4	0
Nov	111462899.6	5735598.5	5735598.6	150621804.7	69286030.2	50664954.4	28269446.7
Dec	179579116	12427130.1	17206795.6	225932707	103929045.2	81626870.9	25699497.0

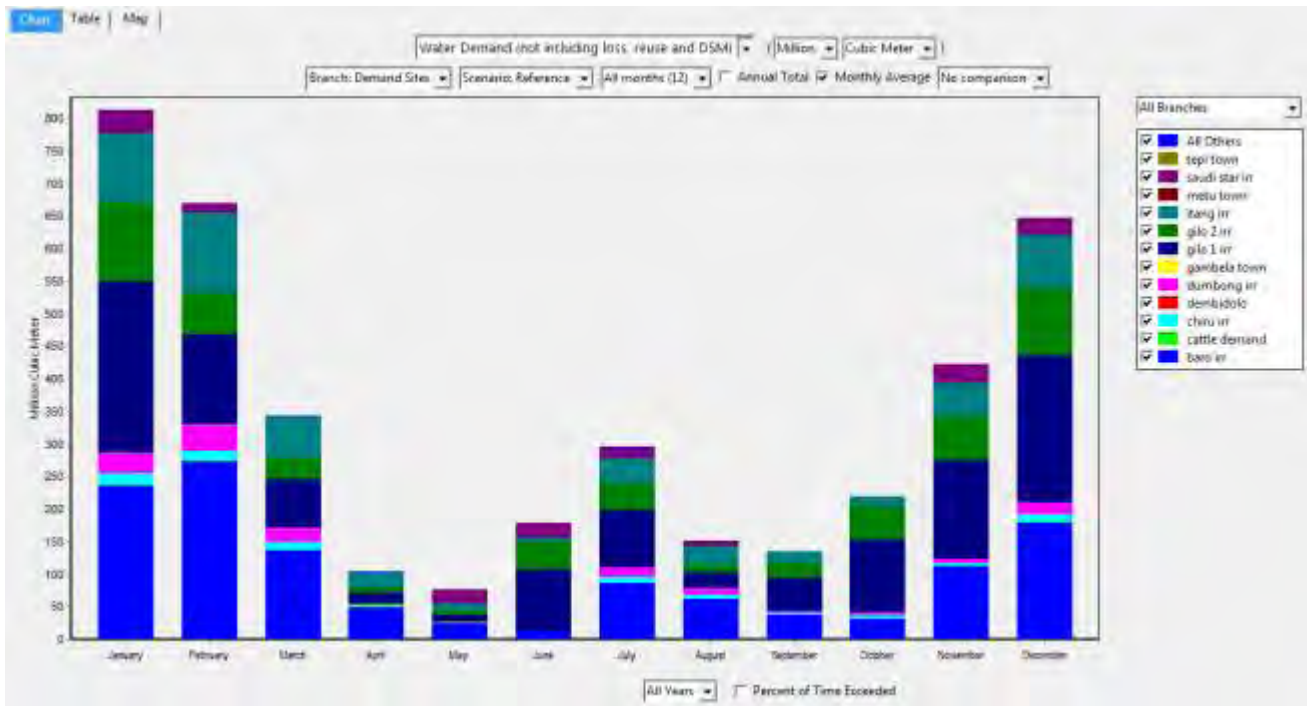


Figure 5. 7 Monthly average water demand for irrigation projects.

5.2.1.3 Irrigation Water Supply Requirement and Supply Delivered

The supply requirement showed below is the model output for irrigation projects. In these projects the supply requirements varies from month to months due to different cropping and rotations. The supply delivered to each demand site depends on the available water source and the demand requirements for the site. If the available water source is sufficient to cover all the demands of the site, then the supply delivered and supply requirement are equal. Otherwise, there will be unmet demands. However considering irrigation improvement for the scenario years the supply requirement and supply delivery is equal for all monthly average values. As shown in the table 5.7 the supply requirement in some months was null for some projects. This is because of the crop harvesting time of each season for one kind of cropping on the project area.

Table 5. 7 Irrigation projects Monthly Average Supply Requirement.

Supply Requirement (including loss, reuse and DSM) (Cubic Meter)							
month	baro irr	chiru irr	dumbong irr	gilo 1 irr	gilo 2 irr	itang irr	saudi star irr
January	235310566	20074595	30111892	263588158	121250553	106959348	34265996
February	272464866	17206796	40149190	138069988	63512194	123847666	14563048
March	136232433	13383063	20074595	75310902	34643015	61923833	0
April	49539066	2294239	573560	18827726	8660754	22517757	0
May	24769533	0	0	12551817	5773836	11258879	20559598
June	12384767	0	0	94138628	43303769	5629439	22272897
July	86693366	9176958	13765436	87862719	40416851	39406076	17132998
August	61923833	6691532	8603398	25103634	11547672	28147197	8566499
September	37154300	3823732	2867799	50207268	23095343	16888318	0
October	30961917	4779665	4301699	112966354	51964523	14073598	0
November	111462900	5735599	5735599	150621805	69286030	50664954	28269447
December	179579116	12427130	17206796	225932707	103929045	81626871	25699497

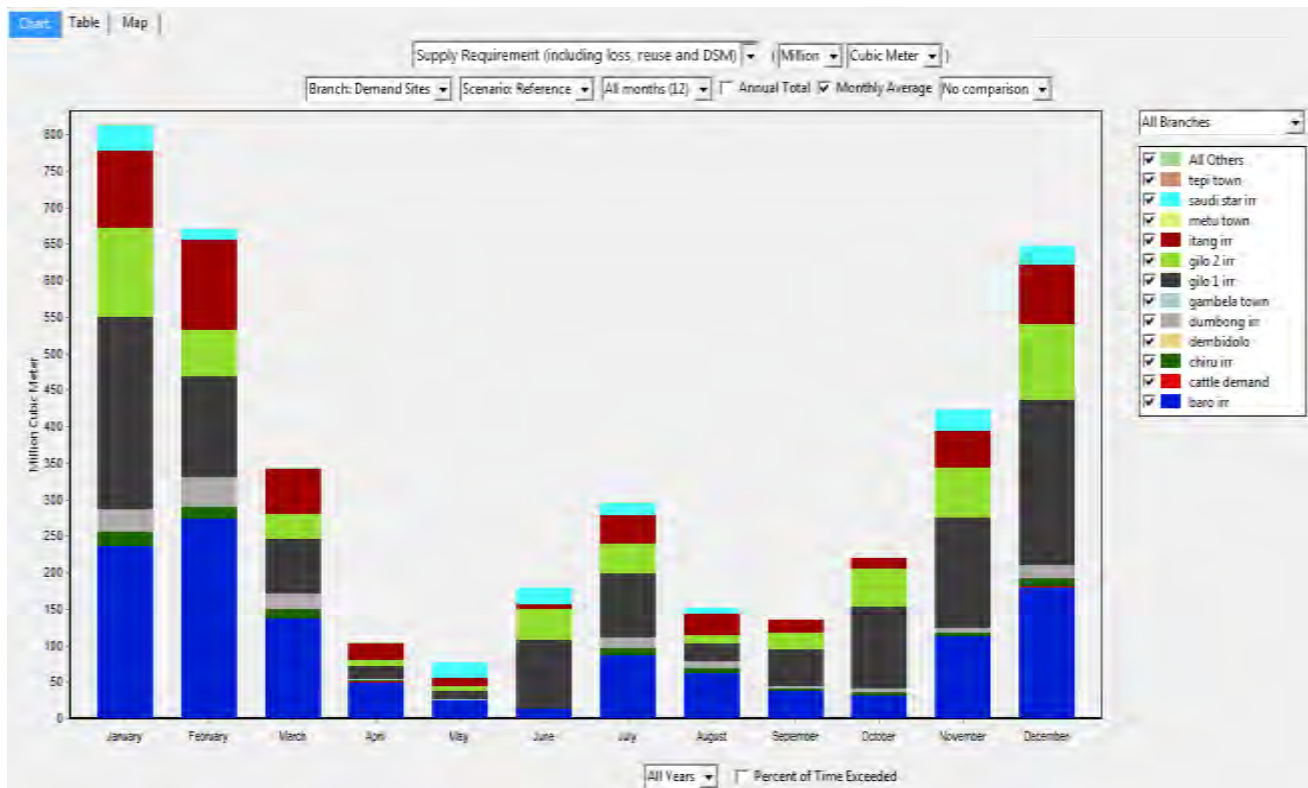


Figure 5. 8 Irrigation projects Monthly Average Supply Requirement

5.2.2 Demand analysis result for towns Water supply

5.2.2.1 Water supply demand

The towns water supply analysis was done based on Growth and transformation program two (GTP2) of Ethiopian standard for water supply demand with per capital demand of 100 liter for category 1 towns. The annual activity level for the towns is people for the current account year with a consumption of 80% out of supply. The model produced a various annual demand for scenario years, which increases with increasing population growth, and different average monthly demands as shown in table 5.8. Nevertheless, as the towns are very small 20% of the demand is considered for industrial use.

Table 5. 8 Annual water demands for different towns

Annual water demand							
year	Dembidolo town	Gambela town	Metu town	Tepi town	Gore town	Mizan Teferi town	sum
2015	1,046,783.5	2,190,000.0	1,049,959.0	627,727.0	398,507.00	616,777.0	5,929,753.5
2016	1,075,308.3	2,249,677.5	1,078,570.3	644,832.5	409,366.3	633,584.1	6,091,339.2
2017	1,104,610.5	2,310,981.2	1,107,961.4	662,404.2	420,521.5	650,849.3	6,257,328.2
2018	1,134,711.1	2,373,955.4	1,138,153.3	680,454.7	431,980.7	668,584.9	6,427,840.4
2019	1,165,632.0	2,438,645.7	1,169,168.0	698,997.1	443,752.2	686,803.9	6,602,999.1
2020	1,197,395.5	2,505,098.8	1,201,027.8	718,044.8	455,844.4	705,519.3	6,782,930.8
2021	1,230,024.5	2,573,362.8	1,233,755.8	737,611.5	468,266.2	724,744.7	6,967,765.7
2022	1,263,542.7	2,643,486.9	1,267,375.7	757,711.4	481,026.5	744,494.0	7,157,637.3
2023	1,297,974.2	2,715,521.9	1,301,911.7	778,359.1	494,134.4	764,781.4	7,352,682.9
2024	1,333,344.0	2,789,519.9	1,337,388.8	799,569.3	507,599.6	785,621.7	7,553,043.5
2025	1,369,677.6	2,865,534.3	1,373,832.6	821,357.6	521,431.7	807,029.9	7,758,864.0
2026	1,407,001.4	2,943,620.1	1,411,269.6	843,739.6	535,640.7	829,021.5	7,970,293.0
2027	1,445,342.2	3,023,833.8	1,449,726.7	866,731.5	550,236.9	851,612.3	8,187,483.5
2028	1,484,727.7	3,106,233.2	1,489,231.7	890,349.9	565,230.9	874,818.8	8,410,592.4
2029	1,525,186.5	3,190,878.1	1,529,813.3	914,612.0	580,633.4	898,657.6	8,639,781.1
2030	1,566,747.9	3,277,829.5	1,571,500.7	939,535.2	596,455.7	923,146.0	8,875,215.1

Table 5. 9 Monthly average water demands for different towns.

average monthly water demand not including loss and reuse(cubic meter)							
Month	Cattle demand	Dembidolo town	Gambela town	Metu town	Tepi town	Gore town	Mizan Teferi town
Jan	197625	109692.5	229490.3	110025.3	65779.58	41759.59	64632.1
Feb	178500	116145.0	242989.7	116497.3	69648.96	44216.04	68434.02
Mar	197625	122597.5	256489.1	122969.4	73518.35	46672.48	72235.91
Apr	191250	122597.5	256489.1	122969.4	73518.35	46672.48	72235.91
May	197625	129050.0	269988.6	129441.5	77387.74	49128.9	76037.79
Jun	191250	103240.0	215990.8	103553.2	61910.19	39303.14	60830.24
Jul	197625	96787.5	202491.4	97081.1	58040.8	36846.7	57028.35
Aug	197625	90335.0	188992.0	90609.0	54171.4	34390.2	53226.46
Sep	191250	96787.5	202491.4	97081.1	58040.8	36846.7	57028.35
Oct	197625	96787.5	202491.4	97081.1	58040.8	36846.69	57028.35
Nov	191250	103240.0	215990.8	103553.2	61910.1	39303.14	60830.24
Dec	197625	103240.0	215990.8	103553.2	61910.2	39303.14	60830.24

The demand coverage of the water supply showed 100% and hence there is no shortage of supply and unmet demands at these projects for the scenario years.

5.2.2.2 Water Supply Requirement and Supply Delivered

The supply delivered to each demand site depends on the available water source and the demands requirements for the sites. If the available water source is sufficient to cover all demands of the site, then the supply delivered and supply requirement are equal. Otherwise, there will be unmet demands. Hence, the Scenario table 5.10 showed that the supply requirements of all towns water supply scheme, which is equal to the supply delivery since the demand coverage is 100%. Hence, for the coming 15 years for these towns the water supply, which is derived from these rivers surface water, is sufficient.

Table 5. 10 monthly Average Supply Requirements.

Supply Requirement (including loss, reuse and DSM) (Cubic Meter)						
month	Dembidolo	gambela town	Metu town	Tepi town	mizan teferi town	Gore town
Jan	109,693	229,490	110,025	65,780	64,632	41,760
Feb	116,145	242,990	116,497	69,649	68,434	44,216
Mar	122,598	256,489	122,969	73,518	72,236	46,672
Apr	122,598	256,489	122,969	73,518	72,236	46,672
May	129,050	269,989	129,442	77,388	76,038	49,129
Jun	103,240	215,991	103,553	61,910	60,830	39,303
Jul	96,788	202,491	97,081	58,041	57,028	36,847
Aug	90,335	188,992	90,609	54,171	53,226	34,390
Sep	96,788	202,491	97,081	58,041	57,028	36,847
Oct	96,788	202,491	97,081	58,041	57,028	36,847
Nov	103,240	215,991	103,553	61,910	60,830	39,303
Dec	103,240	215,991	103,553	61,910	60,830	39,303

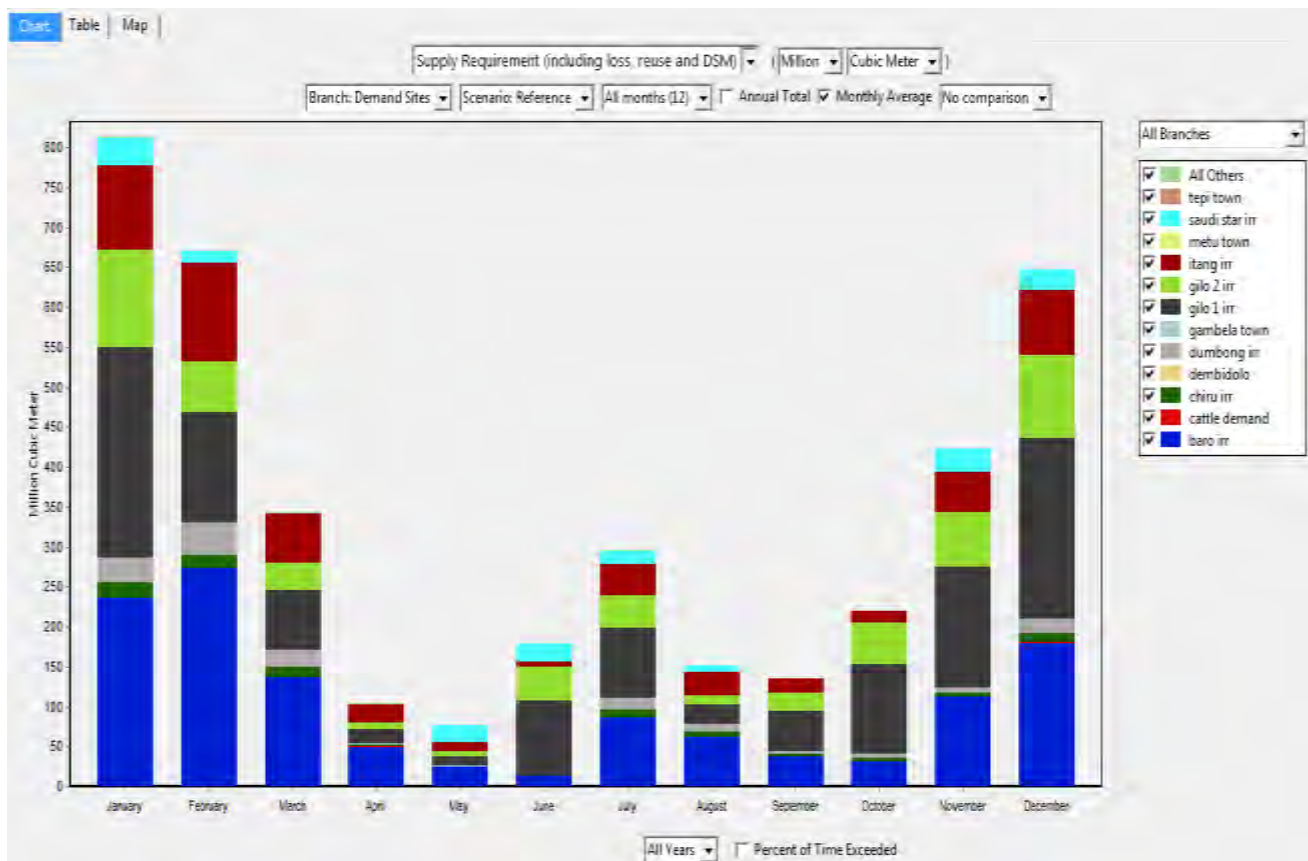


Figure 5. 9 monthly Average Supply Requirements

Table 5. 11 Monthly demand site coverage

demand site coverage(% of requirement)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Baro irrigation	98	96	97	100	100	100	100	100	100	100	100	100
chiru irrigatio	97	92	90	91	100	100	100	100	100	100	100	100
dembidolo town	100	100	100	100	100	100	100	100	100	100	100	100
dumbong irrigation	97	97	90	99	100	100	90	100	100	100	100	100
gambela town	100	100	100	100	100	100	100	100	100	100	100	100
gilo 1 irrigation	95	95	97	100	100	100	100	100	100	100	100	100
gilo 2 irrigation	95	95	97	100	100	100	100	100	100	100	100	100
gore town	100	100	100	100	100	100	100	100	100	100	100	100
itang irrigation	98	96	97	100	100	100	100	100	100	100	100	100
metu town	100	100	100	100	100	100	100	100	100	100	100	100
mizan teferi town	100	100	100	100	100	100	100	100	100	100	100	100
saudi star irrigation	97	95	100	100	98	97	80	100	100	100	100	100
tepi town	100	100	100	100	100	100	100	100	100	100	100	100

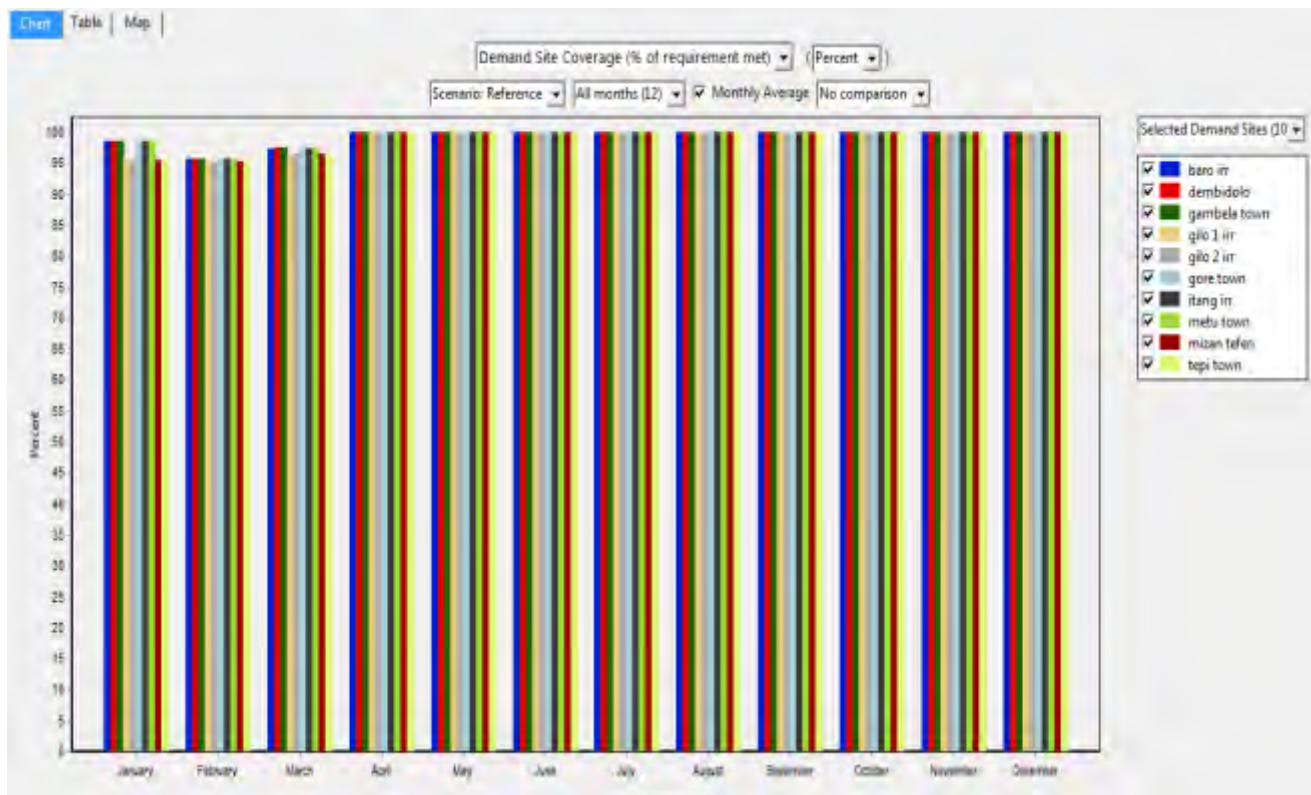


Figure 5. 10 Monthly demand site coverage

Table 5. 12 Annual demand site coverage

Demand site coverage (% of requirement)																
demand sites	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Baro irrigation	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
chiru irrigatio	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
dembidolo town	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
dumbong irr	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
gambela town	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
gilo 1 irrigation	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
gilo 2 irrigation	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
gore town	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
itang irrigation	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
metu town	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
mizanteferi town	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
saudi star irr	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
tepi town	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

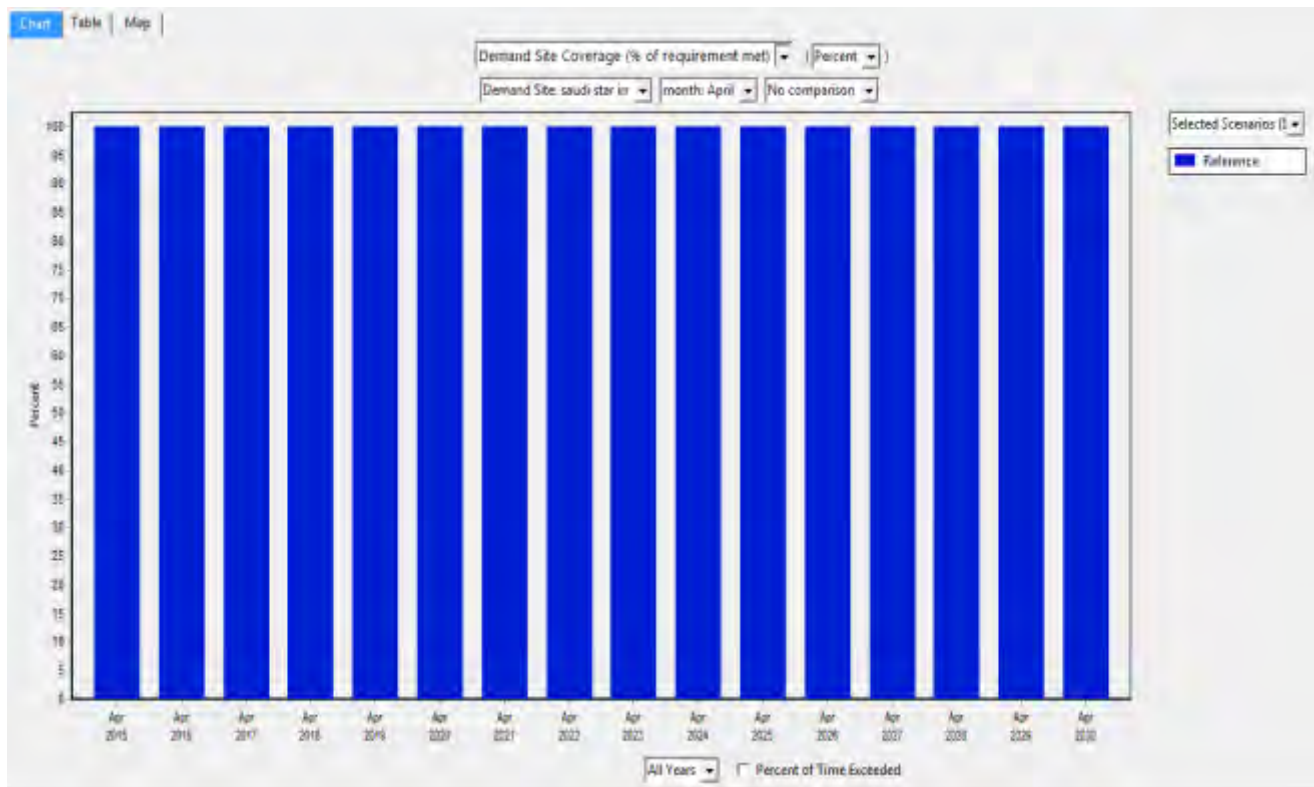


Figure 5. 11 Annual demand site coverage

5.2.3 Cattle demand

Ethiopia is home to about 35 million tropical livestock unit (TLU), and on average, one TLU requires about 25 litres of water per day. Tropical livestock unit is equivalent to an animal of 250 kg live weight on maintenance (King 1983). The authors of ARDCO report expressed the baro-akobo river basin has 321,300 cattle and 180,000 sheep and goats. In Ethiopia the average daily demand for is about 25l/capital. This was used for the projection of the water demand. Based on these figure the future water demands for the animals was projected. The annual water demand is about 3.65 million cubic meters. The result found by the WEAP model shown in table 5.13.

Table 5. 13 average monthly water demand for cattles.

month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
cattle demand	310,000	280,000	310,000	300,000	310,000	300,000	310,000	310,000	300,000	310,000	300,000	310,000	3,650,000

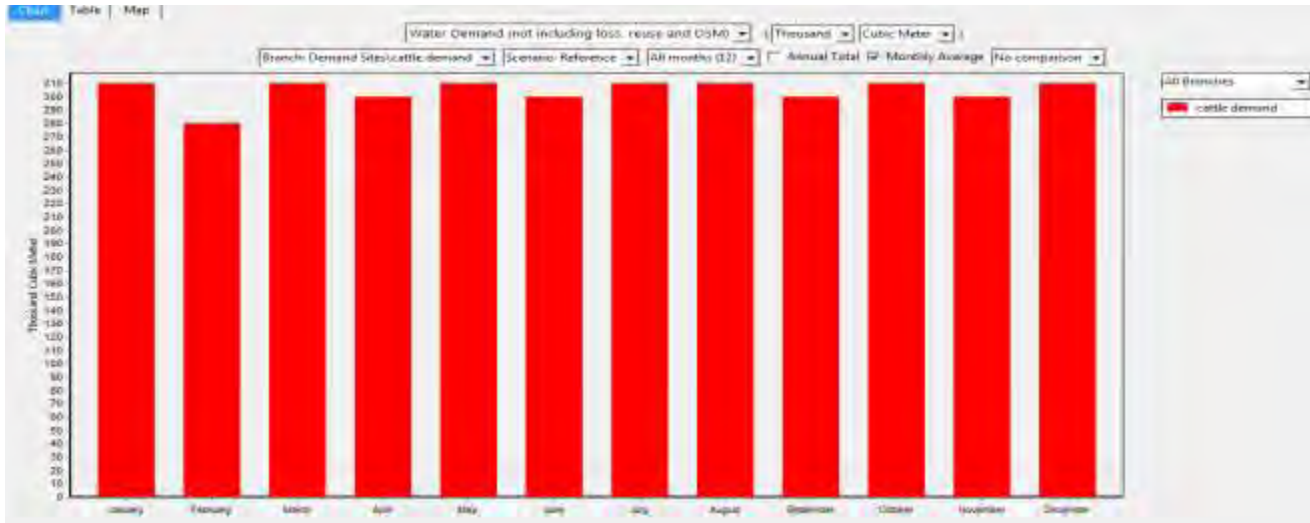


Figure 5. 12 average monthly water demand for cattles

5.2.3 Hydropower Water Demand

The hydropower water demand was varying from month to month. The largest water demand occurred for all projects in April. Moreover, the lowest water demand happened through September to December. The hydropower coverage has a constant value of 100% for all projects. That means for the given capacity the required flow is sufficient. Table 5.14 and table 5.15 show the hydropower water demand and the demand coverage of the supply respectively.

Table 5. 14 Monthly averages Hydropower Demand

Hydropower demand (cubic meter)				
month	TAMS hydropower	baro 1 HP	baro 2 HP	Sum
Jan	1,903,257	308,610	248,370	2,460,237
Feb	1,908,500	308,806	248,416	2,465,723
Mar	1,925,283	309,506	248,592	2,483,380
Apr	1,930,582	309,725	248,647	2,488,955
May	1,925,484	309,524	248,593	2,483,601
Jun	1,900,034	308,508	248,323	2,456,865
Jul	1,893,294	308,285	248,221	2,449,799
Aug	1,883,291	307,918	248,130	2,439,340
Sep	1,876,850	307,660	248,066	2,432,576
Oct	1,876,850	307,660	248,066	2,432,576
Nov	1,876,850	307,660	248,066	2,432,576
Dec	1,876,850	307,660	248,066	2,432,576
Sum	22,777,123	3,701,522	2,979,557	29,458,203

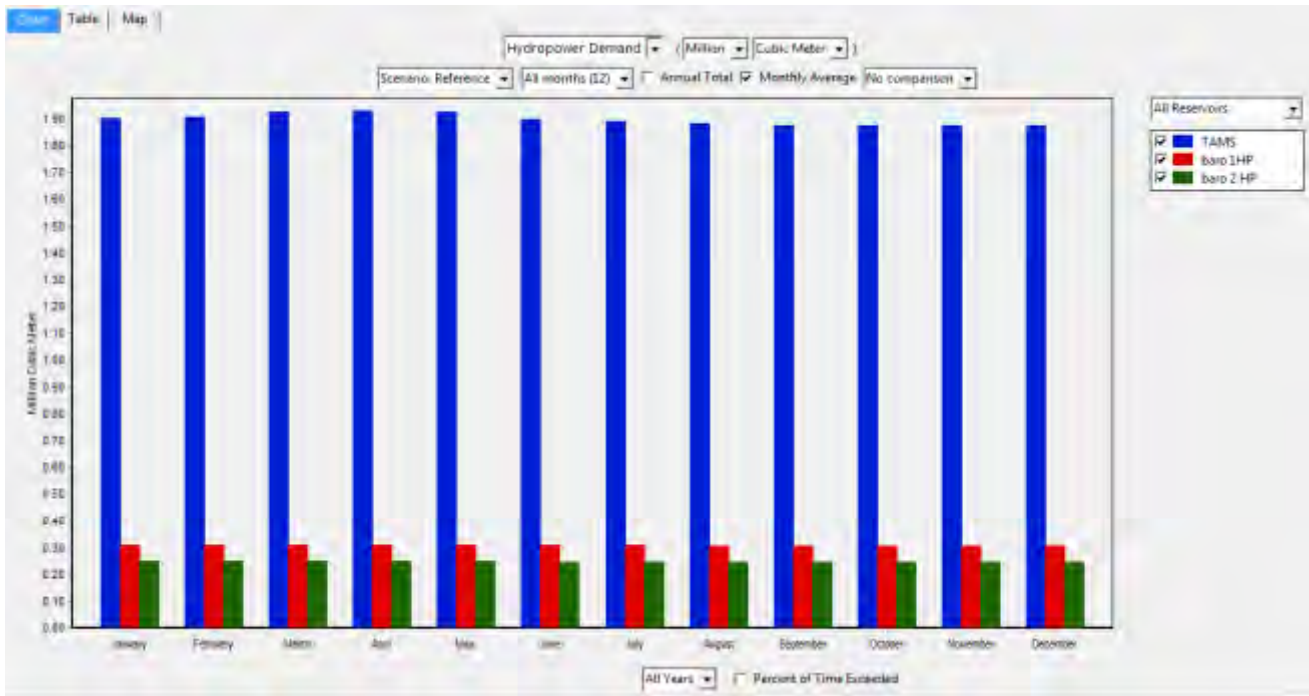


Figure 5. 13 Monthly average Hydropower Demand.

Table 5. 15 Hydropower coverage

Hydropower coverage %			
month	TAMS HP	baro 1 HP	baro 2 HP
Jan	100	100	100
Feb	100	100	100
Mar	100	100	100
Apr	100	100	100
May	100	100	100
Jun	100	100	100
Jul	100	100	100
Aug	100	100	100
Sep	100	100	100
Oct	100	100	100
Nov	100	100	100
Dec	100	100	100

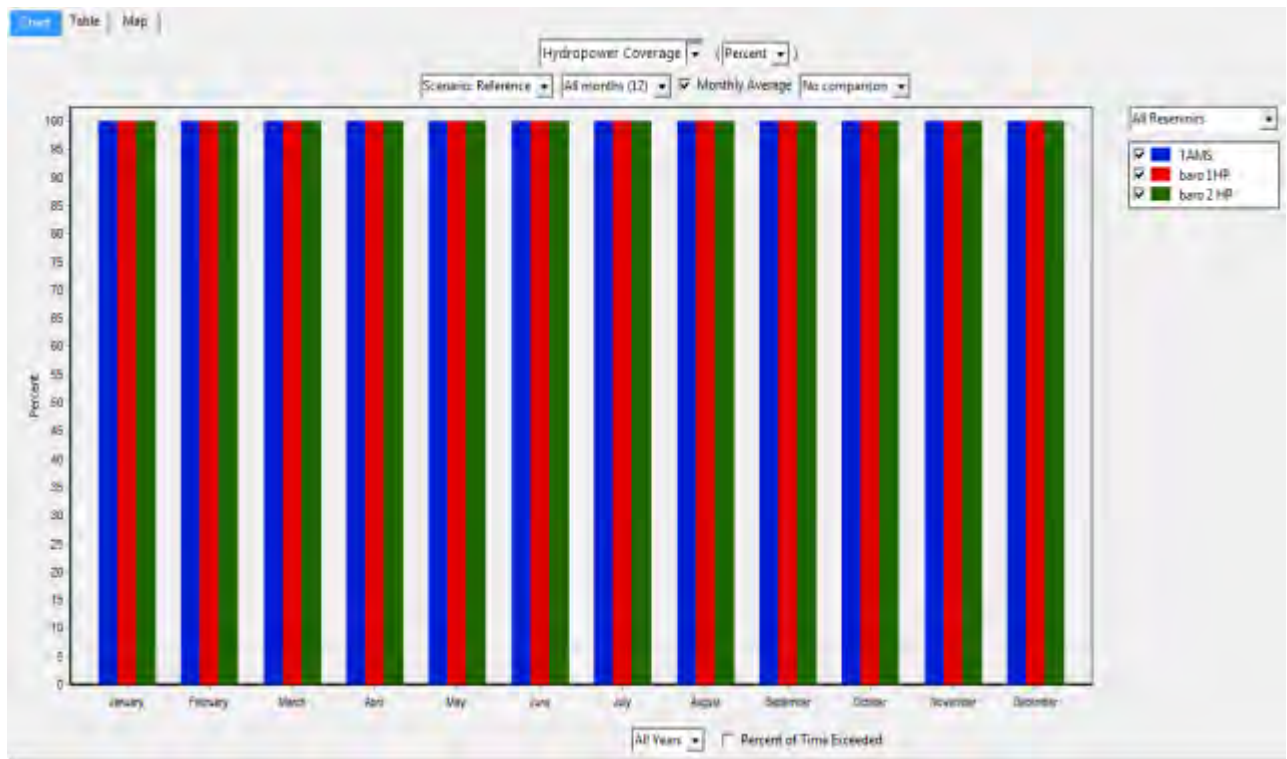


Figure 5. 14 Hydropower coverage

5.3 Comparison of demand and potential

The overall monthly surface water potential and all the demands considered in this research are shown in table 5.16. This research focused on the medium and large-scale projects found in the basin. Thus, the research output indicated that there is much water potential than the demands even though the analysis results were based on these projects. The total surface water potential is about 19Bilion m³ and the total water demand is about 4.085bilion m³, which is about 21.5% of the total surface water potential.

Table 5. 16 Total monthly surface water potential and demands.

MON	Rain (MM)	SURF Q (MM)	LAT Q(MM)	ET(mm)	SURF Q (m ³)	Total monthly Demand(m ³)
1	49.55	814,952,724	814,952,724	814,952,724	283,893,060	814,952,724
2	44.55	673,217,400	673,217,400	673,217,400	110,704,710	673,217,400
3	75.94	345,055,705	345,055,705	345,055,705	196,959,300	345,055,705
4	130.22	105,896,539	105,896,539	105,896,539	620,761,380	105,896,539
5	201.35	78,438,298	78,438,298	78,438,298	2,514,966,510	78,438,298
6	224.31	181,071,193	181,071,193	181,071,193	3,865,156,470	181,071,193
7	218.19	297,762,480	297,762,480	297,762,480	3,448,825,260	297,762,480
8	235.29	153,844,827	153,844,827	153,844,827	3,160,178,010	153,844,827
9	217.29	137,317,613	137,317,613	137,317,613	2,385,245,040	137,317,613
10	158.14	222,338,607	222,338,607	222,338,607	1,359,698,340	222,338,607
11	86.87	425,093,736	425,093,736	425,093,736	641,136,480	425,093,736
12	59.49	649,728,565	649,728,565	649,728,565	406,143,660	649,728,565
sum					19,000,000,120	4,084,717,689

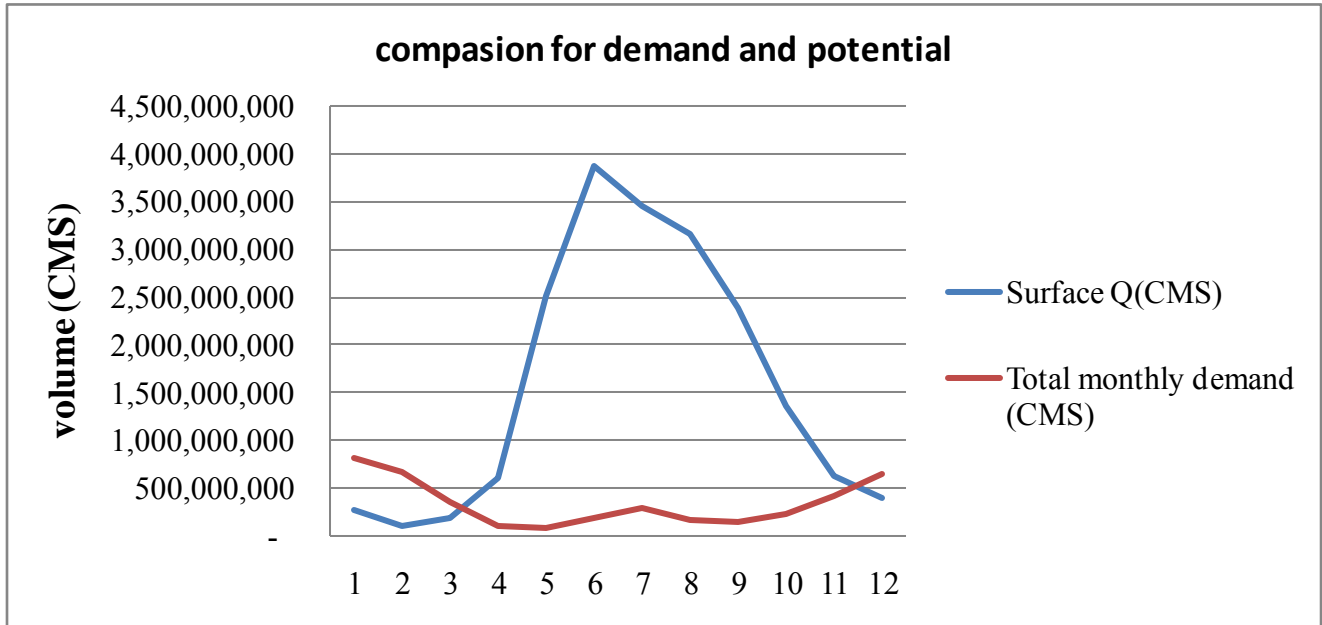


Figure 5. 15 Comparison of total demand and potential.

CHAPTER SIX

6. Conclusion and Recommendation

6.1. Conclusions

In this research, attempt has been made to determine surface water potential and demands based on some model parameters required to estimate surface water potential and demands in Baro-Akobo basin. Thus, based on the applied methodology and results obtained, the following conclusions are drawn: surface run off quantity has been estimated by using land use, soil type, rainfall amount of the basin and slope of the area and other factors of the basin. All these parameters are the inputs of the model and affected the surface runoff. Monthly time step model performance evaluation coefficient results the model is capable of predicting stream flow for the basin.

A good agreement between measured and simulated monthly stream flow at Gambella gauging station was evaluated by correlation coefficient ($R^2 = 0.83$) and Nash-Sutcliffe model efficiency (NS = 0.56) for calibration period and $R^2 = 0.81$ and NS = 0.67 for validation periods.

The SWAT model sensitivity in predicting stream flow was done as a function of size of the threshold area (TA) and the result shows surface runoff is not significantly affected by varying the size of TA. This is because the surface runoff is directly related to the CN, and CN is not affected significantly by the size of the sub watersheds. Plant evapotranspiration, different types of moisture condition and the retention parameter as discussed in chapter 3 affect CN.

The water demand analysis result shows there is no shortage of water supply for scenario year 2015 to 2030 in the basin. The annual overall demand is about 4.085BMC. Whereas the annual demand for irrigation project is 4.077BMC. Comparing the monthly water demand and potential, there is shortage of water in December to march which shows us that there should be storage facilities. However, the overall demand is much less than the potential, which is about 19BMC. The water demand analysis was done by considering some medium and large-scale projects. Even though the analysis focused on these projects, the water demand found by this analysis is about 21.5 % of the total surface water potential of 19BMC of water per year.

Generally this assessment results the annual surface water potential of the basin is about 19BMC. The current and proposed medium and large-scale projects annual demand is about 4.085BMC of water, which indicates the basin water potential is underutilized.

Generally, this research tried to answer the stated objectives, which were quantifying the total surface water potential of the basin and the current and future demands. Then compare the demand with the available water potential.

6.2. Recommendations

The SWAT model is very sensitive and needs accurate input data. Using sufficient time and input data the model can simulate good result, which fits the observed stream flow data. In addition to this up to date land use and management data is essential for SWAT model. More efforts required to find best estimation of the surface water potential using SWAT model.

The water demands in the basin is very small so further investigation is essential to use the available surface water potential of the basin. The overall water demands for the considered large-scale projects are much lower compared to the available surface water potential. Hence, the basin has to be studied for more projects to use this water potential.

7. REFERENCE

1. ARDCO- GEOSERV (1996), Survey and Analysis of the Upper Baro-Akobo Basin. Ministry of Water Resources, Addis Ababa.
2. Arnold, J. G. et al., (1998). Large area hydrologic modeling and assessment part I: model development, *J. Am. Water Resour. Assoc.* 34(1), 73–89.
3. Arnold et al., (1996); Arabi et al., (2007); Schuol et al., (2008); Setegn et al., (2010) The influence of parameter distribution uncertainty on hydrological and sediment modeling: a case study of SWAT model applied to the Daning watershed of the Three Gorges Reservoir Region, China
4. Awulachew et al., (2007), Nile River basin water, agriculture, governance and livelihoods
5. Awulachew, S. B.; et al. 2007. Water Resources and Irrigation Development in Ethiopia. Colombo, Sri Lanka: International Water Management Institute. (Working Paper 123)
6. Belete et al., (2013), GIS-based hydrological zones and soil geo-database of Ethiopia
7. Beven, K.J. (2000). Rainfall-runoff modeling. The Primer. Wiley.
8. Beven, K.J. (1989). Changing ideas in hydrology-the case of the physically-based models, *Journal of Hydrology* 105,(pp. 157- 172).
9. Cunderlik (2003), Hydrologic Models for Inverse Climate Change Impact Modeling.
10. Chow Ven Te, et al. (1988). Applied Hydrology. McGraw hill, New York.
11. Daniel EB, et al., (2011). Watershed modeling and its applications: A state-of-the-art review. *Open Hydrol. J.* 5:26-50.
12. D, Asaro F, Grillone G (2010). Runoff Curve Number method in Sicily: CN determination and analysis of the Initial abstraction ratio. Proceedings of the 4th Federal Interagency Hydrologic Modeling Conference, Las Vegas, Nevada (USA), 06/27/2010-07/01/2010.
13. Dominik Wisser (June 2004) Water Management Methodologies for Water Deficient Regions in Southern Europe.
14. Durrans SR., (2003). Storm water Conveyance Modeling and Design. Haestad Press, Waterbury, CT

15. Gleik, (1996), the changing water paradigm: a look at twenty-first century water resources development.
16. Dzurik,(1996), water resources development planning
17. Global Water Partnership, (2000), Global Water Partnership Technical Advisory Committee, Background Paper no.4.
18. Githui, F.r.t.al,(2009). Climate change impact on SWAT simulated stream flow in western Kenya. *International Journal of Climatology*, 29:1823– 1834.
19. H.M. Raghunath,(2006).Hydrology principles analysis and design revised second edition.
20. Killingtveit A. et al. (1995). *Hydropower Development, Volume No 7, Hydrology*.
21. King J.M. (1983). Livestock water needs in pastoral Africa in relation to climate and forage. ILCA Research Report 7. ILCA (International Livestock Centre for Africa), Addis Ababa, Ethiopia.
22. Kousari, M.R.te.al, (2010). Sensitivity analysis and impact quantification of the main factors affecting peak discharge in the SCS curve number method: An analysis of Iranian watersheds. *Quat. Int.* 226, 66–74.
23. Klemes, V. (1986). Operational testing of hydrological simulation models. *Hydrological Sciences Journal*, Vol. 31, No. 3, 13-24.
24. Loucks, D. P., (2006). Generic simulation models for facilitating stakeholder involvement in water resources planning and management: a comparison, evaluation, and identification of 70. future needs. In *Proceedings of the iEMSs third biennial meeting: —Summit on Environmental Modelling and Software*, Burlington.
25. Magoma, D.M., (2009). Hydrological Modeling Using SWAT in Wetland Catchments: The Case Study of Rugezi Watershed in Rwanda, First annual Nile Basin research conference, Dar es Salaam, Tanzania.Mann, H.B., 1945. Non-parametric test against trend. *Econometrika*, 13: 245– 259.
26. Mimikou, M. (1990). Regional analysis of hydrological variables in Greece. Technical University of Athens, Greece.

27. McCuen Richard H (1989). Hydrology Design and Analysis. Prentice Hall Englewood Cliff, New Jersey.
28. Molle, (2006), Dealing with Closed Basins: The Case of the Lower Jordan River Basin.
29. Munyaneza, O. et.al, (2013). Assessment of surface water resources availability using catchment modelling and the results of tracer studies in the meso-scale Migina Catchment, Rwanda. Hydrol. Earth Syst. Sci. Discuss., 10: 15375-15408.
30. Mugatsia, E. A.,(2010). Simulation and Scenario Analysis of Water Resources Management in Perker-ra Catchment Using WEAP Model. Master,s Thesis, Department of Civil and Structural Engineering, School of Engineering, Moi University, Kenya,(December).
31. Nata Tadesse (2006). “Surface Waters Potential of the Hantebet Basin, Tigray, Northern Ethiopia”)
32. Norwegian Institute of Technology Division of Hydraulic Engineering.
33. National Resources Conservation Service (NRCS), 2004. Estimation of Direct Runoff from Storm Rainfall. National Engineering Handbook Part 630 Hydrology, chapter 10, Washington, D.C.
34. Neitsch et al,(2005), soil and water assessment tool model: current developments and applications.
35. O,Loughlin, G.et. al, (1999). Rainfall-runoff processes and modelling, Journal of Hydraulic Research, 34(6): 733-751.
36. Oyebande, L., (2001). Water problems in Africa-how can sciences help? Hydrological Sciences Journal, 46(6): 947-961.
37. Perrin C.et.al, (2001). Does a large number of parameters enhance model performance? Comparative assessment of common catchment model structures on 429 catchments. Journal of Hydrology, Vol. 242, 527-301.
38. Pieter van der Zaag, UNESCO-IHE Delft & University of Zimbabwe,(2003) Basics of Water Resources
39. Peter Ashton et al.2003 Handbook for the Assessment of Catchment Water Demand and Use”.

40. Sang, J.K., (2005). Modeling the impact of changes in land use, climate and reservoir storage on flooding in the Nyando basin. M.Sc. Thesis, Jomo Kenyatta University of Agriculture and Technology, Kenya.
41. Seleshi et al, (2010), water resources and irrigation development in Ethiopia.
42. Sieber, J.et.al, (2005). WEAP a demand, priority, and preference driven water planning model: Part 1, model characteristics, *Water International*, 30(4), 487–500.
43. Soulis KX et.al, (2009). Investigation of the direct runoff generation mechanism for the analysis of the SCS-CN method applicability to a partial area experimental watershed. *Hydrol. Earth Syst. Sci.* 13:605-615.
44. Supiah S, Normala H., (2002). Rainfall Runoff simulation using Mike11 nam. *Journal of civil engineering* 15: 26-38.
45. Taffa T.,(2002). *Soil and Water Conservation for Sustainable Agriculture*. Mega Publishing Enterprise, CTA, Postbus 380, 6700 AJ Wageningen, the Netherlands.
46. TAMS & ULG (1997), Baro-Akobo River Basin Integrated Development Master Plan Study Annex 1,Annex2 , MoWR Addis Ababa.
47. UNEP. (2010). “Africa Water Atlas”. Division of Early Warning and Assessment (DEWA). United Nations Environment Programme (UNEP). Nairobi, Kenya.
48. UNESCO (1998) world water resources a new appraisal and assessment for the 21st century.
49. WMO-No. 1095, (2012), technical material for water resources assessment.
50. Yates, D.N. & Strzepek, K.M. (1994) Potential Evapotranspiration Methods and their Impact on the Assessment of River Basin Run off under Climate Change, IIASA Working Paper WP± 94± 46 (Laxenburg, Austria, IIASA).
51. Yates D, et .al, (2005a) WEAP21: a demand, priority, and preference driven water planning model: part 2, aiding freshwater ecosystem service evaluation. *Water Int* 30 (4):487–500.
52. Yates D.et al, (2005b) WEAP21. a demand-, priority, and preference driven water planning model part 1, model characteristics. *Water Int* 30(4):487–500.

8. APPENDIXES

APENDEIX A

Prepared Input Data for SWAT model (mean Rainfall, monthly rainfall, maximum Temperature and minimum temperature)

22 years mean monthly rainfall (mm) for fifteen rainfall stations used in SWAT model

	1992-2013 mean monthly rainfall														
month	abobo	ayira	bure	debidolo	gambela	gimbi	gore	jikawo	masha	tepi	itang	mizan tef	alemtef	algea	uka
jan	54.97889	67.92628	26.78636	24.02814	24.07464	72.23143	41.46818	1.928927	57.57909	53.23098	6.460129	78.95955	79.33849	30.11727	33.03182
feb	87.96544	62.80714	18.27909	22.72416	24.45633	41.3316	31.72682	5.324864	45.05727	35.31364	5.314415	62.59909	88.09352	24.00655	32.38182
mar	70.28209	81.66189	51.75318	65.65197	49.52437	98.42168	71.08462	15.45	101.46	94.89136	17.66692	124.4145	80.49579	57.97818	103.9986
apr	92.59001	132.8849	116.1114	136.0547	90.61135	140.2879	108.9745	76.17773	150.4018	178.7277	41.2161	182.3486	157.7226	105.2813	130.2491
may	139.7744	209.1217	206.097	223.4711	163.3898	229.647	244.7522	116.6141	239.1873	210.0574	106.4864	229.36	264.5469	245.3359	223.579
jun	150.3862	303.2895	208.0704	207.3556	160.5041	339.6177	275.3685	109.6082	273.2509	237.0818	111.6855	242.7236	323.9875	288.3661	230.225
jul	162.9627	308.8414	181.7919	187.1009	167.9854	329.5961	287.8407	120.5333	272.0673	200.6133	147.0547	253.1755	316.78	274.8231	246.8071
aug	169.9342	291.1211	225.64	185.091	179.223	348.2566	288.6055	153.1659	282.0918	222.1817	128.6335	299.5127	313.1508	312.5391	256.3442
sep	154.1031	305.0602	189.1373	172.6084	162.5303	328.1841	244.3045	123.6773	256.8109	238.9183	135.8022	255.8736	320.5945	289.8673	297.6495
oct	139.5584	143.7496	141.7301	129.4882	118.8065	161.0508	172.6071	79.1903	191.9627	173.7141	96.23614	210.4623	193.5912	143.9286	221.0695
nov	85.93273	56.44282	50.41275	66.29229	60.09577	56.1532	74.72682	19.98182	87.07091	107.6985	34.75323	153.7418	95.72851	71.83636	82.19791
dec	76.84517	42.9853	23.17727	38.34909	35.37733	58.59379	37.93091	2.568636	74.90818	75.71662	6.638822	108.9977	64.96227	31.64182	47.31
annual	1385.313	2005.892	1438.987	1458.216	1236.579	2203.372	1879.39	824.221	2031.848	1828.145	837.948	2202.169	2298.992	1875.722	1904.844

	gambella station monthly mean(m3/s)used for outlier test											
year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1994	104.375	63.754	43.491	58.314	201.231	432.898	753.346	935.295	1051.947	420.648	221.08	136.058
1995	69.726	45.573	45.162	54.611	119.418	276.948	474.918	784.542	1058.849	639.452	239.138	154.783
1996	111.422	66.166	77.335	76.16	284.801	610.102	912.888	1060.848	1051.091	739.195	270.523	157.024
1997	105.888	63.498	65.789	126.249	241.274	547.726	703.468	1023.372	878.921	713.92	684.739	230.162
1998	127.644	64.516	78.002	56.125	166.505	488.716	810.756	1065.708	1092.001	1096.846	464.576	168.487
1999	111.677	64.603	39.871	53.497	351.449	662.932	747.65	1009.173	919.645	1108.396	399.997	170.127
2000	106.741	61.036	39.563	71.059	219.92	518.331	800.974	874.829	954.498	978.042	461.141	182.201
2001	95.426	63.456	51.578	53.611	154.586	451.994	772.925	925.602	1022.474	755.966	325.675	147.994
2002	113.564	56.523	41.815	62.875	52.732	296.002	552.207	726.946	815.486	490.028	220.463	104.501
2003	52.138	30.095	38.739	38.909	34.834	203.088	551.001	647.903	933.501	591.016	188.63	112.377
2004	56.944	43.405	22.368	23.812	76.61	261.594	681.155	724.983	984.464	676.035	233.526	132.116
2005	69.542	35.77	37.998	12.491	43.136	97.015	242.333	469.289	815.204	867.921	826.695	335.427

Monthly rain fall for fifteen rainfall stations used in SWAT model

		monthly rainfall														
		stations														
year	month	abobo	ayira	bure	debidio	gambe	gimbi	gore	jikawo	masha	tepi	itang	mizan	alemte	algea	uka
1992	1	3.3	3.2	25.9	27.3	45.0	98.1	42.1	3.0	91.4	98.5	0.0	29.8	0.0	26.1	88.6
1992	2	96.3	0.0	20.9	0.0	23.2	0.0	6.3	2.3	69.7	17.4	1.2	186.8	145.0	10.5	49.8
1992	3	3.3	111.6	55.2	99.0	98.1	37.7	80.5	12.9	111.6	63.0	7.5	239.6	0.0	61.9	149.7
1992	4	81.2	63.0	160.4	206.7	177.0	194.9	116.9	59.3	118.4	136.0	6.7	151.0	75.8	141.8	177.5
1992	5	101.0	184.2	204.8	250.4	210.1	207.4	264.1	120.4	198.9	246.6	8.7	309.0	158.8	203.1	236.7
1992	6	47.3	216.7	196.0	184.9	160.8	233.7	227.5	85.2	314.6	185.0	3.7	234.7	252.5	226.2	139.1
1992	7	160.3	311.7	118.9	193.7	168.1	372.1	343.1	202.2	222.9	172.9	3.7	567.5	288.4	293.3	138.0
1992	8	145.4	403.7	388.3	143.4	130.9	454.9	323.4	150.7	302.3	193.9	6.5	610.3	252.8	202.6	252.1
1992	9	162.6	256.5	219.3	212.9	181.5	518.8	224.5	90.8	203.5	214.0	34.3	368.1	171.5	408.3	258.1
1992	10	131.7	183.7	182.8	97.1	96.7	140.6	284.9	25.9	204.8	206.0	24.3	480.4	55.6	199.0	255.6
1992	11	110.8	23.3	74.2	38.0	52.1	106.6	161.1	0.0	135.3	52.6	0.2	116.3	78.2	72.8	141.0
1992	12	42.7	92.8	16.8	25.1	43.4	10.8	14.8	0.0	111.3	93.7	0.6	226.1	0.0	44.7	53.8
1993	1	2.1	85.3	24.0	2.3	26.5	0.0	17.4	1.8	50.7	67.3	0.2	148.7	8.7	27.6	2.4
1993	2	105.9	84.2	40.2	43.8	54.8	10.3	50.2	11.8	65.3	65.2	23.0	78.3	9.0	128.6	29.2
1993	3	46.9	106.6	59.2	21.3	40.6	30.5	141.1	9.8	113.4	82.1	0.6	148.7	13.0	151.9	84.2
1993	4	119.8	110.7	192.2	170.1	149.9	183.5	164.1	110.4	142.9	178.9	31.9	102.4	142.8	110.1	167.1
1993	5	191.4	258.3	186.8	195.1	169.2	134.5	143.9	83.3	206.4	166.7	161.6	208.7	213.1	210.1	193.4
1993	6	178.0	281.0	237.6	217.2	184.7	283.6	268.9	111.2	250.7	155.3	196.6	298.6	346.7	399.6	307.5
1993	7	105.6	352.2	149.2	130.6	121.5	381.3	261.8	201.2	332.3	303.7	139.1	267.2	213.0	301.7	237.2
1993	8	62.3	332.6	259.2	182.2	159.6	367.8	356.3	185.0	272.5	259.4	65.3	228.5	371.5	406.4	251.0
1993	9	128.7	285.7	107.6	116.1	109.9	290.4	247.6	192.1	325.9	559.0	102.7	228.5	331.9	248.4	282.6
1993	10	112.1	176.4	146.2	76.4	81.3	130.2	160.7	62.7	199.4	159.0	105.0	142.2	87.6	151.0	281.8
1993	11	11.0	15.5	13.4	57.4	66.5	6.4	81.7	6.7	62.3	69.7	100.0	79.2	91.6	72.4	54.9
1993	12	0.8	0.3	0.0	20.0	39.6	0.0	0.7	0.0	45.8	65.5	0.7	16.3	7.0	2.4	0.0
1994	1	6.6	0.4	0.0	3.8	27.6	9.5	70.1	0.2	59.7	3.2	0.0	11.9	155.3	19.1	5.7
1994	2	96.3	262.7	0.0	11.4	30.8	0.0	1.3	0.0	46.0	22.0	0.1	8.6	0.0	0.0	0.0
1994	3	5.0	6.1	0.1	47.2	59.7	2.4	14.6	14.9	69.2	53.7	0.2	115.3	0.0	50.3	8.0
1994	4	88.2	299.6	243.4	171.4	150.8	180.2	130.6	20.1	111.7	201.9	47.7	248.6	71.9	118.3	141.3
1994	5	91.4	299.4	281.3	215.1	184.0	329.8	222.2	116.7	352.4	278.5	315.2	212.1	303.3	303.7	189.8
1994	6	106.2	250.5	182.1	123.8	115.6	295.0	277.0	14.4	350.9	344.5	139.1	247.9	178.3	183.1	269.8
1994	7	149.9	392.9	127.5	170.3	150.8	331.4	268.6	186.7	263.0	169.1	135.4	344.2	206.2	192.7	231.1
1994	8	234.8	205.7	344.1	168.6	149.6	371.9	252.1	57.8	164.0	295.2	67.2	298.0	299.5	252.5	286.1
1994	9	23.6	257.7	120.8	171.0	150.5	223.2	270.9	77.1	214.4	193.1	104.1	119.1	255.7	254.4	307.5
1994	10	156.4	176.3	122.3	180.7	158.5	132.3	78.6	59.9	121.2	126.4	201.0	147.1	140.1	42.6	146.9
1994	11	116.4	64.4	28.2	56.9	66.1	123.5	52.8	19.2	58.3	143.7	123.2	375.3	79.4	32.0	176.0
1994	12	103.6	5.4	38.1	2.3	26.5	93.0	18.5	0.0	49.6	100.8	0.0	50.7	12.9	27.9	0.0

Assessment and evaluation of surface water potential and demands in Baro -Akobo river basin, Ethiopia

1995	1	0.0	0.0	1.0	9.1	31.5	0.8	0.2	0.0	2.9	3.5	0.0	0.2	0.0	1.9	0.0
1995	2	94.1	0.0	2.9	3.9	25.3	86.2	39.4	0.0	40.3	21.2	0.0	38.4	0.0	18.9	10.5
1995	3	44.3	60.6	100.3	48.4	60.6	161.0	150.5	8.3	82.8	151.6	0.0	77.8	93.0	61.0	132.0
1995	4	35.9	204.3	74.9	84.2	86.3	176.1	69.3	21.0	125.5	164.5	27.0	141.9	321.8	51.6	46.0
1995	5	136.9	135.8	148.1	121.8	114.9	161.7	149.5	174.3	252.9	193.4	173.9	218.5	248.0	187.0	241.0
1995	6	168.5	228.8	212.2	160.7	142.9	308.0	217.2	76.5	288.2	279.9	53.8	210.4	310.2	178.0	220.1
1995	7	180.3	130.9	241.3	125.0	117.3	202.7	281.1	29.8	220.2	144.6	244.7	190.6	403.9	134.2	299.4
1995	8	106.0	265.3	249.5	119.2	113.0	310.1	274.8	190.6	371.0	373.7	49.6	306.1	243.7	263.5	309.3
1995	9	75.4	320.2	158.1	141.5	128.7	282.5	255.0	101.0	259.6	194.5	95.5	291.7	200.2	304.9	321.8
1995	10	71.6	96.3	113.2	117.5	111.8	63.1	119.0	36.8	128.2	200.3	17.3	198.4	76.5	104.7	183.2
1995	11	23.9	163.2	124.2	174.4	153.1	117.4	67.2	0.0	54.2	98.8	0.0	129.4	14.3	29.5	112.2
1995	12	18.1	2.7	40.3	7.9	30.6	99.0	106.1	0.0	132.1	92.1	0.0	235.8	20.8	39.1	132.6
1996	1	40.6	92.5	46.5	112.3	107.9	12.5	184.7	0.0	78.6	96.8	7.8	79.4	28.0	80.4	231.2
1996	2	136.7	78.3	82.9	136.5	124.2	0.0	56.0	2.1	50.3	61.2	1.3	33.2	7.2	10.6	9.5
1996	3	57.9	93.6	115.0	169.9	150.5	14.2	157.5	0.0	175.5	128.2	38.2	135.7	44.4	59.7	71.2
1996	4	32.9	119.5	243.9	271.9	225.2	49.7	115.5	0.0	216.0	172.4	0.0	172.2	94.7	101.7	114.9
1996	5	39.5	222.3	205.2	224.5	191.0	252.0	326.0	123.3	246.3	181.8	84.9	259.6	308.1	281.7	332.8
1996	6	162.9	290.8	170.3	213.8	182.2	248.0	311.7	100.3	184.5	221.8	81.1	487.1	247.3	319.7	253.7
1996	7	168.2	308.9	174.2	220.6	188.1	321.8	433.1	205.9	223.5	181.2	100.9	227.4	314.0	254.9	203.4
1996	8	168.2	208.6	169.8	220.6	188.1	320.2	334.0	182.7	167.6	172.2	79.2	283.2	181.7	343.6	209.1
1996	9	176.1	253.3	236.7	258.4	215.2	246.2	262.0	76.9	190.4	224.3	80.2	484.0	491.7	264.4	150.0
1996	10	164.0	95.1	144.6	206.3	177.4	37.6	215.2	62.3	91.5	146.3	136.3	171.5	227.8	100.7	204.5
1996	11	122.1	21.7	8.5	75.9	80.1	9.3	92.6	0.5	86.0	81.5	6.0	74.3	3.6	27.9	22.1
1996	12	134.7	6.1	40.3	107.3	104.2	0.8	84.0	3.1	83.3	57.6	0.0	56.3	2.5	19.9	63.3
1997	1	129.2	2.3	16.9	88.8	90.5	2.8	63.1	0.0	81.2	98.9	41.3	46.5	1.0	29.7	18.3
1997	2	112.9	0.5	0.0	67.2	72.1	0.0	12.9	3.8	45.9	24.5	36.6	6.7	140.4	5.2	6.3
1997	3	141.6	1.5	67.1	130.8	121.6	18.5	89.2	16.9	79.5	110.8	43.8	163.2	85.2	71.6	65.7
1997	4	144.9	62.2	96.6	153.1	137.3	107.3	168.5	96.6	133.3	249.2	44.0	325.5	174.6	160.5	217.6
1997	5	164.0	213.1	158.8	206.4	177.6	184.8	291.6	88.0	253.7	250.1	48.3	218.8	304.1	198.8	238.8
1997	6	193.2	303.3	290.8	316.3	258.0	317.5	328.3	111.5	253.4	149.2	53.6	199.0	362.3	291.2	330.9
1997	7	178.1	329.5	214.0	253.9	212.7	351.1	333.7	111.0	290.9	98.2	164.0	232.1	440.6	344.1	196.6
1997	8	191.6	180.9	270.9	299.6	246.5	232.0	252.0	127.7	232.1	153.4	84.0	203.0	379.5	252.4	306.5
1997	9	180.2	148.4	239.8	272.3	225.5	242.5	241.3	39.7	279.0	101.3	30.2	262.9	236.9	200.8	264.9
1997	10	193.0	176.9	286.8	304.4	250.1	351.7	296.8	252.0	356.4	361.7	226.2	249.9	554.6	222.9	140.4
1997	11	132.6	27.0	47.7	111.6	106.6	48.8	104.5	62.4	70.6	142.4	87.5	267.7	93.3	46.8	118.8
1997	12	126.2	0.0	3.9	78.6	83.0	93.0	28.9	0.0	52.2	149.2	0.0	167.0	0.0	4.6	1.1
1998	1	102.9	0.0	0.6	0.0	24.8	93.3	27.2	2.1	46.6	126.2	36.1	180.8	0.0	2.7	7.5
1998	2	90.7	0.0	0.0	0.0	16.7	84.0	34.7	0.0	53.6	76.2	0.0	45.3	0.0	3.2	4.8
1998	3	131.6	12.0	136.7	4.0	96.4	112.0	107.2	27.9	101.8	142.6	82.3	170.1	0.0	55.3	92.9
1998	4	94.3	0.4	65.9	127.4	10.7	43.2	46.3	21.9	129.0	102.0	31.6	245.5	37.7	24.8	44.4
1998	5	152.6	109.7	204.5	218.9	149.0	152.9	193.4	112.5	163.0	216.3	112.3	178.6	347.6	187.7	224.5
1998	6	178.6	279.7	279.5	281.2	221.5	390.1	249.2	161.1	247.0	216.8	165.3	221.2	393.5	376.9	239.4
1998	7	187.4	267.3	211.9	213.8	236.1	262.3	297.7	104.3	237.9	219.1	306.4	263.0	148.2	312.8	215.4
1998	8	145.4	312.7	158.3	143.5	131.0	360.2	216.2	161.7	286.0	335.4	187.3	278.9	300.9	294.8	300.1
1998	9	138.3	247.2	297.4	130.7	120.7	484.9	262.5	25.2	335.2	207.9	41.5	215.2	403.0	221.9	274.4
1998	10	164.9	155.9	162.8	209.4	179.8	324.8	258.8	113.3	377.6	157.5	171.1	246.1	201.2	189.5	347.0
1998	11	118.0	38.1	73.1	62.2	70.0	14.6	23.6	68.1	83.1	58.3	30.0	88.8	24.5	21.4	38.1
1998	12	104.5	0.0	40.3	5.4	28.8	0.0	7.4	0.0	46.8	19.5	0.0	34.9	0.0	2.4	53.9

Assessment and evaluation of surface water potential and demands in Baro -Akobo river basin, Ethiopia

1999	1	106.2	27.8	67.9	11.1	33.0	0.0	25.8	0.0	51.7	16.3	0.0	62.6	8.0	18.9	0.4
1999	2	96.0	76.3	36.4	15.4	29.9	1.0	38.3	4.4	13.0	47.1	2.9	21.1	193.4	17.7	40.2
1999	3	103.8	148.8	142.3	3.1	27.1	93.0	24.8	1.0	308.1	29.1	0.0	112.2	0.0	0.0	0.0
1999	4	134.9	77.4	140.3	119.2	112.2	88.2	127.9	173.3	300.6	246.7	17.8	280.8	115.7	105.3	156.9
1999	5	168.3	287.5	174.5	221.0	188.3	291.1	356.1	49.1	376.3	421.3	95.5	267.9	356.2	301.6	375.5
1999	6	172.1	273.3	226.8	245.1	205.4	274.7	198.7	194.6	304.2	156.7	247.7	187.0	341.3	246.8	243.7
1999	7	150.6	215.0	183.8	161.2	144.1	187.6	249.1	86.5	327.7	173.2	112.4	243.5	305.5	203.3	295.6
1999	8	168.6	349.3	223.7	221.9	189.0	327.7	174.3	59.0	194.6	158.7	147.3	310.2	399.5	270.0	220.8
1999	9	157.1	291.9	203.3	194.1	167.6	305.5	237.2	51.2	277.5	146.8	152.6	230.0	247.8	281.7	282.2
1999	10	155.1	336.8	107.8	176.4	155.3	361.5	208.0	89.9	244.3	179.2	101.9	276.0	197.6	207.4	254.5
1999	11	105.9	10.1	86.3	21.2	39.7	10.6	58.8	0.0	107.1	62.1	67.5	70.2	1.6	38.7	103.8
1999	12	111.8	169.6	40.3	30.0	47.0	122.7	27.7	0.0	101.0	35.9	39.2	84.2	5.8	14.6	74.2
2000	1	105.9	0.1	174.5	9.9	32.1	0.0	28.8	0.0	50.1	22.3	2.4	22.2	0.9	0.0	75.3
2000	2	99.6	79.0	0.5	11.3	31.6	1.0	5.9	0.0	23.9	7.7	0.0	16.0	6.2	1.0	0.0
2000	3	112.9	5.8	20.4	33.8	49.8	130.5	30.5	0.0	59.4	71.4	0.0	79.5	10.5	11.2	7.1
2000	4	146.7	148.4	135.5	159.1	141.7	227.2	111.3	2.1	50.3	200.4	98.0	161.3	98.8	177.8	126.3
2000	5	158.3	209.5	371.0	187.1	163.3	297.5	337.2	110.6	203.0	208.8	64.5	246.7	446.7	231.6	333.9
2000	6	178.5	308.0	282.4	266.4	221.1	281.0	282.3	61.1	302.7	229.1	118.5	221.0	450.9	243.6	244.1
2000	7	146.8	295.1	164.6	148.2	134.5	302.0	235.4	114.4	392.3	138.4	128.1	400.4	369.6	221.6	294.7
2000	8	136.1	252.0	187.0	112.1	107.8	240.4	293.4	84.9	384.4	149.0	199.6	271.3	550.2	311.8	335.4
2000	9	146.2	263.5	114.9	157.4	140.5	350.5	257.6	54.9	222.2	153.9	34.0	132.6	336.9	318.3	409.9
2000	10	155.2	203.4	145.2	176.5	155.4	225.1	241.8	128.0	290.6	231.3	88.0	253.4	372.9	256.9	316.7
2000	11	110.5	107.1	34.0	36.7	51.2	33.4	54.0	2.3	168.3	105.4	25.3	86.3	150.6	65.3	55.5
2000	12	109.6	0.0	5.1	22.4	41.4	0.6	21.7	0.0	97.2	60.6	37.4	24.4	4.6	9.0	7.2
2001	1	102.9	83.7	0.7	0.0	24.8	0.0	2.0	0.0	22.2	42.8	0.0	26.5	0.0	0.8	1.4
2001	2	99.4	75.6	19.0	21.8	38.5	0.0	44.6	0.0	49.7	45.6	1.0	19.3	2.2	19.3	33.2
2001	3	117.0	33.3	17.2	47.5	60.0	32.5	33.8	0.0	101.8	138.9	0.0	129.3	34.7	42.4	31.4
2001	4	126.6	29.5	58.9	91.2	91.5	27.3	118.8	88.5	179.1	169.9	47.5	148.5	12.6	98.5	97.3
2001	5	148.5	138.2	210.9	154.1	138.8	231.0	180.2	146.5	315.4	143.5	42.9	206.0	336.4	344.2	129.9
2001	6	146.9	275.3	249.2	159.8	142.3	280.8	283.4	131.2	277.2	188.9	120.3	347.0	217.9	306.7	201.2
2001	7	153.8	286.9	167.6	172.0	152.1	331.4	223.8	124.3	422.4	157.9	67.7	325.0	358.4	216.0	199.0
2001	8	163.7	301.3	190.1	205.5	176.9	336.3	266.6	59.8	247.2	247.6	177.8	405.7	227.5	308.1	195.8
2001	9	146.7	321.8	243.4	159.0	141.7	167.5	257.0	0.0	272.2	216.6	32.7	371.9	247.0	337.3	230.5
2001	10	134.4	192.7	167.9	106.4	103.5	141.4	225.6	0.0	303.0	89.1	67.7	263.1	162.2	206.1	289.7
2001	11	111.5	9.3	33.1	40.3	53.8	119.5	51.7	0.0	117.1	47.4	0.0	219.7	21.6	30.8	27.8
2001	12	115.9	19.8	23.5	43.9	57.3	34.5	39.2	0.0	66.0	49.2	19.1	227.2	9.7	84.3	70.5
2002	1	93.0	42.4	14.9	6.3	0.0	13.0	107.5	0.0	96.9	38.6	0.0	83.3	2.3	91.9	24.4
2002	2	84.6	0.0	2.2	3.0	1.6	0.8	25.2	0.0	8.1	7.9	0.0	8.7	0.0	3.1	22.5
2002	3	111.6	15.8	73.6	53.0	46.4	6.9	93.9	0.0	87.2	139.9	23.7	134.1	4.2	91.8	87.8
2002	4	45.8	105.7	99.4	36.4	16.6	59.2	111.0	99.4	139.1	251.2	41.1	137.2	104.7	93.5	142.2
2002	5	69.2	60.4	88.1	133.7	74.9	86.3	107.5	143.5	169.2	133.9	33.0	126.1	96.3	133.3	103.1
2002	6	97.4	343.6	225.3	199.7	175.0	375.2	241.9	129.6	357.2	222.8	21.1	225.1	252.2	259.2	340.7
2002	7	160.4	291.8	193.3	144.6	168.4	297.3	281.7	73.5	219.2	85.8	0.0	149.5	302.3	285.4	196.3
2002	8	154.6	258.6	149.0	176.0	153.9	409.0	294.3	255.1	356.6	150.8	24.4	197.5	246.6	299.4	206.2
2002	9	105.2	357.0	107.9	98.1	38.0	321.9	210.3	97.4	188.8	108.1	17.4	126.4	399.9	344.5	344.7
2002	10	118.3	45.7	175.3	86.5	63.2	78.9	139.9	61.7	162.5	177.8	36.9	201.3	147.4	119.1	137.4
2002	11	92.2	5.1	20.2	29.4	5.6	0.0	23.4	0.3	71.2	33.3	41.6	68.9	110.3	2.6	5.3
2002	12	105.9	17.9	22.3	10.0	32.2	2.5	25.4	0.0	65.5	63.3	0.0	111.1	11.8	25.1	20.1

2003	1	96.0	0.0	2.0	0.0	7.4	0.0	24.8	0.0	13.7	11.4	0.4	32.7	0.0	0.0	0.0
2003	2	96.6	138.3	40.4	29.9	31.6	89.6	74.8	0.6	35.2	18.3	0.0	48.7	35.5	58.2	51.5
2003	3	93.4	15.6	53.1	42.6	1.0	49.2	49.2	42.5	50.8	98.6	15.8	116.4	7.0	51.1	52.3
2003	4	107.9	42.5	57.3	107.2	44.7	3.5	73.7	33.9	234.7	130.5	32.0	222.8	37.3	104.8	96.4
2003	5	134.9	101.4	146.8	165.8	104.8	120.7	141.5	89.9	70.1	82.6	28.0	111.8	136.5	95.2	188.0
2003	6	122.9	340.1	242.6	159.8	82.2	356.8	365.2	117.4	319.1	299.3	232.0	320.7	290.5	240.9	276.9
2003	7	127.5	443.2	199.6	252.4	86.2	492.2	272.8	103.8	301.6	210.6	211.7	178.5	494.4	275.5	254.3
2003	8	149.3	249.7	231.6	197.3	140.7	333.7	301.4	121.6	197.1	218.2	31.4	310.8	237.2	307.3	242.3
2003	9	124.4	511.7	156.5	208.5	86.1	343.9	342.4	188.4	296.3	297.6	267.9	275.2	398.5	353.8	392.2
2003	10	106.1	67.4	96.6	53.5	32.8	59.2	83.5	24.8	69.9	191.7	14.2	138.5	53.5	65.2	198.8
2003	11	94.2	58.4	32.2	34.2	10.5	40.3	46.7	60.8	55.9	110.0	7.5	115.7	42.0	31.0	34.0
2003	12	94.0	3.5	13.1	28.1	2.4	9.2	39.6	0.0	125.5	77.4	0.0	104.3	62.0	26.1	9.9
2004	1	110.6	83.7	1.6	25.8	43.9	0.0	11.1	0.0	73.0	30.4	1.4	210.3	5.7	7.2	15.2
2004	2	97.2	84.5	14.3	3.1	25.5	8.9	31.6	58.0	16.1	12.3	1.2	44.1	10.7	10.5	18.4
2004	3	93.7	0.4	18.4	27.6	1.8	93.0	34.0	62.0	95.9	34.2	0.0	49.3	0.2	25.7	38.0
2004	4	106.4	156.3	90.8	171.8	41.0	107.5	137.3	64.3	137.8	209.2	43.1	266.1	73.4	125.9	113.2
2004	5	168.1	168.8	129.1	220.3	187.8	164.5	281.0	77.4	192.3	194.8	154.0	386.0	197.8	284.7	122.6
2004	6	146.4	329.2	179.6	158.0	140.9	354.6	252.8	37.5	196.0	155.2	46.1	142.9	311.5	301.5	245.2
2004	7	163.6	336.4	179.6	205.1	176.6	403.7	246.3	51.4	228.8	376.8	148.6	253.5	424.7	318.7	207.3
2004	8	123.4	331.7	192.5	208.5	76.0	366.9	209.8	214.1	309.2	250.7	88.3	408.5	359.8	495.7	197.2
2004	9	106.4	336.9	189.5	206.0	40.9	365.6	166.3	121.9	218.6	170.4	77.8	330.4	252.4	436.9	318.8
2004	10	97.6	121.7	66.3	27.3	11.6	126.2	112.7	2.1	139.0	40.9	30.3	219.7	161.4	190.2	144.7
2004	11	103.0	92.5	71.3	143.9	32.5	18.7	126.3	39.3	57.2	137.6	17.2	300.8	77.6	144.4	140.4
2004	12	101.4	0.7	12.1	23.7	21.0	1.0	43.7	3.1	86.0	113.9	0.0	285.4	62.6	0.3	11.1
2005	1	0.0	1.3	14.6	3.9	1.6	109.8	15.7	3.5	35.5	23.4	0.0	58.0	8.4	26.5	28.2
2005	2	84.0	0.5	18.4	17.2	0.0	84.2	3.7	0.0	46.1	37.6	3.6	71.4	140.4	1.3	45.7
2005	3	7.6	62.0	43.9	103.7	101.5	115.6	119.8	38.2	136.9	55.5	16.4	123.4	22.7	135.6	65.8
2005	4	46.0	10.9	31.8	47.1	29.0	94.4	46.6	48.1	111.0	129.3	27.3	143.8	53.0	21.9	70.8
2005	5	131.4	186.2	149.2	168.3	146.4	176.5	105.8	51.7	142.6	164.2	126.6	254.2	215.9	131.0	135.1
2005	6	175.9	375.0	246.9	201.3	151.7	398.2	239.4	122.3	273.6	140.8	104.0	193.4	382.8	246.9	201.6
2005	7	153.1	399.3	172.3	201.1	150.2	368.8	243.1	24.2	295.9	279.6	216.5	110.1	263.0	289.8	257.6
2005	8	229.1	290.5	138.7	116.0	141.3	255.3	489.3	105.8	353.5	121.9	187.8	185.4	235.0	312.7	167.3
2005	9	390.5	346.0	179.2	117.2	309.7	383.0	234.5	169.1	356.5	325.9	208.7	141.9	192.2	248.8	297.5
2005	10	114.4	69.9	157.8	108.8	53.5	172.8	202.3	7.3	149.0	117.4	138.8	110.2	283.1	91.8	170.3
2005	11	97.2	82.1	62.0	14.2	17.9	1.6	70.8	1.2	121.1	26.1	26.0	51.0	35.3	80.0	67.3
2005	12	93.0	4.7	0.0	44.5	0.1	2.3	0.7	22.1	69.9	0.0	1.1	0.0	158.3	129.0	0.0
2006	1	97.7	0.0	3.1	6.2	0.2	93.0	5.5	3.5	45.6	36.0	0.0	35.4	5.8	127.1	12.1
2006	2	90.1	13.4	1.2	36.9	5.3	7.3	30.1	0.0	67.5	17.2	0.0	43.8	9.6	120.2	34.5
2006	3	97.7	0.0	9.1	8.4	0.0	94.8	41.4	38.2	90.6	168.2	47.7	150.0	2.9	127.1	61.2
2006	4	105.4	14.1	0.5	67.8	31.2	92.7	11.9	46.1	61.1	87.2	59.4	130.8	17.9	128.6	10.2
2006	5	125.1	263.1	287.4	320.3	171.9	256.3	233.9	42.7	187.7	199.8	162.6	320.6	222.8	232.3	277.3
2006	6	151.1	305.9	180.6	188.2	147.7	488.3	244.8	72.6	311.3	206.8	125.7	363.1	363.7	245.4	417.1
2006	7	133.2	429.5	236.0	192.4	87.9	461.0	294.9	24.2	402.6	351.5	42.1	233.3	412.2	298.9	265.4
2006	8	314.9	366.7	147.5	165.2	175.9	297.2	264.9	105.8	271.9	223.5	88.6	452.9	306.8	273.8	141.1
2006	9	126.2	285.2	240.5	148.8	90.7	398.8	237.4	169.1	254.2	258.6	40.2	226.8	319.5	237.1	386.2
2006	10	146.8	110.0	138.2	95.6	140.5	211.6	182.5	66.5	219.3	187.2	44.9	164.8	222.6	171.1	326.0
2006	11	100.5	4.6	42.9	38.3	17.2	18.2	136.4	1.2	110.4	149.9	0.0	200.1	34.7	124.8	37.0
2006	12	115.4	13.4	59.8	48.2	50.7	41.6	108.4	0.0	106.5	87.9	0.0	142.9	35.0	132.5	113.8

Assessment and evaluation of surface water potential and demands in Baro -Akobo river basin, Ethiopia

2007	1	97.7	11.5	19.5	32.6	0.0	0.0	13.4	0.3	80.0	44.5	0.0	74.6	163.1	25.2	21.3
2007	2	90.7	9.4	40.2	31.6	7.0	26.7	57.2	0.0	89.1	70.4	32.1	49.0	16.7	26.2	62.0
2007	3	109.9	109.3	97.3	183.3	35.1	36.5	67.5	1.4	87.8	99.6	32.3	104.9	231.5	47.4	90.4
2007	4	120.8	94.6	112.7	119.6	75.0	67.1	145.9	104.9	207.3	114.2	56.4	205.7	216.2	135.3	182.5
2007	5	122.4	176.3	177.0	217.1	70.7	214.7	233.9	123.7	210.6	231.6	55.0	267.0	278.4	232.3	199.2
2007	6	137.0	196.9	169.0	175.1	125.3	296.4	274.3	95.2	286.0	102.1	163.7	268.9	297.5	278.1	213.7
2007	7	140.8	225.1	126.1	107.6	155.9	255.9	305.0	250.2	223.8	148.2	229.1	259.4	297.4	311.3	268.9
2007	8	194.8	236.9	340.8	287.4	322.0	383.0	254.5	255.8	309.8	303.3	145.4	455.9	177.5	255.2	333.1
2007	9	169.1	419.3	229.7	166.2	215.7	352.0	243.6	320.9	290.8	266.2	251.0	416.6	443.5	349.9	329.1
2007	10	122.4	121.5	175.4	91.4	64.8	54.0	130.7	89.0	90.6	65.6	55.9	182.9	38.9	117.7	142.4
2007	11	99.9	48.6	33.9	70.7	15.5	21.7	53.9	42.7	123.8	91.4	27.4	259.3	72.1	42.0	66.5
2007	12	97.7	168.9	1.3	0.0	0.0	121.8	10.1	0.0	49.6	6.4	0.0	64.8	0.0	0.0	14.1
2008	1	106.3	14.0	70.7	50.4	26.7	8.1	69.9	25.3	113.8	71.2	24.7	241.1	31.3	91.5	96.5
2008	2	91.4	78.3	3.9	7.1	0.0	0.0	16.5	4.0	45.8	74.0	1.1	237.7	0.0	5.5	29.9
2008	3	106.4	159.5	15.2	39.6	24.9	108.3	27.1	20.3	59.8	64.1	23.5	122.3	0.0	30.2	38.8
2008	4	153.0	221.3	299.9	190.3	168.6	196.6	228.0	91.0	224.7	271.3	105.3	298.3	304.9	226.7	186.6
2008	5	155.8	276.7	265.7	314.7	201.9	371.6	347.3	246.3	318.2	176.5	82.7	189.5	222.4	338.3	295.6
2008	6	139.8	323.8	118.9	294.7	130.5	346.9	300.8	180.0	186.2	848.3	50.1	173.5	285.7	372.0	203.9
2008	7	288.1	270.4	306.3	168.9	215.9	298.3	241.5	214.9	296.9	193.9	73.1	170.1	196.2	240.8	221.9
2008	8	301.9	260.3	218.0	193.6	311.5	340.9	241.5	355.0	296.2	145.7	287.0	328.9	313.6	240.8	216.7
2008	9	299.7	216.5	224.4	161.0	198.3	266.0	195.2	234.5	272.2	232.6	74.9	273.1	172.0	190.2	249.2
2008	10	167.1	50.6	109.5	73.8	116.4	60.9	157.8	128.4	205.3	246.0	89.2	404.3	88.3	147.8	279.0
2008	11	105.4	19.5	74.5	7.5	60.3	27.9	70.8	62.2	65.8	66.4	28.3	236.8	51.0	96.3	121.3
2008	12	19.1	2.7	23.1	96.3	23.6	93.0	40.3	15.3	105.8	175.7	2.4	105.8	24.4	15.7	86.9
2009	1	3.2	13.8	7.4	24.5	3.6	116.8	27.3	0.0	19.0	28.0	26.7	26.0	164.7	8.5	16.1
2009	2	92.3	3.8	47.8	35.7	11.7	30.3	83.8	11.3	72.7	23.6	0.5	186.4	142.7	68.2	92.8
2009	3	14.4	34.2	48.0	101.3	32.8	28.4	97.0	21.7	161.9	156.7	16.6	168.0	31.2	87.2	93.5
2009	4	87.3	189.7	169.4	187.9	176.4	155.3	238.2	280.2	203.4	240.0	32.5	109.0	282.8	172.2	168.4
2009	5	94.2	151.8	82.3	218.8	151.1	97.3	99.2	164.5	160.4	214.8	117.4	119.0	100.7	86.5	122.8
2009	6	243.9	360.8	276.1	245.5	215.4	399.7	209.3	126.3	296.7	164.7	102.3	188.0	402.6	308.2	298.9
2009	7	56.1	216.8	177.2	156.4	69.6	190.1	308.2	87.3	227.0	116.8	55.1	257.0	205.5	314.9	252.1
2009	8	90.4	328.9	259.6	198.4	111.4	357.7	380.3	122.3	339.4	75.2	91.9	238.0	385.2	395.0	238.2
2009	9	99.3	176.1	111.7	135.4	173.8	196.6	226.4	110.7	178.8	255.8	182.9	269.0	273.3	299.0	243.4
2009	10	181.9	111.8	152.7	136.2	117.3	144.7	184.1	120.2	219.7	128.1	83.6	298.2	233.3	182.3	268.8
2009	11	16.0	0.5	2.1	20.6	16.2	0.7	20.4	2.1	110.4	170.6	18.2	110.4	150.4	29.3	31.9
2009	12	13.0	10.9	11.5	32.6	10.3	59.2	27.5	2.4	75.5	73.7	0.5	190.0	162.6	15.5	25.8
2010	1	0.0	164.9	28.2	31.8	0.0	116.0	61.7	0.0	103.1	45.0	1.1	161.0	0.0	17.0	13.3
2010	2	90.2	0.0	19.8	20.9	5.8	0.0	40.4	9.8	71.5	90.1	10.1	91.0	21.4	20.0	19.1
2010	3	0.0	0.0	11.3	14.2	2.5	17.9	31.1	3.2	74.0	45.8	0.0	81.0	0.0	4.3	36.3
2010	4	63.8	122.4	77.4	55.8	2.8	59.1	30.8	29.8	60.0	118.4	32.0	66.0	74.8	51.9	46.0
2010	5	166.5	286.2	243.0	324.0	111.6	289.3	298.1	89.6	330.5	296.5	150.6	272.0	139.6	305.6	36.3
2010	6	212.2	333.4	159.8	211.2	138.7	272.5	320.3	107.9	360.2	406.9	249.4	95.0	142.8	334.2	181.4
2010	7	208.0	377.0	141.6	247.2	276.2	448.0	318.7	139.1	213.9	177.9	181.0	343.0	160.0	326.6	163.1
2010	8	167.7	170.3	152.2	101.0	199.0	298.8	256.8	66.6	223.1	225.7	196.8	156.0	126.1	257.8	178.3
2010	9	192.6	286.4	301.5	232.3	238.3	257.7	233.7	120.0	179.7	227.3	382.6	219.0	350.5	233.0	300.9
2010	10	136.3	176.0	92.8	104.7	133.0	131.9	130.5	137.9	165.3	215.9	120.4	228.0	82.9	117.4	252.4
2010	11	26.2	18.2	57.5	119.7	49.4	0.5	92.8	21.1	80.3	83.8	18.3	11.0	162.7	76.4	64.9
2010	12	70.8	16.7	32.5	101.7	3.6	6.3	47.1	0.0	0.0	99.5	22.0	14.0	36.8	24.8	20.4

Assessment and evaluation of surface water potential and demands in Baro -Akobo river basin, Ethiopia

2011	1	1.0	83.7	31.5	0.0	2.4	0.0	75.1	2.7	30.1	90.2	0.0	19.3	213.6	55.9	37.6
2011	2	88.6	4.7	4.7	0.0	0.4	0.3	12.4	9.0	5.8	16.3	2.3	61.5	143.3	0.0	54.4
2011	3	46.4	23.9	23.4	99.3	60.9	19.4	51.2	1.9	28.9	62.5	16.5	102.4	171.7	29.3	243.5
2011	4	78.6	79.7	106.9	129.9	59.3	44.6	124.7	20.2	188.8	180.4	77.4	156.2	205.8	111.9	193.9
2011	5	186.1	95.0	200.7	170.2	197.7	96.7	253.5	212.9	306.4	317.6	210.1	408.9	221.5	254.1	371.4
2011	6	149.5	305.0	177.6	209.6	179.6	380.9	353.3	143.7	224.1	259.1	44.9	227.3	363.5	360.9	44.9
2011	7	187.9	260.1	199.6	138.8	122.3	210.7	278.9	58.2	237.6	189.7	97.0	166.4	337.1	282.3	325.4
2011	8	208.4	316.7	210.9	126.4	304.9	332.8	386.7	152.4	296.2	167.9	204.2	147.3	376.7	398.1	433.2
2011	9	105.3	361.8	169.0	198.5	218.9	293.7	286.0	151.1	168.9	310.7	290.6	272.5	403.3	280.1	331.0
2011	10	252.6	32.8	130.5	66.6	205.9	43.7	172.0	109.3	103.6	64.6	74.5	56.7	178.0	163.6	218.5
2011	11	46.6	7.5	18.4	17.3	91.3	12.2	63.1	16.7	106.2	292.2	43.1	256.3	155.3	60.7	108.1
2011	12	12.7	0.0	5.0	7.4	2.9	0.0	37.9	0.0	8.6	81.9	4.8	71.8	155.0	14.5	84.4
2012	1	4.5	396.3	28.1	0.0	0.0	448.7	10.0	0.0	61.7	74.2	0.0	97.0	490.2	0.0	15.6
2012	2	0.0	392.2	1.3	0.0	0.0	478.6	10.3	0.0	3.0	20.0	0.0	0.0	466.8	0.0	63.5
2012	3	0.0	412.0	11.3	104.0	9.2	501.3	69.3	18.8	53.3	46.2	0.5	86.8	504.6	49.4	298.5
2012	4	57.1	398.8	27.6	289.2	27.7	480.6	36.2	92.7	30.8	191.5	22.8	134.2	488.4	30.9	220.4
2012	5	181.0	391.0	274.1	304.6	267.9	471.5	324.0	112.8	203.4	241.9	50.1	212.2	485.3	332.4	252.8
2012	6	53.3	374.7	109.1	163.7	130.5	435.9	344.2	64.3	107.6	105.9	43.1	152.0	466.1	349.9	85.6
2012	7	224.2	246.1	203.5	245.4	354.0	285.2	192.4	187.8	237.6	236.5	60.3	207.4	327.3	186.2	238.9
2012	8	190.8	373.8	261.4	293.9	242.4	468.6	366.3	141.5	335.5	349.0	245.2	269.6	416.7	379.5	412.8
2012	9	241.6	395.0	155.8	202.9	145.2	479.9	295.1	156.8	285.0	261.2	361.8	208.0	460.6	321.5	340.1
2012	10	103.0	53.0	126.9	181.0	112.6	54.4	137.7	51.0	85.9	216.4	236.8	135.5	192.1	64.3	184.2
2012	11	146.5	29.8	119.7	172.6	134.8	23.1	149.1	0.0	63.3	191.5	44.3	129.2	170.9	143.8	194.1
2012	12	1.2	0.0	40.3	108.3	104.9	0.0	80.0	10.5	93.9	97.8	15.7	126.1	155.0	61.3	126.5
2013	1	0.0	387.6	9.7	82.5	0.0	466.7	28.9	0.0	59.3	102.4	0.0	89.8	458.6	4.6	15.6
2013	2	1.7	0.0	5.1	3.2	2.0	0.0	22.4	0.0	72.7	1.1	0.0	81.3	447.7	0.0	34.6
2013	3	100.8	383.9	20.5	62.4	9.1	461.4	52.7	0.0	101.9	144.9	23.1	127.1	514.1	31.1	539.7
2013	4	59.6	372.6	68.8	35.9	38.5	448.1	43.9	172.1	203.4	186.9	25.3	163.9	464.3	22.1	145.6
2013	5	188.3	385.8	344.8	364.0	221.8	464.1	494.7	85.8	402.5	60.1	64.8	52.7	480.5	522.1	318.2
2013	6	147.0	376.6	165.2	185.9	78.9	453.7	267.5	167.5	320.2	176.7	95.0	336.0	467.9	275.1	105.6
2013	7	161.4	408.4	111.3	266.9	207.3	496.2	421.7	70.8	167.4	287.9	518.2	180.7	501.3	441.1	468.2
2013	8	91.2	408.5	220.9	191.6	171.6	496.3	160.5	213.8	295.8	317.6	175.1	243.3	501.4	354.9	207.0
2013	9	95.2	373.2	154.0	109.1	238.2	449.0	188.3	172.1	380.1	330.5	123.9	166.3	464.9	241.9	233.3
2013	10	85.5	408.6	116.5	172.3	92.3	496.5	74.2	113.2	296.1	313.3	53.0	62.0	501.5	55.2	120.7
2013	11	0.0	395.2	51.7	115.4	131.7	480.2	42.4	32.9	7.7	154.7	53.0	135.7	485.1	311.5	87.4
2013	12	98.7	409.6	40.3	0.0	24.8	497.9	24.8	0.0	75.8	64.2	2.5	58.8	502.3	2.5	71.3

Monthly average maximum temperature for metrological stations used in SWAT model

monthly average maximum temprture																
station name																
year	month	abobo	ayira	bure	dembidol	gambela	gimbi	gore	jikawo	masha	tepi	itang	mizantef	alemtef	algea	uka
1992	1	40	31	30	29	39.6	30.2	27.4	39	24	34	39	31	36	30	32
1992	2	37.95	32	30.5	30.4	37.3664	30.8	28	39	25	34	42	32	35	31	34
1992	3	42.5	32	32.5	31.9	41.4	28.32	27.6	41	27	35	43	33	36	33	32
1992	4	43.5	33	32.5	28	42.12	29.37	29.1	41	27	36	40	30	36	32	33
1992	5	39	29	29.2	28.2	38.88	27.55	26.5	38	23	33	40	30	33	29	30
1992	6	38.5	28	26	25.6	38.52	26.22	24.6	38	23	31	40	28	33	26	29
1992	7	34.9	28	24	24.4	35.928	25.45	23.5	36	21	30	38	26	33	25	29
1992	8	38.3	25	24.5	25.1	38.376	24	24.6	38	22	29	34	27	31	24	26
1992	9	35.5	25	26	26	36.36	25	22.8	36	22	28	39	28	32	26	26
1992	10	39.5	27	25.8	28	39.24	26.85	25.5	39	23	33	36	30	34	27	28
1992	11	39.5	27	27.5	26.8	39.24	26.2	26.5	39	23	33	40	29	34	27	28
1992	12	37.1	27	28.2	27.6	37.512	27.6	24.4	37	23	31	40	29	32	28	28
1993	1	38.5	31	29.5	28.5	38.52	28.6	27.1	38	24	33	38	30	33	30	31
1993	2	37.83	34	32.5	30.2	37.2782	30.4	27.8	39	24	34	41	32	34	31	34
1993	3	42	34	31.5	33.3	41.04	32.2	29.2	40	25	36	42	35	36	32	34
1993	4	42	34	26.9	28.1	41.04	27.83	26.9	40	24	35	41	30	33	32	34
1993	5	40	34	31.2	27.3	39.6	25.8	28.8	39	25	36	39	29	33	29	34
1993	6	35	29	25.2	24.4	36	26.8	27.9	36	24	33	36	26	31	25	30
1993	7	35.5	26	26.4	23.6	36.36	25.8	24	36	22	30	39	26	31	24	27
1993	8	34	25	28.3	25	35.28	26.92	25.6	35	23	31	37	27	31	25	26
1993	9	37	25	28.1	24.9	37.44	25.128	23	37	21	32	40	27	33	25	26
1993	10	39	28	27.2	25.7	38.88	26.192	24.6	38	22	31	43	28	32	26	28
1993	11	39	27	27.7	26.8	38.88	27.9	27	38	24	31	43	29	33	27	28
1993	12	41	27	35.5	27.9	40.32	28.6	28	40	24	35	44	30	33	30	28
1994	1	39.5	28	30.2	29.3	39.24	29.09	28.7	39	25	35	45	31	35	30	28
1994	2	37.7	28	31.8	30	37.19	26.36	24.8	39	22	36	46	32	39	31	29
1994	3	41.3	33	32.7	30.5	40.536	29.65	29.5	40	25	36	40	32	37	30	33
1994	4	41.4	31	33.6	30	40.608	30	30	40	26	34	40	32	34	30	31
1994	5	40.2	30	29	26	39.744	27.424	26.3	39	23	32	40	28	33	29	30
1994	6	39.1	26	24.8	23.6	38.952	26.22	24.6	38	22	30	37	26	29	26	27
1994	7	39.5	26	25.1	22.7	39.24	25.73	23.9	39	21	30	34	25	27	25	27
1994	8	41.5	24	26.5	23	40.68	24.708	22.4	40	20	30	39	25	27	25	26
1994	9	39.8	26	28.3	25.5	39.456	25.414	23.4	39	21	32	38	27	29	25	27
1994	10	39.5	28	29.5	26.4	39.24	27.48	26.4	39	23	31	36	28	30	26	28
1994	11	41.5	28	30.5	27	40.68	26.248	24.6	40	22	31	36	29	31	27	28
1994	12	39.4	28	31	28	39.168	26.472	25	39	22	33	38	30	33	28	29

Assessment and evaluation of surface water potential and demands in Baro -Akobo river basin, Ethiopia

1995	1	39.2	27	31	28.9	39.024	28.95	28.5	38	25	34	39	31	34	29	28
1995	2	37.83	28	32.1	30.2	37.2782	29.23	28.9	39	25	36	40	32	34	29	29
1995	3	42	28	32.8	31	41.04	30	30	40	26	36	41	33	36	31	29
1995	4	43	30	30.8	32.2	41.76	27.48	26.4	41	23	36	39	34	35	31	31
1995	5	38	28	27.5	28.6	38.16	28.25	27.5	38	24	33	40	30	32	29	29
1995	6	37	26	25.4	27.5	37.44	25.352	23.4	37	24	32	40	29	33	26	27
1995	7	38	24	24.5	23.4	38.16	24.68	22.4	38	21	30	39	25	30	24	26
1995	8	34	26	25	25	35.28	25.94	24.2	35	24	31	40	27	30	26	27
1995	9	36	26	25.8	25.6	36.72	26.15	24.5	36	22	31	39	28	29	26	27
1995	10	36.5	27	28.2	26.4	37.08	27.55	26.5	37	24	30	40	28	30	28	28
1995	11	38	27	29	25.5	38.16	27.55	26.5	38	23	30	40	27	32	28	28
1995	12	39.5	28	30.6	26.6	39.24	27.9	27	39	24	33	40	28	33	30	28
1996	1	37	30	31.7	30	37.44	27.2	26	37	23	33	39	32	33	31	30
1996	2	38.58	31	36.5	31.4	37.8074	28.46	27.8	40	24	35	40	33	33	33	31
1996	3	40.2	30	32.7	31.5	39.744	27.2	26	39	23	33	41	33	33	33	30
1996	4	38.2	31	33.3	31	38.304	28.95	28.5	38	25	38	43	33	32	30	32
1996	5	37.3	31	28	29.5	37.656	27.55	26.5	37	25	34	38	31	31	29	31
1996	6	36.6	28	25.8	24.6	37.152	26.36	24.8	37	22	31	39	27	28	28	29
1996	7	37.6	25	25	25	37.872	26.85	25.5	37	23	29	39	27	28	24	26
1996	8	35.2	26	26.9	24.5	36.144	25.352	23.4	36	21	30	38	26	29	25	27
1996	9	38.4	24	25.8	25.5	38.448	25.45	23.5	38	21	28	39	27	28	27	26
1996	10	38.4	28	29.2	26	38.448	27.06	25.8	38	23	31	39	28	31	28	29
1996	11	38.2	28	30.3	26.5	38.304	27.9	27	38	24	32	39	28	31	30	28
1996	12	38.6	29	31.7	29	38.592	27.76	26.8	38	23	32	39	31	30	29	29
1997	1	39.8	29	31.5	30.5	39.456	27.62	26.6	39	23	33	41	32	30	28	29
1997	2	37.39	33	33	29.5	36.9695	28.18	27.4	39	24	35	42	31	35	31	32
1997	3	43.2	32	33.7	30.5	41.904	28.95	28.5	41	25	36	44	32	29	31	32
1997	4	41.2	30	33.2	30	40.464	28.74	28.2	40	24	34	42	32	33	29	30
1997	5	39.8	31	30.5	26	39.456	26.29	24.7	39	22	33	39	28	33	30	32
1997	6	39.8	28	25.6	26	39.456	26.01	24.3	39	22	31	39	28	33	28	28
1997	7	38.2	28	25	23	38.304	26.528	25	38	24	32	40	25	31	28	29
1997	8	37.4	28	24.7	23	37.728	26.472	25	37	23	30	40	25	31	28	29
1997	9	39.2	29	26.8	24	39.024	26.976	25.7	38	24	32	40	26	31	29	30
1997	10	39.2	30	28.7	25.4	39.024	26.85	25.5	38	24	32	40	27	32	29	30
1997	11	38.6	30	29.2	25.6	38.592	26.5	25	38	25	31	40	28	32	29	30
1997	12	38.2	31	33.6	27.5	38.304	26.78	25.4	38	22	31	43	29	33	30	31
1998	1	39.2	31	31.7	28.5	39.024	28.88	28.4	38	26	32	43	30	34	30	31
1998	2	37.7	33	33.4	30	37.19	28.95	28.5	39	26	33	43	32	35	31	33
1998	3	39.8	34	34.8	30	39.456	30.28	30.4	39	26	34	43	32	35	32	33
1998	4	39.5	33	33.8	28.1	39.24	29.65	29.5	39	27	34	43	30	34	31	32
1998	5	37.4	30	34.5	26.1	37.728	27.76	26.8	37	25	32	40	28	33	29	30
1998	6	39.4	27	29	24	39.168	26.22	24.6	39	24	30	39	26	30	27	27
1998	7	39.8	28	25.5	23.3	39.456	25.66	23.8	39	23	31	40	25	29	28	29
1998	8	39.8	29	25	23.4	39.456	26.864	25.5	39	23	30	39	25	29	29	29
1998	9	39.2	29	26.5	24	39.024	26.15	24.5	38	23	32	39	26	30	29	30
1998	10	39.2	29	27.5	25.4	39.024	26.71	25.3	38	23	32	38	27	31	29	30
1998	11	38.5	31	29.5	26	38.52	27.76	26.8	38	25	34	39	28	32	30	31
1998	12	40.3	33	31	27	39.816	28.39	27.7	39	25	33	39	29	33	32	33

Assessment and evaluation of surface water potential and demands in Baro -Akobo river basin, Ethiopia

1999	1	40.4	33	34	28.1	39.888	28.6	28	39	26	36	39	30	35	31	33
1999	2	37.07	33	34	29	36.749	29.65	29.5	38	28	36	39	31	34	31	33
1999	3	41.5	29	34.7	30.6	40.68	30.7	31	40	28	35	38	32	35	29	30
1999	4	43.4	29	33.8	30.3	42.048	26.864	25.5	41	27	34	38	32	36	29	29
1999	5	39.8	29	30.5	27.5	39.456	26.92	25.6	39	25	31	38	29	33	29	30
1999	6	39.8	29	26.5	24.3	39.456	26.36	24.8	39	24	31	39	26	31	28	28
1999	7	39.6	26	25	23.2	39.312	26.64	25.2	39	23	30	37	25	31	28	28
1999	8	39.2	26	25.5	24.2	39.024	25.45	23.5	38	21	30	36	26	31	26	27
1999	9	38.2	27	27	24.4	38.304	25.8	24	38	22	30	38	26	29	27	28
1999	10	39.2	28	29.7	26.6	39.024	26.64	25.2	38	22	31	40	28	29	28	29
1999	11	39.2	28	31.2	26.2	39.024	27.2	26	38	23	32	40	28	32	29	30
1999	12	39.2	29	31.5	27.7	39.024	27.34	26.2	38	23	40	41	29	31	34	36
2000	1	39.2	31	33	28.6	39.024	28.7	27.4	38	24	34	42	30	32	29	30
2000	2	37.7	28	33	30	37.19	31	29	39	25	31	37	32	31	28	29
2000	3	43	31	35.3	31.5	41.76	32.6	32	41	27	37	39	33	33	30	31
2000	4	42.5	33	30.5	30	41.4	31.5	29.5	41	25	34	42	32	31	28	29
2000	5	40.5	30	32	26.5	39.96	26.36	24.8	39	22	32	38	28	40	28	29
2000	6	36	27	26.5	25	36.72	27.5	24.5	36	22	31	36	27	29	28	29
2000	7	35.5	28	24	24.5	36.36	24.6	24.5	36	22	33	36	26	28	29	30
2000	8	33.5	26	25.3	23.5	34.92	24.5	22.8	35	21	30	35	26	28	26	26
2000	9	35	26	26.3	25	36	25.8	24	36	22	29	40	27	29	26	27
2000	10	40.5	27	30.5	25	39.96	26	24.2	39	22	31	40	27	29	27	28
2000	11	37.5	29	31.5	26.2	37.8	26.36	24.8	37	22	32	41	28	29	28	29
2000	12	33.2	30	32.3	27.5	34.704	27.55	26.5	34	23	33	38	29	30	29	30
2001	1	40.5	31	33	30	39.96	28.39	27.7	39	24	33	42	32	32	30	31
2001	2	38.02	33	34	30.5	37.4105	29.72	29.6	39	25	35	43	32	33	32	34
2001	3	40.6	34	33	30	40.032	29.65	29.5	39	25	36	44	32	33	31	33
2001	4	42.2	35	33	32.5	41.184	29.72	29.6	40	25	34	41	34	31	33	35
2001	5	39.8	33	32.2	27	39.456	27.9	27	39	24	32	38	29	31	31	32
2001	6	39.8	27	26.5	25	39.456	25.45	23.5	39	21	30	42	27	30	27	27
2001	7	38.2	27	25	25.5	38.304	25.24	23.2	38	21	30	41	27	30	26	27
2001	8	39.2	26	26.5	24	39.024	25.8	24	38	22	31	41	26	31	27	28
2001	9	33.8	27	28.2	25.5	35.136	26.15	24.5	35	22	30	35	27	30	27	28
2001	10	35.4	27	30	26	36.288	26.92	25.6	36	23	31	36	28	32	29	30
2001	11	36.2	28	31.5	26.5	36.864	26.85	25.5	36	23	32	36	28	35	28	29
2001	12	36.6	29	32	27.5	37.152	27.34	26.2	37	23	32	36	29	38	29	30
2002	1	37.07	31	33.5	29	45.5	28.04	27.2	38	24	33	37	31	35	29	31
2002	2	38.65	33	34.2	31.5	47	29.37	29.1	40	25	37	37	33	35	31	33
2002	3	39.5	34	34	31.5	46	32.6	28.5	40	25	38	38	33	39	31	33
2002	4	41.8	35	33	31	46	33	28.5	40	25	36	39	33	36	31	33
2002	5	41.5	31	32	28	46	31.5	27.3	40	24	32	38	30	36	30	31
2002	6	39.2	31	24.5	26	39.024	27	26.8	38	23	32	37	28	33	30	31
2002	7	35.5	28	25.5	25.5	36.36	25.6	24.5	36	22	31	39	27	32	28	29
2002	8	35.5	27	25.7	26.5	35.6465	27	24	37	22	31	39	28	28	27	28
2002	9	39.5	27	26.5	26	39.24	25.5	25	39	22	32	38	28	33	28	29
2002	10	38	29	27.2	26.5	38.16	26.5	25	38	22	31	37	28	35	29	31
2002	11	39	29	27.5	26.5	38.88	26.78	25.4	38	22	32	37	28	36	28	29
2002	12	42	30	30.7	27.5	41.04	29	26	40	23	32	38	29	36	29	31

Assessment and evaluation of surface water potential and demands in Baro -Akobo river basin, Ethiopia

2003	1	42	33	32.2	30.5	45.5	31.5	28.3	40	34	35	40	32	35	31	33
2003	2	38.96	33	32	32	45	29.44	29.2	40	28	36	42	33	37	32	34
2003	3	43	33	32.7	31	45	31	28	41	28	36	41	33	36	31	33
2003	4	41	34	32	33	45.5	32	29.6	40	28	38	42	34	36	33	35
2003	5	39	34	30.5	29.5	44.5	32	25.5	38	26	33	40	31	36	29	29
2003	6	39	28	29.5	26.5	41.5	28	24.9	38	24	31	37	28	38	28	29
2003	7	36	26	30	25	36.5	24	23.3	36	22	29	33	27	35	26	27
2003	8	40.5	26	23.5	25	36.5	26.64	25.2	39	23	30	38	27	31	28	29
2003	9	34.55	27	25	25	38.9	26.5	24.8	37	23	31	37	27	30	28	29
2003	10	37	29	26.4	27	40.9	27	26	37	24	33	40	29	33	29	30
2003	11	38	30	27	28	40.2	28.4	26.2	38	23	32	39	30	34	29	30
2003	12	39	30	28.5	29	41	28.04	27.2	38	25	32	41	31	34	30	32
2004	1	37.7	32	30	30	37.19	31	27.6	39	26	34	41	32	36	31	32
2004	2	38.33	32	31	31	37.631	32	29	39	26	35	42	33	35	32	33
2004	3	40.4	34	31	31.5	45.5	29.86	29.8	39	27	36	42	33	37	32	33
2004	4	39	34	30.5	31	45	32.4	30.5	38	26	34	43	33	36	32	34
2004	5	39.4	32	26.5	28	39.168	31	27.9	39	24	33	43	30	33	30	31
2004	6	35	27	28.8	25.5	36	26.8	24	36	22	30	35	27	30	27	28
2004	7	33.5	27	23.5	24	34.92	24	24	35	23	30	35	26	28	27	28
2004	8	34	27	24	25.5	36.5	27	23.6	35	23	31	36	27	28	28	29
2004	9	34.5	28	24.5	25.5	39.5	25.8	24	35	22	30	36	27	29	28	29
2004	10	37	29	26.5	26.5	41.5	26.92	25.6	37	23	32	37	28	33	29	30
2004	11	37	29	28	27	41.3	28	26.7	37	23	32	38	29	33	29	31
2004	12	38.2	29	27.5	27.5	41.5	28.2	26	38	23	32	39	29	35	29	31
2005	1	38.2	32	29	30	43	31.5	27.5	38	24	34	42	32	35	31	32
2005	2	39.59	35	29	33	47.5	34	31.5	40	27	33	42	34	37	29	30
2005	3	42	35	30	32	45.6	30.7	31	40	26	37	44	33	39	33	35
2005	4	43.3	34	31.2	31	41.976	31.8	29	41	27	36	43	33	37	32	34
2005	5	42.5	31	28	29.5	39	28.25	27.5	41	25	33	38	31	35	30	32
2005	6	36	30	24.5	25.5	36.72	27.6	26.5	36	23	31	35	27	32	29	30
2005	7	34.8	26	24	24	37	25	24.3	35	23	30	34	26	30	27	28
2005	8	35.5	28	24	25.5	37	26.2	24	36	23	31	33	27	34	28	29
2005	9	35.5	27	26	25.5	36.36	26.2	24.6	36	23	31	33	27	33	29	30
2005	10	40	28	27	26	39.6	26.64	25.2	39	24	32	35	28	31	28	29
2005	11	39	30	27.2	27	39.5	26.5	25	38	22	33	37	29	33	29	30
2005	12	40	31	28.5	28.5	40.5	29.5	26.8	39	25	35	38	30	34	30	31
2006	1	41.8	33	30.5	31.5	42.5	29.3	29	40	27	36	39	33	37	31	33
2006	2	38.65	33	32.5	31.5	43	32.2	29.5	40	27	38	40	33	37	32	34
2006	3	43.5	33	31	31.5	43	32.6	29.6	41	26	37	41	33	37	32	34
2006	4	42.5	34	30	31	42	33.2	30.2	41	26	34	42	33	37	33	35
2006	5	42.5	35	26.5	29.5	41.5	32.5	31.5	41	26	32	36	31	36	32	34
2006	6	33.5	28	25.4	26	36.2	27.5	25.2	35	22	32	37	28	29	28	29
2006	7	35.1	28	24.7	25	35.5	25.4	24.6	36	24	31	36	27	29	28	28
2006	8	34	29	25.5	24.5	34.2	26	24.5	35	23	30	35	26	30	29	30
2006	9	39.5	27	26	25	35.2	26.15	24.5	39	23	31	38	27	32	28	29
2006	10	36.5	30	26.5	27	38	27	25.5	37	25	32	36	29	32	28	29
2006	11	38	29	27	26	37	28	25.5	38	24	31	39	28	32	31	32
2006	12	39.1	29	28.5	27	36.5	28	25.5	38	23	30	38	29	33	28	29

Assessment and evaluation of surface water potential and demands in Baro -Akobo river basin, Ethiopia

2007	1	41.5	30	34	28.5	40.68	27.62	26.6	40	24	33	50	31	35	29	31
2007	2	38.02	32	31.5	30.5	42.5	29.16	28.8	39	26	34	37	33	38	31	32
2007	3	44.1	34	33.5	31	42	34.8	29.5	42	27	37	45	35	37	32	34
2007	4	44.2	36	29.5	29	43	31	28.6	42	27	35	42	33	36	30	33
2007	5	41.5	30	32	28	41	30.5	27	41	24	32	40	32	35	28	39
2007	6	37.5	30	25	29	39.9	26.43	24.9	36	24	31	38	30	34	27	30
2007	7	37	27	26.5	24.5	37.5	25.5	24.4	34	22	30	38	31	21	25	28
2007	8	33.1	27	24.5	24	34.632	25	24.5	40	22	30	35	29	21	25	28
2007	9	33	29	26	25	34.56	26.5	25	34	23	31	36	29	34	25	29
2007	10	38.3	28	27.5	26.5	38.376	27.5	25.8	39	24	32	38	28	25	27	30
2007	11	39	29	28.5	27	38.88	27.48	26.4	36	23	35	38	29	21	28	32
2007	12	39.1	30	30	28.5	39.4	27.62	26.6	38	25	34	39	36	26	29	31
2008	1	41.2	31	30.5	30.5	41	30.5	27.8	40	26	33	40	31	30	30	32
2008	2	37.7	32	31	30	41	31.5	28.5	41	26	34	41	31	30	31	32
2008	3	42.6	34	33.5	31.5	42	32.5	30	42	26	35	43	34	30	32	35
2008	4	40.5	32	31	29.5	40.5	31.5	29.5	41	25	33	41	33	36	30	33
2008	5	39.4	30	30.5	26.5	37.5	26.85	25.5	39	24	33	37	31	25	27	30
2008	6	36	28	26	26	37	26	24.8	38	22	32	35	31	25	24	30
2008	7	39.2	30	27	24.5	36.5	24.6	23.6	37	21	29	37	31	25	26	27
2008	8	35.5	26	24.5	24.5	34	25.52	23.6	34	23	29	33	31	25	26	27
2008	9	34.87	29	25.5	26.5	35.5	26.36	24.8	34	24	31	36	30	26	27	29
2008	10	35.5	28	28	26.5	37.5	26.752	25.4	37	24	31	36	29	33	27	29
2008	11	36.5	29	27.5	28	38	26.64	25.2	37	22	32	37	31	30	28	29
2008	12	38.5	29	28.5	28.5	39	26.64	25.2	38	25	33	39	31	34	29	29
2009	1	39.5	31	29.5	29	39.5	28.6	28	39	27	34	39	37	39	29	30
2009	2	37.39	33	30.5	29.5	41	28.6	28	41	26	35	40	31	31	30	31
2009	3	41.5	34	32.5	30.5	43.5	32	28.8	46	26	35	42	36	38	32	32
2009	4	40.2	33	32	28.5	41	30.8	29.4	41	26	32	42	36	38	30	31
2009	5	39	31	31.5	28.5	39.5	30	29.5	39	25	34	38	31	31	29	31
2009	6	38	29	27	30	38.5	28	25.5	37	25	32	40	35	38	27	29
2009	7	37.5	28	26.5	25.5	37.5	26	23.5	38	23	30	38	31	26	25	28
2009	8	38	28	25.5	25	37.5	27	23.8	36	22	30	41	35	38	26	29
2009	9	37.5	29	27.5	26.5	37.5	26.92	25.6	37	24	32	38	31	35	26	30
2009	10	38	29	28.5	27.5	37.8	26.85	25.5	36	24	32	37	31	34	27	29
2009	11	39.5	29	37	29	40	28.2	25.6	37	25	34	38	30	34	28	30
2009	12	40.5	28	29	29	40	29	26	40	24	31	38	31	35	30	29
2010	1	39.5	31	36.5	28.5	42.5	28.32	27.6	42	25	34	40	31	31	31	31
2010	2	38.96	33	32.5	32	44	28.6	28	43	24	36	43	35	36	32	33
2010	3	43.5	36	39.5	32	44.5	30.35	30.5	43	28	39	43	35	38	32	36
2010	4	43	35	33.5	32.5	44.5	29.552	29.4	43	25	35	43	31	35	32	34
2010	5	38	36	27	29.5	38	30.28	30.4	40	26	32	40	31	35	29	36
2010	6	36.5	29	28	28.5	38.5	26.92	25.6	37	25	31	36	30	34	27	30
2010	7	34	27	26.5	28.5	35.5	25	24	35	23	31	40	30	34	25	28
2010	8	40	27	26.5	25.5	36	25.4	24.4	39	22	30	35	30	34	25	28
2010	9	34.87	27	25.5	26	35.2055	26.2	24	34	22	31	35	29	33	27	28
2010	10	36	27	28	28.5	36.72	27	24	36	25	33	35	31	35	28	28
2010	11	37	29	28	28	37.44	27.5	24.8	36	26	31	36	31	35	28	29
2010	12	37.07	31	28.5	29	37.44	28	24	37	25	33	38	31	35	30	28

2011	1	40.2	29	31	30	42	30	25.2	41	25	32	41	32	35	30	29
2011	2	38.02	36	30.4	30.5	44	32	24.6	49	22	36	43	32	35	31	28
2011	3	42	34	31.2	30	43.5	33	28	43	24	36	43	32	35	32	33
2011	4	41.7	34	37.5	30.5	44	28.04	27.2	42	24	35	42	32	35	32	32
2011	5	40.2	28	29	27.5	42.5	31.5	24.8	41	22	31	40	29	33	30	29
2011	6	39	29	25	25.5	36	26.5	24	36	22	30	37	27	32	26	28
2011	7	37	29	23.5	25.5	37	26	27.2	34	24	35	35	27	32	27	32
2011	8	38.7	27	28.5	25	35	25.24	23.2	34	21	29	35	27	32	26	27
2011	9	35.5	27	25	25	35.5	27	21.6	34	20	27	34	27	32	26	25
2011	10	37.5	29	29.5	26.5	37.5	28	25.6	34	23	32	35	34	36	28	30
2011	11	37.5	29	27.3	26.5	40.5	26.92	25.6	33	23	32	36	28	33	27	30
2011	12	37.5	31	29.2	29	40.5	28.5	28	38	24	36	36	31	34	30	33
2012	1	38.5	28	29.8	29.5	41	28.74	28.2	38	24	34	40	31	35	30	29
2012	2	40	33	31.5	30.5	42.5	30	30	42	26	36	42	30	34	32	33
2012	3	41	33	31	31.5	43.8	28.88	28.4	43	27	37	43	33	36	33	33
2012	4	43	26	31.5	31	43.5	25.24	23.2	43	28	35	46	33	36	33	27
2012	5	37.8	27	31.4	29	39.5	28.95	28.5	37	25	30	37	31	34	31	28
2012	6	33.5	28	25.5	25.5	36	26.36	24.8	35	22	30	36	27	32	26	29
2012	7	32.66	26	23.9	25	33.6	23.689	21	33	19	26	35	27	32	25	24
2012	8	33.5	28	25.3	25.5	34.7	24.238	21.8	33	20	27	35	27	32	25	25
2012	9	34.5	28	25.7	26	36	24.394	22	34	23	27	35	28	33	26	25
2012	10	36.5	29	26	27	36.5	28.25	27.5	35	26	35	35	29	33	28	25
2012	11	36	30	27	26.5	37.5	24.904	22.7	36	26	28	36	28	33	28	26
2012	12	37	30	35.5	27.5	39	28.236	27.5	37	25	32	36	29	33	29	32
2013	1	41	28	31.5	29	40.8	26.36	24.8	40	22	31	39	31	34	31	29
2013	2	43.5	28	33.5	31	43.5	26.36	24.8	42	22	31	39	33	36	32	29
2013	3	43	33	34.5	30	43	28.6	28	41	24	36	39	32	35	33	33
2013	4	41.5	29	32.5	30	42.2	26.64	25.2	42	22	32	34	32	35	33	29
2013	5	38	27	28.5	27	37.5	25.8	24	38	27	30	31	29	33	29	28
2013	6	35	27	28.5	26	36	19.36	14.8	35	24	30	40	28	33	29	28
2013	7	39	23	24.5	24.5	34	18.8	14	34	15	30	37	30	34	26	24
2013	8	35	23	25	24	35.3	19.08	14.4	36	15	27	33	26	31	25	25
2013	9	33.4	24	25.5	27.5	36	26.5	25	35	22	27	33	29	33	25	25
2013	10	38.3	24	26.5	25.5	37	24.708	22.4	38	20	28	35	29	33	28	26
2013	11	39.6	34	28	26	39.312	25.296	23.3	36	21	29	36	28	33	28	27
2013	12	39	34	28.8	27	38.88	25.61	23.7	39	29	30	36	29	33	27	27

Monthly average minimum temperature for metrological stations used in SWAT model

monthly average minimum temperature																
all stations used for analysis																
year	month	abobo	ayira	bure	dembidol	gambela	gimbi	gore	jikawo	masha	tepi	itang	mizantef	alemtef	algea	uka
1992	1	8.5	9.0	11.5	8.2	16.9	14.8	14.7	18.5	6.9	10.0	19.0	7.7	12.8	12.2	8.2
1992	2	9.4	10.0	13.5	7.9	17.4	13.0	11.2	18.9	8.1	11.4	19.0	7.6	10.4	14.2	5.5
1992	3	19.5	10.0	14.5	8.6	23.5	13.8	12.8	23.5	9.3	12.0	21.0	7.8	12.7	14.0	6.0
1992	4	16.5	14.8	14.5	13	21.7	13.7	12.5	22.1	8.8	13.5	20.6	9.6	12.0	13.2	8.2
1992	5	17.5	14.8	13	12	22.3	13.7	12.5	22.6	8.8	13.0	21.2	9.2	12.2	13.0	12.2
1992	6	15.5	14.3	13.5	11	21.1	13.2	11.5	21.7	8.4	12.8	20.0	8.8	11.8	13.3	12.2
1992	7	16.28	14.8	13	11.9	21.6	11.2	12.7	22.0	8.9	13.0	20.0	9.2	11.8	12.6	9.3
1992	8	15.32	14.6	13	11.1	21.0	11.0	12.2	21.6	8.5	12.9	21.0	8.8	11.6	12.4	10.2
1992	9	15.92	14.9	12.5	11.6	21.4	13.8	12.8	21.9	8.9	12.9	19.8	9.0	10.6	12.5	10.3
1992	10	12.5	14.4	13	10	19.3	12.0	11.8	20.3	8.3	12.0	21.0	8.4	11.3	11.0	8.3
1992	11	10.5	14.9	12.8	8.2	18.1	13.8	12.8	19.4	8.0	9.6	19.6	7.7	10.2	13.0	7.6
1992	12	14.2	14.2	11.5	9	20.3	10.4	11.2	21.1	8.1	10.0	19.4	8.0	8.5	11.7	7.4
1993	1	11.6	13.7	11.6	7.4	18.8	9.4	10.2	19.9	7.3	9.0	18.9	7.4	8.9	13.8	8.2
1993	2	11.48	14.2	10.6	7.9	18.7	9.4	11.3	19.9	8.0	11.6	18.6	7.6	9.0	14.3	8.4
1993	3	17	14.2	13.7	11.5	22.0	8.0	11.2	22.4	7.9	10.5	20.6	9.0	11.0	14.2	5.3
1993	4	19	14.8	14.3	11.4	23.2	13.7	12.6	23.3	8.8	12.8	20.6	9.0	11.1	14.8	10.0
1993	5	18.5	13.6	14	12.2	22.9	11.8	10.1	23.0	7.3	14.0	20.5	9.3	10.0	13.7	13.3
1993	6	18.5	14.2	13	11.3	22.9	10.0	11.3	23.0	8.0	12.4	20.5	8.9	11.5	14.3	8.6
1993	7	16	15.9	13	10	21.4	12.0	14.9	21.9	10.2	12.1	19.8	8.4	11.9	15.9	8.6
1993	8	15	13.9	13.2	12.1	20.8	12.8	10.7	21.5	7.6	12.3	19.6	9.2	8.3	14.0	8.6
1993	9	14	14.2	10.5	11	20.2	13.0	11.2	21.0	7.9	11.8	19.6	8.8	11.5	14.2	7.9
1993	10	7.4	14.2	12.7	10.1	16.2	13.1	11.3	18.0	8.0	12.1	18.0	8.4	11.2	14.3	8.5
1993	11	15.2	14.1	13.2	10.6	20.9	12.9	11.0	21.5	7.8	11.4	20.0	8.6	11.5	14.0	8.6
1993	12	16	14.8	12.9	9.4	21.4	13.7	12.5	21.9	8.8	12.1	18.4	8.2	11.2	13.5	8.6
1994	1	8	15.8	13.5	8.4	16.6	14.8	14.7	18.3	10.1	8.4	17.0	7.8	10.6	13.0	8.7
1994	2	12.8	15.7	14.8	9	19.5	14.7	14.6	20.5	10.0	8.5	19.0	8.0	11.2	14.0	9.0
1994	3	8.5	14.6	15	11	16.9	13.5	12.2	18.5	8.6	12.6	18.2	8.8	13.0	13.0	9.1
1994	4	14	13.9	14.5	12.7	20.2	12.8	10.7	21.0	7.6	14.0	14.6	9.5	13.0	15.4	9.0
1994	5	10.3	14.6	14.8	13.8	18.0	13.5	12.2	19.3	8.6	12.4	11.1	9.9	9.0	13.6	9.2
1994	6	10	13.8	14	12.5	17.8	12.7	10.5	19.2	7.5	13.5	10.0	9.4	10.0	12.0	9.5
1994	7	11.4	14.1	13.5	11.2	18.6	12.9	11.0	19.8	7.8	12.9	10.0	8.9	9.0	12.7	10.2
1994	8	10	14.1	13.5	10.7	17.8	12.9	11.0	19.2	7.8	13.5	10.0	8.7	8.0	12.4	10.2
1994	9	11.5	14.6	13	12	18.7	13.5	12.2	19.9	8.6	11.5	11.0	9.2	8.5	13.0	10.0
1994	10	9.5	14.5	13.3	17	17.5	13.4	12.0	19.0	8.4	11.0	10.0	11.2	9.5	12.0	6.6
1994	11	9.3	9.0	14	16.5	17.4	7.4	13.2	18.9	1.0	12.5	10.0	11.0	10.0	13.2	7.5
1994	12	10.5	14.8	12.5	9.2	18.1	13.7	12.5	19.4	8.8	11.8	10.0	8.1	10.2	12.0	8.0

Assessment and evaluation of surface water potential and demands in Baro -Akobo river basin, Ethiopia

1995	1	10.5	15.0	13.5	9.5	18.1	13.9	13.0	19.4	9.1	10.2	11.9	8.2	12.7	10.3	5.5
1995	2	12.2	14.9	13.5	8.5	19.1	13.8	12.8	20.2	8.9	10.7	12.3	7.8	12.0	12.0	5.7
1995	3	7	14.8	14	8.2	16.0	13.7	12.5	17.9	8.8	8.7	12.4	7.7	10.5	13.0	8.0
1995	4	16	14.8	14	12.6	21.4	13.7	12.5	21.9	8.8	15.5	11.4	4.4	10.0	13.6	10.0
1995	5	15	14.5	14.5	13	20.8	13.4	12.0	21.5	9.1	14.0	10.2	9.6	10.0	12.2	9.0
1995	6	14	14.5	14	12.5	20.2	13.4	12.0	21.0	10.6	12.2	10.0	9.4	11.9	12.5	8.8
1995	7	15	14.8	13	11	20.8	13.7	12.5	21.5	9.2	13.6	10.0	4.4	9.5	11.9	11.7
1995	8	15	13.6	12	10.6	20.8	12.4	10.0	21.5	9.6	12.8	10.2	8.6	10.2	12.3	10.0
1995	9	13	14.9	13.2	11.4	19.6	13.8	12.8	20.6	10.0	14.0	12.2	9.0	10.0	12.2	10.2
1995	10	14	14.8	12.9	9	20.2	13.7	12.6	21.0	7.6	11.2	12.2	8.0	10.0	12.8	8.5
1995	11	14	15.3	14.2	9.6	20.2	14.3	13.7	21.0	9.2	11.0	13.4	8.2	10.0	13.2	8.2
1995	12	12	14.3	13.4	10	19.0	13.2	11.5	20.1	9.2	12.1	12.8	8.4	10.0	14.4	6.4
1996	1	9	14.0	14.5	10.6	17.2	12.8	10.8	18.8	8.2	10.5	12.8	8.6	8.7	12.4	6.2
1996	2	16.4	14.9	13	12	21.6	13.9	12.9	22.1	9.8	12.5	14.2	9.2	9.5	13.2	8.4
1996	3	20.5	14.8	13.9	11.5	24.1	13.8	12.7	23.9	10.0	14.5	12.2	9.0	9.5	13.4	10.2
1996	4	20	14.5	15.5	10.8	23.8	13.4	12.0	23.7	8.4	13.0	13.4	8.7	9.9	14.0	10.5
1996	5	23	14.8	14.5	11.6	25.6	13.7	12.5	25.1	10.2	13.0	10.2	9.0	9.0	13.6	10.5
1996	6	11.9	13.9	13.4	10.5	18.9	12.7	10.6	20.1	7.6	13.6	10.0	8.6	0.7	12.8	11.6
1996	7	14.2	14.5	13	12	20.3	13.3	11.9	21.1	8.4	13.7	10.0	9.2	8.0	13.0	12.6
1996	8	13.2	14.4	13.7	12.5	19.7	13.3	11.8	20.6	8.3	13.0	10.2	4.4	8.0	12.6	11.4
1996	9	14.6	14.5	14	12.5	20.6	13.4	12.0	21.3	8.4	14.2	10.2	9.4	9.5	12.2	9.0
1996	10	12	14.1	13	10.6	19.0	12.9	11.0	20.1	7.8	12.8	10.6	8.6	10.0	12.7	10.0
1996	11	14	15.0	12.5	9.3	20.2	13.9	13.0	21.0	9.1	8.5	12.6	8.1	10.5	13.9	9.2
1996	12	15.2	15.2	12.5	9.5	20.9	14.2	13.5	21.5	9.4	12.3	12.0	8.2	8.0	14.2	9.0
1997	1	10.4	9.0	14	8	18.0	7.4	11.5	19.4	1.0	11.6	10.6	7.6	10.0	12.2	7.5
1997	2	12.115	9.0	13.5	8.5	19.1	7.4	12.2	20.2	1.0	10.0	14.8	7.8	10.6	14.2	9.2
1997	3	14.2	9.0	14	9	20.3	7.4	12.0	21.1	1.0	12.5	14.4	8.0	10.0	14.0	8.5
1997	4	17.4	14.5	14.5	11.5	22.2	13.4	12.0	22.5	8.4	13.5	10.2	9.0	9.0	13.2	9.6
1997	5	10.4	14.6	15	13	18.0	13.5	12.1	19.4	8.5	12.0	10.0	9.6	12.1	13.0	10.5
1997	6	11.4	14.6	14	11.5	18.6	13.5	12.2	19.8	10.1	10.5	10.2	9.0	11.4	13.3	12.3
1997	7	15.4	14.6	12.5	10.7	21.0	13.5	12.2	21.6	9.7	12.9	10.0	8.7	12.0	12.6	10.3
1997	8	15.1	14.3	13	11	20.9	13.2	11.5	21.5	10.5	13.8	10.2	8.8	12.5	12.4	10.4
1997	9	11.4	13.8	13.5	11.7	18.6	12.6	10.4	19.8	10.1	14.0	10.0	9.1	12.8	12.5	10.2
1997	10	15.2	14.5	13.4	11	20.9	13.4	12.0	21.5	10.5	12.9	10.2	8.8	12.0	11.0	10.3
1997	11	14.4	14.8	12.5	7.5	20.4	13.7	12.5	21.2	11.4	14.0	10.2	4.4	12.0	13.0	7.8
1997	12	14.1	15.4	12.5	8.2	20.3	14.3	13.8	21.0	10.0	13.5	10.2	7.7	11.5	11.7	7.6
1998	1	11.4	14.2	12	6.2	18.6	13.0	11.2	19.8	9.7	11.5	14.2	4.4	10.0	14.2	7.5
1998	2	11.52	14.7	15	8	18.7	13.6	12.3	19.9	8.6	11.6	14.2	7.6	10.4	14.7	7.5
1998	3	12.4	14.9	15	8	19.2	13.8	12.8	20.3	11.1	14.0	14.2	7.6	10.0	14.9	8.5
1998	4	10.4	15.2	15.5	9.1	18.0	14.2	13.5	19.4	12.0	14.5	14.2	4.4	10.0	15.3	10.0
1998	5	10.4	14.9	14	12	18.0	13.8	12.8	19.4	8.9	12.5	12.0	9.2	11.8	15.0	10.4
1998	6	15.2	14.8	13.4	12.1	20.9	13.7	12.7	21.5	10.0	15.0	12.4	9.2	11.8	14.9	10.3
1998	7	14.4	14.8	13	11.2	20.4	13.7	12.6	21.2	8.8	12.0	10.2	8.9	11.5	14.9	8.3
1998	8	10.4	14.5	12.5	10.5	18.0	13.4	12.0	19.4	8.4	13.0	10.0	8.6	11.3	14.6	10.4
1998	9	10.4	14.7	15	9.9	18.0	13.6	12.4	19.4	9.9	13.5	10.0	4.4	10.0	14.8	10.5
1998	10	10.4	15.0	14.5	8.9	18.0	13.9	13.0	19.4	10.2	12.5	10.2	8.0	9.6	15.0	9.4
1998	11	10.2	14.8	14.5	9.2	17.9	13.7	12.5	19.3	8.6	11.6	10.2	8.1	7.5	14.8	7.6
1998	12	10.4	14.8	17	8.5	18.0	13.7	12.6	19.4	8.8	9.5	10.2	7.8	8.5	14.8	8.6

Assessment and evaluation of surface water potential and demands in Baro -Akobo river basin, Ethiopia

1999	1	10.1	14.8	17	8	17.9	13.7	12.5	19.2	8.8	12.0	10.2	7.6	8.5	14.8	8.3
1999	2	11.996	15.3	18.7	8.4	19.0	14.2	13.6	20.1	9.4	9.3	10.6	7.8	10.0	15.3	8.9
1999	3	10.4	15.2	16	8	18.0	14.2	13.5	19.4	9.2	9.5	12.2	7.6	6.5	15.3	7.9
1999	4	10.4	13.8	16	11	18.0	12.7	10.5	19.4	10.8	15.7	12.2	8.8	8.0	13.9	8.7
1999	5	15.5	13.6	14.3	12.5	21.1	12.4	10.0	21.7	10.2	14.8	10.2	9.4	8.0	13.7	10.0
1999	6	16.4	13.8	15.5	11.9	21.6	12.7	10.5	22.1	9.8	13.8	10.0	9.2	8.5	13.9	9.2
1999	7	15.4	14.1	14.5	11	21.0	12.9	11.0	21.6	8.0	11.8	10.0	8.8	11.5	14.2	9.0
1999	8	17.4	11.3	15	11.2	22.2	13.1	11.3	22.5	9.4	12.4	10.0	8.9	8.6	14.3	9.1
1999	9	15.4	13.4	14	10.5	21.0	14.6	14.3	21.6	9.4	12.1	10.2	8.6	8.8	15.6	8.8
1999	10	13.4	11.0	15	10.3	19.8	13.1	11.4	20.7	8.1	11.6	10.2	8.5	9.5	14.3	9.1
1999	11	14.4	9.8	16.5	9	20.4	13.4	12.0	21.2	8.4	9.5	12.0	8.0	9.5	14.6	9.5
1999	12	13.4	10.2	17	9.1	19.8	13.2	11.5	20.7	9.0	12.6	12.6	8.0	9.0	14.4	9.6
2000	1	15.1	10.5	17	11.8	20.9	10.4	11.5	21.5	7.8	9.7	14.2	9.1	8.5	14.4	7.5
2000	2	12.71	12.5	13.4	9	19.4	13.5	12.2	20.4	8.8	10.0	18.9	8.0	10.0	14.7	6.5
2000	3	14.4	13.0	14.1	9.5	20.4	12.7	12.2	21.2	8.2	10.6	19.4	8.2	6.5	14.7	9.5
2000	4	12.3	13.4	15.5	13	19.2	12.2	9.5	20.2	10.6	14.5	18.8	9.6	8.0	13.5	11.3
2000	5	11.5	13.5	14.3	13	18.7	12.5	11.4	19.9	10.0	14.5	18.6	9.6	8.0	14.3	8.9
2000	6	9.5	13.5	15	10.5	17.5	11.5	12.0	19.0	9.6	12.0	18.1	8.6	8.5	14.6	12.4
2000	7	12.5	13.2	14.5	11	19.3	14.6	14.4	20.3	9.4	12.3	18.9	8.8	11.5	15.7	9.0
2000	8	13.4	12.5	15	9.5	19.8	11.5	10.6	20.7	9.2	12.8	19.1	8.2	8.6	14.0	10.0
2000	9	10.5	13.0	14.5	11.5	18.1	11.5	14.2	19.4	9.6	12.5	10.6	9.0	8.8	15.6	9.0
2000	10	12.5	12.5	12.5	10.5	19.3	12.5	11.6	20.3	9.2	13.0	10.4	8.6	9.5	14.4	6.2
2000	11	10.2	9.4	14.2	6	17.9	13.7	12.5	19.3	7.8	5.0	10.2	6.8	9.5	14.8	8.5
2000	12	8.5	10.4	15.5	8	16.9	9.5	12.5	18.5	7.4	10.1	10.6	7.6	9.0	14.8	5.2
2001	1	11.5	8.4	17.5	6.5	18.7	13.0	11.2	19.9	7.2	9.0	16.2	7.0	11.5	14.2	5.0
2001	2	12.71	15.2	16.5	9	19.4	12.6	13.5	20.4	8.6	9.4	17.4	8.0	10.0	15.3	5.0
2001	3	11.4	12.5	16	10.5	18.6	10.6	12.7	19.8	8.9	13.2	16.8	8.6	9.9	14.9	5.8
2001	4	17.4	14.4	13.3	12	22.2	11.0	13.5	22.5	9.3	14.5	17.4	9.2	10.0	15.3	8.2
2001	5	15.2	14.0	15.3	12.5	20.9	13.0	13.9	21.5	10.6	12.3	19.6	9.4	10.0	15.5	9.0
2001	6	16.2	15.4	15	11.2	21.5	11.2	14.0	22.0	9.7	12.9	12.4	8.9	10.5	15.5	7.2
2001	7	15.2	12.8	14.5	10	20.9	11.8	11.8	21.5	8.8	12.0	10.2	8.4	14.2	14.5	8.4
2001	8	17.4	14.5	16.5	10.5	22.2	13.4	12.0	22.5	9.4	13.8	12.4	8.6	10.4	14.6	8.2
2001	9	17.4	13.5	14.7	12	22.2	12.4	12.0	22.5	9.6	14.0	20.2	9.2	14.3	14.6	6.4
2001	10	14.6	13.0	15.3	10.5	20.6	12.0	11.8	21.3	10.2	13.8	19.4	4.4	10.1	14.5	7.2
2001	11	10.2	15.4	16.3	8.5	17.9	11.5	14.0	19.3	7.0	12.1	18.3	7.8	10.4	15.5	4.6
2001	12	10.6	11.6	17	8.5	18.2	11.5	12.2	19.5	8.6	12.5	18.4	7.8	12.4	14.7	5.4
2002	1	10.4	10.4	16	9	18.0	10.0	14.2	19.4	9.0	12.1	18.3	8.0	10.0	15.6	5.4
2002	2	13.9	12.4	15.5	10	20.1	13.2	11.6	21.0	9.0	11.0	19.3	8.4	10.0	14.4	5.0
2002	3	11.5	14.8	17	11.5	18.7	13.0	12.5	19.9	10.4	13.5	18.6	9.0	10.0	14.8	9.2
2002	4	18.5	15.1	16.7	12.5	22.9	14.0	13.3	23.0	10.0	15.2	20.5	4.4	10.0	15.2	12.4
2002	5	20	15.0	16	13.5	23.8	13.9	13.0	23.7	9.1	15.0	15.4	4.4	10.2	15.1	12.6
2002	6	24	13.8	11	11.5	26.2	13.3	11.8	25.5	10.2	13.8	18.3	9.0	10.5	14.5	12.0
2002	7	12.5	13.5	12.8	11	19.3	12.5	13.0	20.3	10.2	12.8	18.2	8.8	12.1	15.1	13.0
2002	8	9.5	14.0	13.4	11	17.5	13.9	13.0	19.0	9.1	13.8	18.4	8.8	10.8	15.1	12.0
2002	9	12.4	13.0	12.7	12	19.2	12.5	12.4	20.3	8.7	11.4	18.8	9.2	11.8	14.8	10.8
2002	10	10.5	12.4	13.8	10.2	18.1	12.8	13.0	19.4	9.2	12.5	18.3	8.5	10.1	15.0	9.4
2002	11	14	11.8	13.7	9.5	20.2	11.5	12.8	21.0	8.9	12.8	19.5	8.2	10.2	14.9	11.0
2002	12	18	8.6	13.5	7	22.6	9.5	11.5	22.8	8.1	8.4	17.0	7.2	10.1	14.4	5.0

Assessment and evaluation of surface water potential and demands in Baro -Akobo river basin, Ethiopia

2003	1	15.09	14.3	11.5	7.5	20.9	11.0	11.6	21.5	7.2	9.6	15.3	7.4	10.0	14.4	7.0
2003	2	14.495	12.9	10.5	10.5	20.5	12.9	11.0	21.2	9.2	11.0	17.5	8.6	10.5	14.2	6.2
2003	3	21	15.0	13.5	9	24.4	13.0	12.5	24.2	8.8	13.3	19.0	8.0	8.2	14.8	11.0
2003	4	21.4	14.5	12.4	11	24.6	15.0	12.5	24.3	10.2	13.6	21.5	8.8	10.0	14.8	11.2
2003	5	20	14.5	13.8	11	23.8	14.0	13.5	23.7	11.4	12.2	21.0	8.8	9.0	15.3	8.8
2003	6	18.8	14.7	13.2	12	23.1	12.8	12.4	23.2	9.6	13.2	20.4	9.2	9.5	14.8	9.8
2003	7	18.6	13.0	13.5	11.5	23.0	12.0	12.5	23.1	9.8	13.2	19.9	9.0	14.0	14.8	10.8
2003	8	18	14.0	13.5	11	22.6	13.6	12.4	22.8	8.7	14.5	15.0	8.8	10.0	14.8	13.6
2003	9	18.5	14.5	13.6	12	22.9	13.4	12.0	23.0	9.8	13.2	15.0	9.2	14.5	14.6	11.6
2003	10	17	11.8	10.2	8	22.0	13.0	12.0	22.4	8.2	11.9	19.5	7.6	14.0	14.6	8.2
2003	11	16	11.5	14.4	10.5	21.4	12.8	12.5	21.9	8.8	11.1	20.2	8.6	10.2	14.8	9.2
2003	12	14.8	10.5	13	8.5	20.7	12.2	13.2	21.4	9.2	10.5	16.0	7.8	12.5	15.1	5.2
2004	1	13.5	11.4	11.5	9.5	19.9	13.9	12.9	20.8	9.0	11.4	19.1	8.2	12.0	15.0	7.4
2004	2	10.925	10.3	13	7.5	18.4	13.4	12.0	19.6	7.6	8.8	19.6	7.4	12.0	14.6	6.6
2004	3	17.5	15.0	13.2	12	22.3	13.5	12.6	22.6	10.6	14.1	19.0	4.4	12.0	14.9	12.8
2004	4	19.5	14.7	13	13	23.5	14.5	12.4	23.5	10.5	10.3	16.9	9.6	10.0	14.8	10.2
2004	5	15	13.5	13.5	13	20.8	13.4	12.0	21.5	10.2	13.3	17.2	9.6	9.5	14.6	12.0
2004	6	15.8	14.4	12.5	11	21.3	13.0	11.8	21.8	9.0	11.4	17.0	8.8	10.0	14.5	11.2
2004	7	15.8	14.6	12.5	11.5	21.3	12.5	12.2	21.8	8.6	10.8	16.5	9.0	12.0	14.7	10.0
2004	8	16	14.0	12.5	11.5	21.4	13.4	12.0	21.9	8.4	12.0	18.0	9.0	12.0	14.6	13.0
2004	9	16.5	13.0	12.5	11	21.7	12.2	11.8	22.1	9.0	11.0	20.1	8.8	12.0	14.5	12.2
2004	10	15	11.0	13.5	8.5	20.8	12.0	12.6	21.5	8.0	9.0	20.1	7.8	12.0	14.9	7.8
2004	11	16.2	14.3	13.5	10	21.5	12.5	11.5	22.0	8.8	11.0	21.5	8.4	12.0	14.4	10.1
2004	12	13.5	11.8	13	8	19.9	11.8	12.8	20.8	9.2	10.5	19.5	7.6	12.0	15.0	8.4
2005	1	16.3	10.0	12.5	8.5	21.6	10.0	11.4	22.0	7.0	8.3	19.8	7.8	11.5	14.3	6.0
2005	2	14.495	13.0	13.5	10.5	20.5	15.5	15.5	21.2	10.6	11.4	20.2	8.6	11.3	16.2	8.7
2005	3	19	13.5	13.5	11	23.2	12.9	11.0	23.3	10.0	12.5	18.5	8.8	11.0	14.2	9.2
2005	4	19	12.2	14.2	13.5	23.2	14.4	12.3	23.3	10.8	12.8	16.0	9.8	12.0	14.7	12.2
2005	5	18	13.8	14.5	13	22.6	13.0	12.0	22.8	10.0	13.5	16.0	9.6	11.0	14.6	13.0
2005	6	17.8	14.2	13	11	22.5	13.2	11.5	22.7	10.0	13.6	15.0	8.8	10.0	14.4	12.0
2005	7	18.3	13.4	13	11.5	22.8	12.8	12.0	22.9	10.0	13.8	18.0	9.0	11.5	14.6	12.0
2005	8	18.1	13.6	13	11	22.7	12.5	11.0	22.8	10.4	14.1	17.0	8.8	12.0	14.2	12.8
2005	9	19.1	14.1	12.2	13	23.3	13.2	11.8	23.3	10.2	12.5	17.0	9.6	11.5	14.5	8.6
2005	10	19.3	13.0	12.5	10.5	23.4	12.5	12.0	23.4	9.4	12.0	16.4	8.6	12.0	14.6	10.4
2005	11	19.5	14.7	14	8	18.0	12.5	12.4	23.5	7.2	8.2	16.0	7.6	10.5	14.8	7.2
2005	12	16.5	15.2	14	8.5	17.5	11.5	13.5	22.1	7.2	7.0	14.0	7.8	10.6	15.3	5.4
2006	1	15.2	11.3	13.5	9	18.0	13.9	13.1	21.5	9.1	8.5	8.4	8.0	11.6	15.1	8.4
2006	2	15.09	13.5	14.2	11	20.5	13.7	12.5	21.5	8.8	10.2	10.5	8.8	11.0	14.8	9.0
2006	3	14	14.0	14.6	11	20.0	12.5	12.8	21.0	10.4	12.6	12.0	8.8	10.5	15.0	9.6
2006	4	19	15.1	13.5	10.5	22.0	14.0	11.8	23.3	9.6	13.3	14.6	8.6	10.5	14.5	11.0
2006	5	18.5	14.2	13.5	12	20.0	13.1	11.4	23.0	9.4	9.8	12.0	9.2	10.0	14.3	12.6
2006	6	19	14.0	11.3	13	19.5	13.7	12.5	23.3	8.8	13.9	13.0	9.6	10.0	14.8	12.2
2006	7	19.1	14.0	11.2	13	20.5	13.0	12.0	23.3	10.0	12.2	20.7	5.9	11.3	14.6	12.2
2006	8	18.4	14.8	13.5	11.5	20.2	13.7	12.5	23.0	9.0	13.8	12.7	8.0	12.3	14.8	12.0
2006	9	18	14.1	13.4	12	20.2	11.0	12.0	22.8	9.6	14.0	20.4	8.0	13.4	14.6	12.4
2006	10	19.1	13.5	11.5	11.5	20.1	12.0	12.5	23.3	10.0	12.5	20.7	7.5	13.0	14.8	12.2
2006	11	18	14.5	14	8.5	17.0	11.5	12.0	22.8	9.0	12.0	19.5	7.1	13.0	14.6	9.2
2006	12	12.115	14.0	13.5	8.5	15.0	9.0	10.8	20.2	7.7	11.0	18.3	6.2	11.0	14.1	9.6

Assessment and evaluation of surface water potential and demands in Baro -Akobo river basin, Ethiopia

2007	1	12	11.0	11.5	8.5	19.0	9.0	13.1	20.1	8.6	10.0	10.0	7.4	10.6	11.5	8.8
2007	2	12.115	11.5	14	8.5	17.0	11.5	13.0	20.2	9.1	11.0	18.8	6.5	12.0	13.9	8.8
2007	3	17	14.1	11.5	10.5	18.5	1.5	13.0	22.4	9.6	11.5	10.0	4.5	11.3	12.0	9.4
2007	4	17.5	14.5	11	11	22.3	13.0	12.0	22.6	10.0	14.5	14.5	4.4	11.4	13.3	10.6
2007	5	19.7	14.6	9.5	8.5	21.0	11.5	12.2	21.0	11.0	11.9	17.0	5.5	10.6	9.2	8.1
2007	6	14.7	14.4	10.5	12.5	20.0	11.4	12.1	20.0	10.0	12.5	17.0	9.4	11.9	13.0	11.8
2007	7	12.2	13.5	13.5	11.5	20.0	10.5	11.4	20.0	10.0	13.5	18.0	6.0	10.8	11.4	12.2
2007	8	12	13.4	13	10.5	19.0	8.8	11.7	20.5	8.3	12.0	18.0	8.6	10.6	12.5	9.4
2007	9	13.8	14.8	13.5	11.5	20.1	11.2	12.5	20.0	10.0	12.5	18.0	9.0	11.6	12.5	8.8
2007	10	12.8	14.8	11	8.5	19.5	9.5	12.6	20.0	8.8	11.6	13.0	7.8	10.1	13.4	7.6
2007	11	14	11.8	13.5	11	20.2	10.4	12.0	20.5	1.0	12.8	14.5	8.8	10.0	12.4	10.0
2007	12	13.5	10.5	14	8	17.5	13.7	12.5	18.5	7.0	8.5	13.5	5.3	10.4	13.5	7.0
2008	1	15.5	14.5	12.5	9.5	18.0	9.8	12.0	19.0	8.4	10.0	18.0	8.2	10.0	13.5	8.0
2008	2	13.9	12.2	11.5	10	19.0	9.0	13.0	19.0	9.1	10.0	17.0	8.4	10.3	13.0	9.6
2008	3	11.5	14.9	15	10.5	19.5	11.5	12.8	20.0	10.0	11.0	20.0	5.5	10.5	14.8	8.8
2008	4	19	14.5	13.5	12	21.0	10.5	12.0	20.0	8.4	13.5	19.0	5.5	11.8	14.6	6.4
2008	5	17.47	13.8	13.5	13	22.3	10.2	12.2	18.0	8.6	11.0	19.0	5.5	15.0	12.5	8.4
2008	6	11.3	14.5	13.5	11	20.0	10.0	12.0	20.5	8.4	12.0	19.0	5.5	10.4	12.4	11.2
2008	7	7	13.5	11	11	19.0	13.6	12.4	19.0	9.0	13.2	17.4	5.0	10.8	12.0	10.8
2008	8	7.5	13.6	13.5	11.5	19.5	13.7	12.5	20.3	9.5	12.0	12.5	5.0	10.8	12.0	11.0
2008	9	7	13.0	13	11	20.2	12.9	11.0	19.5	9.5	13.8	17.4	5.0	10.4	12.7	12.0
2008	10	15.09	12.6	13	10.5	20.5	13.6	12.4	20.0	9.4	12.0	18.0	8.6	10.2	12.8	11.6
2008	11	17	10.0	13.5	8	19.5	13.4	12.0	18.0	7.0	7.5	18.0	7.6	10.0	14.2	6.6
2008	12	15.09	15.1	14.5	8.5	19.0	14.0	13.2	19.5	7.5	11.5	17.5	7.8	10.0	13.4	7.2
2009	1	10.5	11.6	14.5	8.5	19.0	13.7	12.5	18.5	8.8	12.8	19.0	7.8	10.6	5.6	10.0
2009	2	12.8	14.3	14.5	9	18.5	13.2	11.5	20.0	9.0	11.0	21.0	8.0	10.0	14.2	7.8
2009	3	15.09	14.6	14	10	20.0	12.6	12.2	17.0	10.0	13.4	18.0	8.4	11.1	13.5	11.2
2009	4	18.065	13.5	14.5	11	20.0	13.3	11.8	20.0	8.3	13.7	19.0	8.8	11.4	13.5	11.8
2009	5	15.09	14.8	13.8	11	20.9	12.5	12.6	20.5	9.5	13.0	19.0	8.8	10.7	13.6	8.8
2009	6	17.47	13.6	13.5	11	19.5	12.8	11.8	20.5	9.5	11.8	18.5	8.8	11.4	12.4	8.0
2009	7	19.5	14.1	13.5	12.5	21.0	11.0	11.0	20.0	7.8	13.2	17.5	9.4	10.8	11.7	10.8
2009	8	19.5	14.2	13.5	12	20.0	11.4	11.6	20.5	9.5	14.0	16.5	9.2	11.8	12.0	12.2
2009	9	20	14.0	14.5	12	20.5	12.0	12.0	21.0	10.0	14.5	17.0	9.2	11.8	13.8	9.2
2009	10	19	14.6	13.5	11.5	0.0	11.5	12.3	20.0	9.5	12.8	16.0	9.0	11.6	13.6	10.0
2009	11	15	14.8	19.5	8.5	18.0	10.0	12.5	19.5	8.8	11.0	19.6	7.8	10.6	13.8	6.2
2009	12	13.305	10.6	13.5	9.5	19.8	10.0	12.8	15.0	9.5	13.0	17.0	8.2	10.9	11.0	8.0
2010	1	10.5	16.3	11	9	15.5	13.9	13.0	14.5	9.1	9.5	18.0	8.0	10.5	10.5	6.2
2010	2	13.28	15.2	14.5	9.4	18.0	11.5	13.5	18.5	7.5	12.0	19.5	8.2	10.6	13.5	9.2
2010	3	15	13.4	14.5	8.5	19.5	12.5	12.2	20.0	8.6	13.0	20.0	7.8	10.6	15.0	8.2
2010	4	20	15.5	15.5	13	23.0	15.0	14.0	21.5	10.0	16.5	20.0	9.6	12.1	14.8	11.8
2010	5	18.5	15.5	13.6	10	22.5	13.5	12.2	21.0	11.0	11.9	20.0	8.4	11.1	14.5	8.2
2010	6	18	14.4	13.5	11.5	20.5	12.5	11.8	19.5	11.0	14.5	16.0	9.0	11.6	12.0	13.6
2010	7	16	14.2	13.8	12	20.0	13.0	12.3	20.0	10.0	13.0	16.5	9.2	11.8	13.0	12.4
2010	8	14.6	14.0	13.5	10.5	17.5	13.5	12.2	19.5	10.0	14.0	16.0	8.6	11.3	13.0	9.6
2010	9	14.6	13.7	14	10.5	20.6	11.6	12.1	20.0	10.0	13.8	15.0	8.6	11.3	12.5	12.0
2010	10	13.4	13.0	13.5	9.5	19.8	11.6	12.7	20.0	10.0	14.0	16.0	8.2	10.9	12.5	11.2
2010	11	12.5	12.2	13.5	9.5	19.3	12.0	12.3	20.0	9.5	12.5	17.0	8.2	10.9	12.0	8.4
2010	12	10	11.2	13.5	8	17.8	11.0	12.6	20.0	8.5	11.0	17.0	7.6	10.4	13.4	10.0

Assessment and evaluation of surface water potential and demands in Baro -Akobo river basin, Ethiopia

2011	1	12	14.9	12.5	8	15.5	9.0	12.8	18.5	7.5	12.7	16.5	7.6	10.4	13.4	9.8
2011	2	10.4	12.0	15	7	15.0	12.0	14.6	17.5	7.5	9.0	17.5	7.2	10.1	7.0	9.1
2011	3	10	14.6	13.5	11	18.5	12.5	12.2	22.5	8.6	12.7	19.5	8.8	11.4	14.7	9.8
2011	4	11.5	14.5	12.5	10	19.5	14.0	12.4	22.5	8.7	14.0	18.5	8.4	11.1	14.8	12.6
2011	5	12.2	14.5	14.5	8.5	20.5	13.0	12.5	19.5	8.8	12.5	17.0	7.8	10.6	14.8	9.4
2011	6	14.5	14.5	14	12	20.5	11.0	12.1	20.5	8.5	12.5	19.4	9.2	11.8	13.0	9.4
2011	7	11.9	13.4	13.5	11.5	20.0	11.0	14.8	20.5	10.2	12.2	15.2	9.0	11.6	12.4	8.7
2011	8	18	15.8	14	11	19.5	10.5	14.8	20.5	10.2	12.2	16.0	8.8	11.4	12.0	8.8
2011	9	19	13.4	13.5	11	19.0	14.8	14.9	21.0	10.2	12.2	17.0	8.8	11.4	12.0	8.7
2011	10	14	12.3	14	8.5	20.0	11.5	14.9	20.0	10.2	12.2	17.0	7.8	10.6	12.5	8.8
2011	11	14	15.9	12.5	5	15.5	14.8	14.9	15.5	10.2	12.1	17.5	6.4	9.5	10.5	8.5
2011	12	13	15.8	13	7	16.5	8.5	14.7	15.0	10.1	12.1	18.5	7.2	10.1	11.0	8.6
2012	1	13	14.3	13.5	9	15.5	13.2	11.5	18.0	6.5	10.0	19.5	8.0	10.8	11.5	12.4
2012	2	12	14.5	12.5	11	19.0	13.4	11.9	20.1	9.0	13.9	19.0	8.8	11.4	13.8	12.2
2012	3	15.2	13.5	13.5	11	20.9	12.3	9.8	19.5	7.1	13.5	20.0	8.8	11.4	11.5	10.8
2012	4	18.5	13.6	13.5	11	20.8	12.4	10.0	19.0	10.0	14.5	20.0	8.8	11.4	11.8	12.2
2012	5	17	13.6	11.5	12	19.5	12.4	10.0	19.0	7.2	15.0	20.1	9.2	11.8	12.0	9.0
2012	6	18.5	14.8	10.5	11	19.5	13.7	12.7	20.2	8.9	13.9	17.5	8.8	11.4	12.0	12.4
2012	7	12.5	14.2	12.5	10.5	19.5	14.7	14.6	20.0	10.1	8.0	18.9	8.6	11.3	12.5	8.5
2012	8	16.4	12.6	11.8	10.5	19.5	14.9	15.0	20.0	10.3	12.1	15.5	8.6	11.3	13.0	8.3
2012	9	18	13.7	12.5	11	22.6	14.9	14.9	21.0	8.5	14.0	16.0	8.8	11.4	13.0	8.5
2012	10	18.5	14.1	13	9.5	18.8	12.9	11.0	19.5	7.0	11.5	16.0	8.2	10.9	13.0	8.6
2012	11	18.5	12.6	11.2	10.5	19.5	13.4	12.0	19.0	9.0	12.1	20.5	8.6	11.3	13.6	8.1
2012	12	17.5	10.5	13.5	9	17.0	14.7	14.6	18.0	10.1	12.0	17.0	8.0	10.8	9.0	8.7
2013	1	16	11.3	14	8.8	17.2	13.7	12.7	17.5	8.9	14.0	16.5	7.9	10.7	11.5	12.4
2013	2	15.5	12.0	14	11	18.0	13.5	12.3	17.5	8.6	14.0	19.0	8.8	11.4	13.0	12.4
2013	3	20	14.0	14.5	11	20.0	13.3	11.9	21.5	8.4	11.6	20.9	8.8	11.4	14.0	7.6
2013	4	20.5	14.6	13.5	11	21.0	13.5	12.3	23.9	8.6	14.0	21.0	8.8	11.4	13.0	12.4
2013	5	20	14.6	12	9.5	20.5	13.5	12.3	20.2	9.5	12.2	20.9	8.2	10.9	13.0	8.7
2013	6	0	14.8	13	12.5	20.2	13.7	12.6	20.0	8.5	13.0	18.5	9.4	11.9	14.9	10.6
2013	7	17.6	15.8	12.5	13	19.8	14.7	14.7	20.5	10.1	12.5	20.3	9.6	12.1	15.8	8.5
2013	8	14.6	15.8	12.5	10.5	20.6	14.7	14.7	18.8	10.1	10.5	21.0	8.6	11.3	15.8	5.2
2013	9	17	14.4	12.5	12.5	19.5	13.3	11.8	20.0	8.3	12.1	18.0	9.4	11.9	14.5	8.5
2013	10	14	15.9	12.5	10	18.5	14.9	15.0	20.5	10.3	12.1	19.5	8.4	11.1	13.0	8.5
2013	11	11.4	15.9	12.5	10	19.8	14.9	15.0	20.0	10.3	12.1	19.5	8.4	11.1	13.6	8.5
2013	12	10.6	16.0	12.8	8	18.2	15.0	15.2	18.0	7.0	12.1	22.0	7.6	10.4	16.0	8.5

APENDIX B

Prepared input data for main stations for Weather generator in SWAT model

Monthly maximum temperature ($^{\circ}\text{C}$) at Gore station for eight years

monthly maximum temprature												
station: gore												
month	1	2	3	4	5	6	7	8	9	10	11	12
years												
1997	24.3	25.9	25.7	24.0	22.6	21.9	23.9	23.7	23.8	23.0	22.8	24.0
1998	25.3	27.1	26.2	27.5	24.2	22.7	20.9	23.9	22.1	22.5	25.3	25.6
1999	26.4	27.9	28.4	24.2	22.9	22.1	20.4	20.8	22.0	21.7	24.6	24.8
2000	25.9	27.3	28.4	25.2	23.4	22.1	21.2	21.7	22.3	22.3	23.6	24.7
2001	25.4	27.4	26.2	26.5	24.2	21.7	22.0	21.5	22.7	24.1	23.9	24.7
2002	24.7	26.9	26.2	26.1	24.9	23.5	22.2	21.6	22.6	23.4	24.1	23.9
2003	26.0	27.7	26.8	26.5	23.5	22.8	21.7	22.8	23.4	24.7	24.6	25.3
2004	26.0	27.0	27.6	26.1	25.1	21.9	22.7	22.1	22.2	24.7	24.0	24.8
average	25.5	27.2	26.9	25.8	23.8	22.4	21.9	22.3	22.6	23.3	24.1	24.7
STD	1	1	1	1	1	1	1	1	1	1	1	1

Monthly maximum temperature ($^{\circ}\text{C}$) at Masha station for eight years

monthly maximum temprature												
station: masha												
month	1	2	3	4	5	6	7	8	9	10	11	12
years												
1997	21	22	23	21	20	20	20	20	22	22	21	22
1998	23	25	23	25	24	22	20	20	20	21	23	23
1999	23	26	26	24	22	22	19	19	20	20	22	22
2000	23	24	25	22	21	20	20	20	20	20	21	22
2001	22	24	23	23	22	20	20	20	21	22	21	22
2002	22	24	23	23	22	21	20	20	21	21	22	21
2003	24	25	25	24	24	21	19	20	21	23	22	23
2004	24	24	24	24	21	20	20	21	20	22	21	22
average	22.8	24.2	23.9	23.3	22.0	20.8	19.8	20.0	20.7	21.4	21.7	22.1
STD	1	1	1	1	1	1	0	0	1	1	1	1

Monthly maximum temperature ($^{\circ}\text{C}$) at Tepi station for eight years

monthly maximum temprature												
station:Tepi												
month	1	2	3	4	5	6	7	8	9	10	11	12
years												
1997	30	33	33	29	29	29	30	28	30	29	29	29
1998	29	31	31	32	30	27	27	27	30	30	31	32
1999	33	34	33	31	29	29	27	27	28	28	31	31
2000	32	28	34	30	30	29	29	27	27	29	30	31
2001	31	33	31	30	29	28	27	27	28	29	30	31
2002	31	34	32	33	30	28	28	28	30	29	30	30
2003	32	34	34	34	31	28	27	27	29	31	30	30
2004	31	32	35	30	30	28	28	28	28	31	29	30
average	31.2	32.6	32.9	31.1	29.6	28.2	27.8	27.5	28.7	29.5	29.9	30.5
STD	1	2	1	2	0	0	1	1	1	1	1	1

Monthly minimum temperature(⁰c) at Gore station for eight years

monthly minimum temprature												
station: gore												
month	1	2	3	4	5	6	7	8	9	10	11	12
years												
1997	13.9	14.2	14.6	14.4	13.7	13.0	13.5	13.2	13.3	13.5	14.0	15.0
1998	14.2	14.9	13.5	16.3	14.8	13.4	13.7	13.9	13.5	13.8	13.9	14.0
1999	14.5	15.6	15.3	13.8	11.8	12.2	12.1	12.4	14.7	12.8	13.2	13.2
2000	14.2	15.1	13.4	13.7	12.7	12.8	14.8	12.6	14.7	13.4	14.1	14.5
2001	13.9	14.8	15.1	14.4	14.4	14.5	13.2	13.5	13.1	13.3	15.3	14.5
2002	15.6	15.6	15.1	15.8	15.0	13.4	14.2	14.3	14.1	13.7	13.4	14.6
2003	15.4	15.6	15.2	15.4	15.6	13.3	13.3	13.6	13.2	14.1	14.7	14.8
2004	15.2	14.9	16.2	15.4	14.3	13.3	13.0	13.5	13.1	13.6	14.2	14.6
average	14.6	15.1	14.8	14.9	14.0	13.2	13.5	13.4	13.7	13.5	14.1	14.4
STD	1	1	1	1	1	1	1	1	1	0	1	1

 Monthly minimum temperature (⁰c) at Masha station for eight years

monthly minimum temprature												
station: masha												
month	1	2	3	4	5	6	7	8	9	10	11	12
years												
1997	9.1	7.6	9.5	9.9	9.5	12.2	11.6	11.6	11.3	12.0	12.3	11.7
1998	11.9	10.2	13.1	13.8	10.2	12.4	9.5	9.6	11.9	11.9	11.2	9.7
1999	10.5	10.7	11.6	12.3	11.3	11.2	11.0	11.0	11.1	8.9	9.2	10.4
2000	10.4	10.9	11.9	12.1	11.9	11.1	11.1	11.2	11.4	11.6	10.3	10.0
2001	9.6	11.3	10.4	9.9	12.2	10.0	10.9	11.5	11.1	11.4	10.6	10.0
2002	10.8	11.2	12.0	12.2	10.3	11.7	12.0	9.9	9.8	11.1	9.3	10.1
2003	10.6	11.4	10.4	12.2	12.5	11.7	11.7	9.4	11.5	11.0	10.1	10.2
2004	10.4	10.6	12.6	12.5	12.2	11.8	9.1	9.4	11.5	11.0	11.1	11.2
average	10.4	10.5	11.4	11.8	11.3	11.5	10.9	10.5	11.2	11.1	10.5	10.4
STD	1	1	1	1	1	1	1	1	1	1	1	1

 Monthly minimum temperature (⁰c) at Tepi station for eight years

monthly minimum temprature												
station:Tepi												
month	1	2	3	4	5	6	7	8	9	10	11	12
years												
1997	13.6	11.9	15.5	16.0	15.6	15.3	14.2	16.4	15.8	14.3	16.4	15.8
1998	16.3	12.5	17.1	17.6	17.2	17.0	14.0	16.6	16.6	13.9	12.8	12.1
1999	12.9	13.4	15.2	17.0	16.7	15.9	15.2	12.8	15.3	15.4	12.3	13.1
2000	13.1	12.9	15.8	16.6	16.6	15.8	12.6	14.8	16.0	16.1	13.7	13.5
2001	12.2	13.9	15.9	17.1	13.1	16.2	15.7	16.4	15.7	16.1	15.3	14.3
2002	14.6	13.9	16.7	16.8	16.9	14.8	16.2	14.8	15.4	14.1	15.1	14.8
2003	13.4	13.5	14.8	16.9	12.5	15.6	14.6	15.1	15.1	13.8	13.4	12.6
2004	13.9	12.8	14.9	15.8	15.5	15.2	14.4	14.5	14.6	13.3	13.5	13.4
average	13.8	13.1	15.7	16.7	15.5	15.7	14.6	15.2	15.6	14.6	14.1	13.7
STD	1	1	1	1	2	1	1	1	1	1	1	1

Monthly wind runs (m/s) at Gore station for eight years

monthly wind run												
station: Gore												
month	1	2	3	4	5	6	7	8	9	10	11	12
yrs												
1997	1.3	1.3	1.6	1.6	1.4	1.4	1.1	1.4	1.7	1.4	1.1	1.0
1998	1.1	1.1	1.4	1.5	1.3	1.4	1.0	1.1	1.2	1.1	1.1	1.1
1999	1.1	1.5	1.5	1.7	1.6	1.5	1.1	1.1	1.2	1.2	1.2	1.1
2000	1.1	1.3	1.4	1.7	1.5	1.3	1.1	1.1	1.2	1.1	1.1	0.9
2001	1.1	1.4	1.5	1.6	1.5	1.1	1.0	1.0	1.3	1.1	0.9	0.9
2002	1.0	1.1	1.4	1.6	1.4	1.3	1.1	1.0	1.3	1.0	0.9	0.9
2003	0.9	1.5	1.6	1.4	1.3	1.1	0.9	2.8	1.1	1.1	0.8	0.8
2004	0.9	1.2	1.2	1.1	1.2	0.9	0.9	0.9	1.0	1.0	0.8	0.6
average	1.1	1.3	1.4	1.5	1.4	1.2	1.0	1.3	1.2	1.1	1.0	0.9
STD	0	0	0	0	0	0	0	1	0	0	0	0

Monthly wind run(m/s) at Masha station for eight years

monthly wind run												
station: Masha												
month	1	2	3	4	5	6	7	8	9	10	11	12
yrs												
1997	0.8	1.0	1.0	1.0	0.9	0.8	0.8	0.8	0.9	0.9	0.7	0.8
1998	0.7	1.0	0.9	1.1	0.9	0.9	0.7	0.7	0.7	0.7	1.0	1.0
1999	1.0	1.1	1.2	1.0	0.9	0.9	0.7	0.7	0.7	2.2	0.8	0.8
2000	0.9	1.0	1.1	0.8	0.8	0.8	0.7	0.8	0.5	0.5	0.6	0.6
2001	0.7	0.8	0.7	0.7	0.7	0.5	0.6	0.5	0.5	0.5	0.5	0.5
2002	0.6	0.7	0.7	0.8	0.8	0.6	0.5	0.5	0.6	0.5	0.5	0.5
2003	0.5	0.6	0.6	0.7	0.7	0.5	0.4	0.5	0.5	0.5	0.4	0.5
2004	0.4	0.5	0.5	0.5	0.6	0.4	0.3	0.3	0.4	0.4	0.4	0.4
average	0.7	0.9	0.8	0.8	0.8	0.7	0.6	0.6	0.6	0.8	0.6	0.6
STD	0	0	0	0	0	0	0	0	0	1	0	0

Monthly wind run(m/s) at Tepi station for eight years

monthly wind run												
station: Tepi												
month	1	2	3	4	5	6	7	8	9	10	11	12
yrs												
1997	0.3	0.4	0.5	0.4	0.4	0.3	0.3	0.3	0.4	0.3	0.3	0.3
1998	0.3	0.3	0.3	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.6	0.4
1999	0.4	0.6	0.5	0.5	0.4	0.4	0.3	0.3	0.4	0.3	0.3	0.4
2000	0.4	0.4	0.6	0.5	0.4	0.4	0.3	0.3	0.4	0.4	0.3	0.3
2001	0.3	0.5	0.5	0.5	0.4	0.4	0.3	0.3	0.4	0.3	0.3	0.4
2002	0.4	0.5	0.5	0.5	0.4	0.4	0.3	0.3	0.4	0.4	0.4	0.3
2003	0.3	0.4	0.6	0.5	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
2004	0.3	0.4	0.4	0.4	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.3
average	0.3	0.4	0.5	0.5	0.4	0.3	0.3	0.3	0.3	0.3	0.4	0.3
STD	0	0	0	0	0	0	0	0	0	0	0	0

 Average Monthly solar radiation (MJ/m²-day) at Tepi, Masha and Gore station for eight years

8 year average monthly solar radion												
station: Tepi												
month	1	2	3	4	5	6	7	8	9	10	11	12
SRD	5.6	13.1	17.6	12.9	6.8	1.5	3.5	10.0	13.6	12.6	8.5	1.9

8 year average monthly solar radion												
station:masha												
month	1	2	3	4	5	6	7	8	9	10	11	12
SRD	5.9	13.7	17.2	13.2	6.6	1.5	3.5	10.0	13.4	12.6	8.4	2.0

8 year average monthly solar radion												
station:gore												
month	1	2	3	4	5	6	7	8	9	10	11	12
SRD	6.0	14.2	17.5	13.6	6.7	1.4	3.4	9.8	13.3	12.5	8.5	2.1

Dew output data for Weather generator inputs for stations Gore, masha and Tepi

This file has been generated by the program 'de w02.exe'

Input Filename = gore data.txt

Number of Years = 8

Number of Records = 2922

Number of NoData Values

tmp_max = 0

tmp_min = 0

hmd = 0

Average Daily Dew Point Temperature for Period (1997 - 2004)

Month	tmp_max	tmp_min	hmd	dewpt
Jan	25.48	14.59	70.11	15.02
Feb	27.15	15.09	63.01	14.46
Mar	26.93	14.78	66.74	15.20
Apr	25.76	14.91	72.06	15.75
May	23.83	14.13	78.11	15.61
Jun	22.35	13.26	83.51	15.47
Jul	21.88	13.47	86.13	15.75

Aug	22.26	13.38	85.89	15.90
Sep	22.64	13.65	83.90	15.87
Oct	23.29	13.53	80.58	15.53
Nov	24.10	14.05	77.19	15.56
Dec	24.74	14.40	73.50	15.29

tmp_max = average daily maximum temperature in month [°C]

tmp_min = average daily minimum temperature in month [°C]

hmd = average daily humidity in month [%]

dewpt = average daily dew point temperature in month [°C]

This file has been generated by the program 'dew02.exe'

Input File name = masha data.txt

Number of Years = 8

Number of Records = 2922

Number of NoData Values

tmp_max = 0

tmp_min = 0

hmd = 0

Average Daily Dew Point Temperature for Period (1997 - 2004)

Month	tmp_max	tmp_min	hmd	dewpt
-------	---------	---------	-----	-------

Jan	22.70	10.40	74.35	12.82
Feb	24.17	10.49	66.46	11.97
Mar	23.93	11.45	69.73	12.89
Apr	23.40	11.85	75.70	13.98

May	22.02	11.27	82.47	14.28
Jun	20.79	11.50	87.23	14.55
Jul	19.77	10.86	90.23	14.23
Aug	19.94	10.47	90.10	14.16
Sep	20.67	11.21	88.30	14.55
Oct	21.33	11.10	87.28	14.74
Nov	21.73	10.51	80.81	13.56
Dec	22.12	10.42	77.20	13.06

tmp_max = average daily maximum temperature in month [°C]

tmp_min = average daily minimum temperature in month [°C]

hmd = average daily humidity in month [%]

dewpt = average daily dew point temperature in month [°C]

PCP stat output data for Weather generator inputs for stations Gore, masha and Tepi

Statistical Analysis of Daily Precipitation Data (1997 - 2004)

Input Filename = tepi PCP.txt

Number of Years = 8

Number of Leap Years = 2

Number of Records = 2921

Number of NoData values = 0

Month	PCP_MM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD
Jan.	47.94	4.5943	4.6915	0.2011	0.4783	8.63
Feb.	28.24	3.0201	4.0715	0.1371	0.4510	6.38
Mar.	96.85	6.2636	3.2262	0.3212	0.5766	13.88
Apr.	186.42	9.6571	2.3387	0.5349	0.6883	19.25
May.	212.39	8.9377	1.5098	0.5600	0.7283	21.63
Jun.	203.91	10.2924	2.6095	0.6230	0.7598	22.38
Jul.	178.34	8.0785	2.7255	0.8136	0.7302	23.63
Aug.	205.91	9.6715	1.8463	0.6364	0.7308	22.75
Sep.	172.26	7.9057	1.8947	0.7931	0.7143	22.75
Oct.	186.29	7.9757	1.7802	0.3750	0.8261	23.00
Nov.	88.16	6.0611	2.6862	0.2879	0.6111	13.50
Dec.	73.48	5.3860	2.9687	0.2453	0.5281	11.13

PCP_MM = average monthly precipitation [mm]

PCPSTD = standard deviation

PCPSKW = skew coefficient

PR_W1 = probability of a wet day following a dry day

PR_W2 = probability of a wet day following a wet day

PCPD = average number of days of precipitation in month

Statistical Analysis of Daily Precipitation Data (1997 - 2004)

Input File name = gore.txt

Number of Years = 8

Number of Leap Years = 2

Number of Records = 2921

Number of NoData values = 0

Month	PCP_MM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD
Jan.	36.29	4.0314	6.0677	0.0870	0.8636	13.75
Feb.	33.50	3.6259	6.2098	0.0833	0.8679	13.25
Mar.	57.83	3.9393	3.4230	0.2523	0.7591	17.13
Apr.	111.85	7.4513	3.2608	0.2740	0.8503	20.88
May.	236.07	10.0447	1.8335	0.4366	0.8023	22.13
Jun.	275.23	9.7052	1.6487	0.8182	0.8309	25.88
Jul.	267.55	10.6747	1.9980	0.9048	0.8855	28.38
Aug.	250.99	9.2561	1.8082	1.0000	0.9103	29.25
Sep.	246.83	8.0372	1.1707	0.7143	0.8950	27.38
Oct.	195.89	9.6860	3.0181	0.4444	0.8454	24.25
Nov.	61.13	4.6495	3.6779	0.2353	0.7273	15.13
Dec.	29.21	2.8464	5.6501	0.1625	0.6705	11.00

PCP_MM = average monthly precipitation [mm]

PCPSTD = standard deviation

PCPSKW = skew coefficient

PR_W1 = probability of a wet day following a dry day

PR_W2 = probability of a wet day following a wet day

PCPD = average number of days of precipitation in month

Average Daily Precipitation in Month

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1997	2.04	0.46	2.88	5.61	9.41	10.94	10.76	8.13	8.04	9.57	3.48	0.93
1998	0.88	1.24	3.46	1.54	6.24	8.31	9.60	6.97	8.75	8.35	0.79	0.24
1999	0.83	1.37	0.80	4.26	11.49	6.62	8.04	5.62	7.91	6.71	1.96	0.89
2000	0.93	0.20	0.98	3.71	10.88	9.41	7.59	9.46	8.59	7.80	1.80	0.70
2001	0.06	1.59	1.09	3.96	5.81	9.45	7.22	8.60	8.57	7.28	1.72	1.26
2002	3.47	0.90	3.03	3.70	3.47	8.06	9.09	9.49	7.01	4.51	0.78	0.82
2003	0.80	2.67	1.59	2.46	4.56	12.17	8.80	9.72	11.41	2.69	1.56	1.28
2004	0.36	1.09	1.10	4.58	9.07	8.43	7.95	6.77	5.54	3.64	4.21	1.41

Total Monthly Precipitation

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total Yearly PCP
1997	63.10	12.90	89.24	168.45	291.60	328.30	333.70	251.96	241.30	296.80	104.50	28.94	2210.79
1998	27.23	34.70	107.20	46.32	193.40	249.20	297.70	216.20	262.50	258.80	23.60	7.40	1724.25
1999	25.80	38.33	24.80	127.90	356.10	198.70	249.10	174.30	237.20	208.00	58.79	27.70	1726.72
2000	28.80	5.90	30.50	111.30	337.20	282.30	235.40	293.40	257.60	241.80	54.00	21.70	1899.90
2001	2.00	44.60	33.80	118.80	180.20	283.40	223.80	266.60	257.00	225.60	51.72	39.20	1726.72
2002	107.51	25.19	93.90	111.00	107.50	241.90	281.66	294.26	210.30	139.90	23.40	25.40	1661.92
2003	24.80	74.78	49.20	73.70	141.50	365.20	272.75	301.37	342.42	83.48	46.70	39.60	1815.50
2004	11.10	31.60	34.00	137.31	281.03	252.80	246.30	209.80	166.30	112.70	126.30	43.70	1652.94

Statistical Analysis of Daily Precipitation Data (1997 - 2004)

Input Filename = masha PCP.txt

Number of Years = 8

Number of Leap Years = 2

Number of Records = 2921

Number of NoData values = 0

Month	PCP_MM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD
Jan.	56.47	3.8708	4.6548	0.3119	0.7338	17.38
Feb.	29.89	1.7584	2.8078	0.1983	0.7364	13.75
Mar.	104.76	4.7744	2.5855	0.4091	0.8873	25.50
Apr.	149.68	9.0895	3.3281	0.4333	0.8222	22.50
May.	217.13	9.0636	1.9677	0.5000	0.8810	26.25
Jun.	278.01	9.9684	2.2097	0.9375	0.9018	28.00
Jul.	297.81	10.5485	1.8892	0.9000	0.9286	29.75
Aug.	281.92	9.2787	1.3784	0.6667	0.9414	29.88
Sep.	256.40	9.0959	1.6452	0.9231	0.9119	28.38
Oct.	259.71	10.1796	1.5750	0.5862	0.8904	27.38
Nov.	96.40	6.6396	6.4524	0.3947	0.8911	25.25
Dec.	84.70	5.9116	4.3433	0.3295	0.7937	20.00

PCP_MM = average monthly precipitation [mm]

PCPSTD = standard deviation

PCPSKW = skew coefficient

PR_W1 = probability of a wet day following a dry day

PR_W2 = probability of a wet day following a wet day

PCPD = average number of days of precipitation in month

Average Daily Precipitation in Month

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1997	2.58	1.61	2.60	4.25	8.15	8.55	7.99	8.49	9.62	10.44	3.64	1.69
1998	1.65	1.74	3.19	3.83	5.36	7.42	8.09	8.99	11.21	12.65	3.33	1.66
1999	1.67	0.38	8.89	10.21	12.77	10.34	9.72	6.92	8.42	8.80	2.68	3.71
2000	2.08	0.99	1.88	1.55	5.47	10.26	12.20	12.08	8.52	9.96	5.80	3.14
2001	0.69	1.57	3.27	5.56	9.70	8.82	13.58	8.83	8.53	10.62	3.93	2.31

2002	3.28	0.29	2.37	3.44	6.03	11.79	7.40	11.37	7.04	4.86	2.99	2.11
2003	0.27	1.35	1.73	7.82	2.08	10.07	10.08	6.42	8.93	3.48	1.66	4.25
2004	2.35	0.56	3.09	3.25	6.46	6.89	7.79	9.65	6.10	6.21	1.68	3.00

Total Monthly Precipitation

Total Monthly Precipitation														
Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total Yearly PCP	
1997	79.94	44.98	80.56	127.44	252.64	256.50	247.80	263.30	288.72	323.70	109.26	52.24	2127.08	
1998	51.30	48.86	98.80	115.00	166.30	222.68	250.90	278.62	336.40	392.10	99.80	51.60	2112.36	
1999	51.70	10.70	275.70	306.34	396.00	310.10	301.20	214.56	252.60	272.80	80.40	114.90	2587.00	
2000	64.38	28.70	58.30	46.64	169.60	307.72	378.10	374.60	255.50	308.80	174.00	97.20	2263.54	
2001	21.40	44.00	101.52	166.68	300.80	264.70	421.10	273.78	255.90	329.30	117.80	71.54	2368.52	
2002	101.70	8.10	73.60	103.26	186.88	353.60	229.50	352.40	211.20	150.70	89.80	65.50	1926.24	
2003	8.30	37.70	53.70	234.70	64.62	302.22	312.50	198.90	267.90	107.80	49.88	131.74	1769.96	
2004	73.00	16.10	95.90	97.40	200.20	206.60	241.36	299.16	183.00	192.50	50.28	92.90	1748.40	

Statistical Analysis of Daily Precipitation Data (1997 - 2004)

Input Filename = tepIPCP.txt

Number of Years = 8

Number of Leap Years = 2

Number of Records = 2921

Number of NoData values = 0

Month	PCP_MM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD
Jan.	47.94	4.5943	4.6915	0.2011	0.4783	8.63
Feb.	28.24	3.0201	4.0715	0.1371	0.4510	6.38
Mar.	96.85	6.2636	3.2262	0.3212	0.5766	13.88
Apr.	186.42	9.6571	2.3387	0.5349	0.6883	19.25

May.	212.39	8.9377	1.5098	0.5600	0.7283	21.63
Jun.	203.91	10.2924	2.6095	0.6230	0.7598	22.38
Jul.	178.34	8.0785	2.7255	0.8136	0.7302	23.63
Aug.	205.91	9.6715	1.8463	0.6364	0.7308	22.75
Sep.	172.26	7.9057	1.8947	0.7931	0.7143	22.75
Oct.	186.29	7.9757	1.7802	0.3750	0.8261	23.00
Nov.	88.16	6.0611	2.6862	0.2879	0.6111	13.50
Dec.	73.48	5.3860	2.9687	0.2453	0.5281	11.13

PCP_MM = average monthly precipitation [mm]

PCPSTD = standard deviation

PCPSKW = skew coefficient

PR_W1 = probability of a wet day following a dry day

PR_W2 = probability of a wet day following a wet day

PCPD = average number of days of precipitation in month

Average Daily Precipitation in Month

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1997	3.13	0.38	4.08	8.25	8.12	4.82	3.32	4.69	2.98	12.17	4.89	4.81
1998	4.07	2.72	4.60	3.17	6.87	7.57	6.40	10.73	7.71	5.09	1.94	0.63
1999	0.53	1.68	0.94	6.99	14.66	5.36	5.36	5.35	3.72	6.27	2.74	1.16
2000	0.72	0.22	2.34	6.68	6.74	7.31	4.68	4.91	4.99	7.60	3.51	1.95
2001	1.33	1.69	4.48	5.66	4.55	6.38	4.84	8.05	7.37	2.94	1.48	1.68
2002	1.25	0.28	4.31	8.07	4.73	7.52	2.76	4.84	3.55	5.73	1.18	2.08
2003	0.37	0.65	3.13	4.40	2.40	10.25	6.69	7.07	9.38	6.78	3.18	2.97
2004	0.98	0.42	1.11	6.50	6.74	5.17	11.98	7.52	6.25	1.51	4.59	3.67

Total Monthly Precipitation

Total Monthly Precipitation													
Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total Yearly PCP
1997	97.10	10.60	126.50	247.50	251.80	144.60	102.80	145.30	89.50	377.30	146.70	149.20	1888.90
1998	126.20	76.20	142.60	95.00	213.00	227.10	198.40	332.60	231.20	157.70	58.26	19.50	1877.76
1999	16.30	47.10	29.10	209.60	454.40	160.70	166.10	165.80	111.60	194.30	82.20	35.90	1673.10
2000	22.30	6.50	72.60	200.40	208.80	219.40	145.00	152.10	149.60	235.60	105.40	60.60	1578.30
2001	41.20	47.20	138.90	169.90	141.00	191.30	149.90	249.40	221.00	91.00	44.40	52.20	1537.40
2002	38.60	7.90	133.60	242.00	146.70	225.50	85.50	149.90	106.50	177.50	35.30	64.40	1413.40
2003	11.40	18.30	97.10	132.00	74.40	307.50	207.50	219.10	281.30	210.20	95.30	92.10	1746.20
2004	30.40	12.10	34.40	195.00	209.00	155.20	371.50	233.10	187.40	46.70	137.70	113.90	1726.40

APENDIX C

Soil data used in SWAT model

FID	Shape *	SYMBOL	SOIL_TYPE	Area_sqkm	MUID	SNAM	NLAYERS	HYDGRP
0	Polygon	VRd	Dystric Vertisols	1281.893	ET055	DYVERTISOLS	1	D
1	Polygon	LPd	Dystric Leptosols	5967.804	ET030	DYLEPTOSOLS	1	A
2	Polygon	ALu	Humic Alisols	2837.787	ET003	HUALISOLS	1	B
3	Polygon	NTh	Haplic Nitisols	2767.426	ET042	HPNITISOLS	1	D
4	Polygon	CMe	Eutric Cambisols	292.108	ET017	EUCAMBISOLS	1	D
5	Polygon	WR	Water bodies	61.502	ET058	WATER1	1	D
6	Polygon	LPq	Lithic Leptosols	1905.1	ET033	LTLEPTOSOLS	1	A
7	Polygon	NTu	Humic Nitisols	31293.87	ET044	HUNITISOLS	1	B
8	Polygon	ALh	Haplic Alisols	5207.146	ET002	HPALISOLS	1	B
9	Polygon	CMx	Chromic Cambisols	1621.186	ET019	CHCAMBISOLS	1	D
10	Polygon	VRe	Eutric Vertisols	13256.39	ET056	EUVERTISOLS	1	D
11	Polygon	FLe	Eutric Fluvisols	8618.636	ET022	EUFLUVISOLS	1	A

SOL_ZMX	ANION_EXCL	SOL_CRK	TEXTURE_1	SOL_Z1	SOL_BD1	SOL_AWC1_1	SOL_K1	SOL_CBN1
1000	0.5	0.5	Clay	100	1.2	75	0.0004	1.24
300	0.5	0.5	Sandy loam	30	1.58	15	180	0.65
1000	0.5	0.5	loam	100	1.38	150	18	2.83
1000	0.5	0.5	Clay	100	1.2	150	0.0004	4.04
1000	0.5	0.5	Clay	100	1.25	50	0.0004	1.17
0	0.2	0	Water	0	1	0	0	1
100	0.5	0.5	Sandy loam	10	1.59	50	180	1.4
1000	0.5	0.5	loam	100	1.39	150	18	2.25
1000	0.5	0.5	loam	100	1.39	100	18	1.16
1000	0.5	0.5	Clay	100	1.24	150	0.0004	1.43
1000	0.5	0.5	Clay	100	1.22	125	0.0004	1.05
1000	0.5	0.5	lomy sand	100	1.62	150	360	0.58

CLAY1_1	SILT1_1	SAND1_1	ROCK1_1	SOL_ALB1	USLE_K1	S_ECE	Tex_Code	ObjectID
58	29	13	3	0.231	0.142071	0.1	6	256
10	14	76	23	0.226	0.155865	0	2	232
26	28	46	1	0.226	0.123305	0	3	205
56	29	15	0	0.226	0.119308	0	6	243
48	29	23	10	0.226	0.134617	0.1	6	219
0	0	0	0	0	0	0	7	259
9	18	73	21	0.226	0.139526	0	2	235
24	31	45	9	0.226	0.127311	0.1	3	245
23	37	40	8	0.226	0.153334	0.1	3	204
50	29	21	2	0.226	0.126115	0.1	6	221
56	25	19	4	0.231	0.132894	0.1	6	257
8	12	80	18	0.231	0.157739	0.1	2	224

One-sided 10 percent significance outlier test K_N values for a normal distribution (Interagency Advisory Committee on Water Data, 1982, after Grubbs and Beck, 1972).

Sample size	K_N value	Sample size	K_N value	Sample size	K_N value	Sample size	K_N value
10	2.036	45	2.727	80	2.940	115	3.064
11	2.088	46	2.736	81	2.945	116	3.067
12	2.134	47	2.744	82	2.949	117	3.070
13	2.175	48	2.753	83	2.953	118	3.073
14	2.213	49	2.760	84	2.957	119	3.075
15	2.247	50	2.768	85	2.961	120	3.078
16	2.279	51	2.775	86	2.966	121	3.081
17	2.309	52	2.783	87	2.970	122	3.083
18	2.335	53	2.790	88	2.973	123	3.086
19	2.361	54	2.798	89	2.977	124	3.089
20	2.385	55	2.804	90	2.981	125	3.092
21	2.408	56	2.811	91	2.984	126	3.095
22	2.429	57	2.818	92	2.989	127	3.097
23	2.448	58	2.824	93	2.993	128	3.100
24	2.467	59	2.831	94	2.996	129	3.102
25	2.486	60	2.837	95	3.000	130	3.104
26	2.502	61	2.842	96	3.003	131	3.107
27	2.519	62	2.849	97	3.006	132	3.109
28	2.534	63	2.854	98	3.011	133	3.112
29	2.549	64	2.860	99	3.014	134	3.114
30	2.563	65	2.866	100	3.017	135	3.116
31	2.577	66	2.871	101	3.021	136	3.119
32	2.591	67	2.877	102	3.024	137	3.122
33	2.604	68	2.883	103	3.027	138	3.124
34	2.616	69	2.888	104	3.030	139	3.126
35	2.628	70	2.893	105	3.033	140	3.129
36	2.639	71	2.897	106	3.037	141	3.131
37	2.650	72	2.903	107	3.040	142	3.133
38	2.661	73	2.908	108	3.043	143	3.135
39	2.671	74	2.912	109	3.046	144	3.138
40	2.682	75	2.917	110	3.049	145	3.140
41	2.692	76	2.922	111	3.052	146	3.142
42	2.700	77	2.927	112	3.055	147	3.144
43	2.710	78	2.931	113	3.058	148	3.146
44	2.719	79	2.935	114	3.061	149	3.148

APENDIX D

SWAT model Result for surface water potential assessments.

AVE ANNUAL BASIN VALUES

PRECIP = 1701.6 MM

SNOW FALL = 0.00 MM

SNOW MELT = 0.00 MM

SUBLIMATION = 0.00 MM

SURFACE RUNOFF Q = 279.68 MM

LATERAL SOIL Q = 103.84 MM

TILE Q = 0.00 MM

GROUNDWATER (SHAL AQ) Q = 918.51 MM

GROUNDWATER (DEEP AQ) Q = 48.97 MM

REVAP (SHAL AQ => SOIL/PLANTS) = 15.18 MM

DEEP AQ RECHARGE = 49.22 MM

TOTAL AQ RECHARGE = 984.46 MM

TOTAL WATER YLD = 1331.13 MM

PERCOLATION OUT OF SOIL = 987.40 MM

ET = 350.3 MM

PET = 759.2MM